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Adaptation of California's Electricity Sector to Climate Change

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Supported with funding from Next Ten, Pacific Gas and Electric Company, and The Nature Conservancy

This report is part of a larger PPIC study, *Preparing California for a Changing Climate*. Other reports in this collection are available at http://www.ppic.org/main/publication.asp?i=755.

November 2008

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Climate change is likely to pose considerable new challenges to California's electricity sector. On the one hand, as the second largest source of greenhouse gas (GHG) emissions in California, this sector will be a primary target of efforts to reduce emissions under California's Global Warming Solutions Act of 2006 (Assembly Bill (AB) 32). At the same time, the sector will need to adapt to changing demand and supply conditions resulting from climate change. AB 32 goals could be more difficult to meet if there is reduced hydroelectric generation or increased use of carbon-based back-up generation in extreme heat events.

This report focuses on the adaptation challenges of an important component of the energy arena: electricity demand in the residential and commercial sectors and electricity supply (natural gas is briefly mentioned as a secondary topic). The primary challenge to California's electricity sector will likely be the increase in demand for air conditioning as a result of rising temperatures. In addition, renewable energy sources, which are an increasing share of the electricity portfolio, are particularly vulnerable to climate change. (Notably, hydroelectric sources – a key resource for meeting peak demands – are challenged by the declining snowpack).

Many of the key players – including state regulatory agencies and the investor-owned utilities which serve most of the state's customers – have been actively considering the implications of climate change. Because electricity generation accounts for nearly 30 percent of GHG emissions, this sector has been a target of the state's efforts to reduce emissions. Fortunately, many of the same tools can simultaneously improve the sector's resilience to a changing climate. Demand management strategies and supply diversification are both important strategies.

Local governments can play a central role in encouraging the adoption of more energy efficient building codes and the use of more renewable sources, such as solar energy. The positive steps taken by many local governments are encouraging. Steps to increase public awareness are an important, often missing component, however. Increases in research, development, and demonstration to improve system resiliency and develop new energy conservation tools are also needed.

Acronyms

AB	Assembly Bill
ARB	Air Resources Board
Cal-ISO	California Independent System Operator
CEC	California Energy Commission
CEQA	California Environmental Quality Act
CICS	California Institute for Climate Solutions
CPUC	California Public Utilities Commission
CSAC	California State Association of Counties
DWR	Department of Water Resources
EEM	energy-efficient mortgage
IPCC	Intergovernmental Panel on Climate Change
LCC	League of California Cities
LEED	Leadership in Energy and Environmental Design
MGPD	million gallons per day
MW	megawatts
PG&E	Pacific Gas and Electric
PIER	Public Interest Energy Research
PV	Photovoltaic
RD&D	research, demonstration and development
RPS	Renewable Portfolio Standard
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric
T&D	transmission and distribution
USBR	United States Bureau of Reclamation

Acknowledgments

I would like to thank the following people for providing information or advice for the preparation of this report: Cal Broomhead (City and County of San Francisco), Merwin Brown (California Institute for Energy and Environment), Lloyd Cibulka (California Institute for Energy and Environment), Guido Franco (California Energy Commission), Gary Freeman (Pacific Gas & Electric Company), Marshall Hunt (UC Davis Western Cooling Efficiency Center), Norm Miller (Lawrence Berkeley National Laboratory), Evan Mills (Lawrence Berkeley National Laboratory), Joe O'Hagan (California Energy Commission), Wendy Pulling (Pacific Gas & Electric Company), Sue Tierney (Analysis Group), and Lorraine White (California Energy Commission).

I would also like to thank the reviewers of an earlier version of this report: Guido Franco, Evan Mills, Wendy Pulling, and Michael Teitz. Finally, I am indebted to Louise Bedsworth, Ellen Hanak, and Lynette Ubois of the Public Policy Institute of California who made this report more intelligible than I could produce.

Introduction

The energy sector is among the most resilient of all U.S. economic sectors in terms of responding to changes within the range of historical experience (e.g., changes in energy prices, market conditions, policy changes, financial variables, and weather) (Bull et al. 2007). Climate change is likely to pose considerable new challenges to this sector. On the one hand, as the second largest source of greenhouse gas emissions in California, the energy sector will be a primary target of efforts to reduce emissions under California's Global Warming Solutions Act (Assembly Bill (AB) 32). At the same time, the sector will need to adapt to changing demand and supply conditions resulting from climate change. AB 32 goals may not be met if there is reduced hydroelectric generation or increased use of carbon-based back-up generation in extreme heat events.

This report focuses on the adaptation challenges of an important component of the energy arena: electricity and natural gas demand in the residential and commercial sectors and electricity supply. The report begins with a review of the impacts of climate change on the electricity sector in California – principally an increase in demand for air conditioning as summers become hotter, combined with greater difficulties meeting these peak demands through hydropower. Following an overview of the role of various institutions and regulatory structures that can or should play a role in climate-related policy, the report then discusses the types of adaptation strategies that will be needed as a result of climate warming.

Given its impressive investment resources and experience with risk management (e.g., water variability and availability risks due to floods and droughts), the energy sector has the potential to be a leader in adaptation initiatives. On the whole, the study finds that electricity sector's institutions are well-placed to handle adaptation challenges. Although much remains to be done, both public and private entities are addressing three critical dimensions of adaptation: improving awareness of the problem, directing analytic capacity to find solutions, and taking action where it is needed.[1]

It bears noting at the outset that adaptation to climate change and mitigation of greenhouse gas emissions are closely tied in the electricity sector. Mitigation efforts are focusing on increased efficiency and demand management and on the development of renewable electricity sources that emit less carbon into the atmosphere. Some of these same policies – particularly increased efficiency and demand management – are also important components of the adaptation toolkit. At the same time, climate change will increase the vulnerability of some renewable, low-emissions sources of electricity (particularly hydropower), potentially creating some conflicts between adaptation and mitigation goals.

[1] See Moser and Luers (2008) for a general discussion of adaptive response challenges and the importance of these three factors.

1. **Climate Change Impacts on the Electricity Sector**

California's electricity sector faces three main challenges as a result of a changing climate. The primary challenge will be responding to the increase in energy demand as a result of increasing temperatures. Currently, air conditioning is the main driver of increased peak summer demand for electricity in California, and warmer temperatures will raise the demand for air conditioning. A second challenge is the ability of the electricity generation system to adapt to changing climatic conditions. Some renewable power sources – particularly hydropower – are especially vulnerable to climate change. Third, climate change poses risks to transmission and distribution networks and other elements of electricity infrastructure.

Impacts on Electricity and Natural Gas Demand

Miller et al. (2007) analyzed the relationship among climate change, extreme heat, and electricity demand in California through the use of atmosphere-ocean general circulation models. These analyses indicated that extreme heat events in California will increase rapidly, exceeding the rate of increase in mean temperature.[2] The number of extreme heat days in Los Angeles may increase from the present-day value of 12 days per year up to 96 days per year by 2100. In other words, current heat wave conditions may last for the entire summer. The prospect of additional and longer heat waves could have a significant impact on electricity use in buildings due to increased air-conditioning loads. Natural gas is used in homes for heating, and the use of natural gas in buildings is expected to decrease as winter temperatures become more moderate. However, natural gas is also used for generating electricity in power plants: if more electricity is needed in the summer as a result of increased temperatures, then the cost of natural gas may increase if demand exceeds the supply of natural gas.

One of the earliest studies on the effects of climate change on regional electricity use was conducted in California (Baxter and Calandri 1992). This study found that although climate change will affect energy demand for both heating and cooling, the increased demands for cooling substantially outweigh the reductions from lower heating needs, particularly in a scenario with higher temperature increases. More recently, using Intergovernmental Panel on Climate Change (IPCC) scenarios of climate change from three climate models downscaled for California, Franco and Sanstad (2006) found a high correlation between the simple average daily temperature and daily peak electricity demand in the California Independent System Operator (Cal-ISO) region, which comprises most of California. They projected an increase in energy demand over the century, depending on the amount of warming (Figure 1). Under a high emissions scenario, peak demand could increase 19.5 percent above the 1961 to 1990 baseline by the end of the century.

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[2] Extreme heat events are defined as days with temperatures above the 90th percentile for a given baseline period..

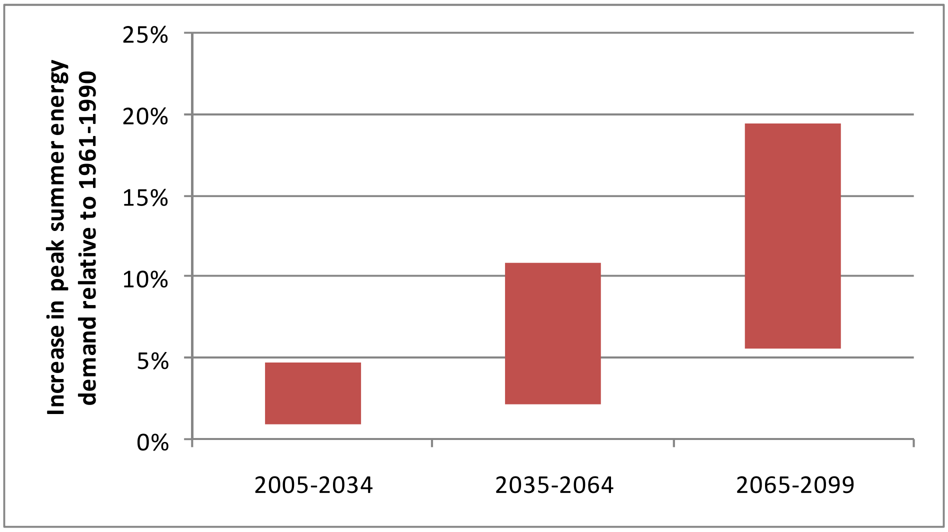

Figure 1: Projected increase in peak summer energy demand under high and low emission scenarios, relative to 1961 to 1990 baseline

Source: Franco and Sanstad, 2006.

In 2004, 30 percent of California peak demand was attributable to residential and commercial air conditioning use alone (California Energy Commission 2004). With long-term climate change, not only will those who already have air conditioning use it more often; additional homes and businesses will install cooling systems. If there is insufficient capacity to meet increased peak energy demands, California could face a greater probability of brownouts and blackouts during the peak demand period. Nationally, the number of significant weather-related incidents to the electricity system has grown significantly since the mid-1990s: for example, from five in 1995 to 55 in 2006 (Mills 2008). During the July 2002 heat wave, there was an all-time single day record electricity demand of 52,863 MW (compared to a typical daily demand of around 40,000 to 45,000 MW during that summer), and several regions within California were without power from hours to days.[3] In addition to public health risks, power outages can incur serious economic problems (LaCommare and Eto 2004). These findings suggest potential shortfalls in transmission and supply during future peak electricity demand periods, which will be both more frequent and longer-lasting. However, these potential impacts may be reduced or avoided by behavioral adaptation strategies: for example, raising the air conditioner thermostat in the summer (Miller et al. 2007).[4]

Although climate-related increases in energy demand will affect household and business energy costs, studies suggest that these increases would not exceed a few percentage points from a statewide perspective (Mendelsohn, 2003; Franco, 2005; Franco and Sanstad, 2006). Of course, increased costs may be much harder to bear for low-income households, who may face

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[3] In addition to being without power due to generation, transmission and distribution problems, households also suffer more air-conditioning breakdowns at higher temperatures (Mills 2008).
[4] In the Miller et al study (2007), changing the thermostat by ten degrees could reduce projected increases in electricity demand by roughly one third for inland cities and by as much as 95 percent for cooler coastal cities.

difficulties keeping cool during hot summer spells, suggesting an increased need for special programs targeted to these groups. As discussed below, direct temperature-driven impacts on energy costs may be exacerbated by climate impacts on energy supply, particularly hydroelectric generation capacity.

Impacts on Generation Capacity

Electricity providers will likely be challenged to meet these increases in peak demands. This challenge will arise both because of direct climate effects on generation infrastructure as well as limits on current infrastructure capacity. Although the most vulnerable component of the energy sector is hydroelectric power, other renewable sources and thermoelectric power sources may also be vulnerable. In 2006, the primary energy sources generating electricity used in California were natural gas, large hydro, coal, and nuclear energy (Figure 2). Just over one-fifth of the total volume is imported from out-of-state, including all coal-based electricity and some hydroelectricity.

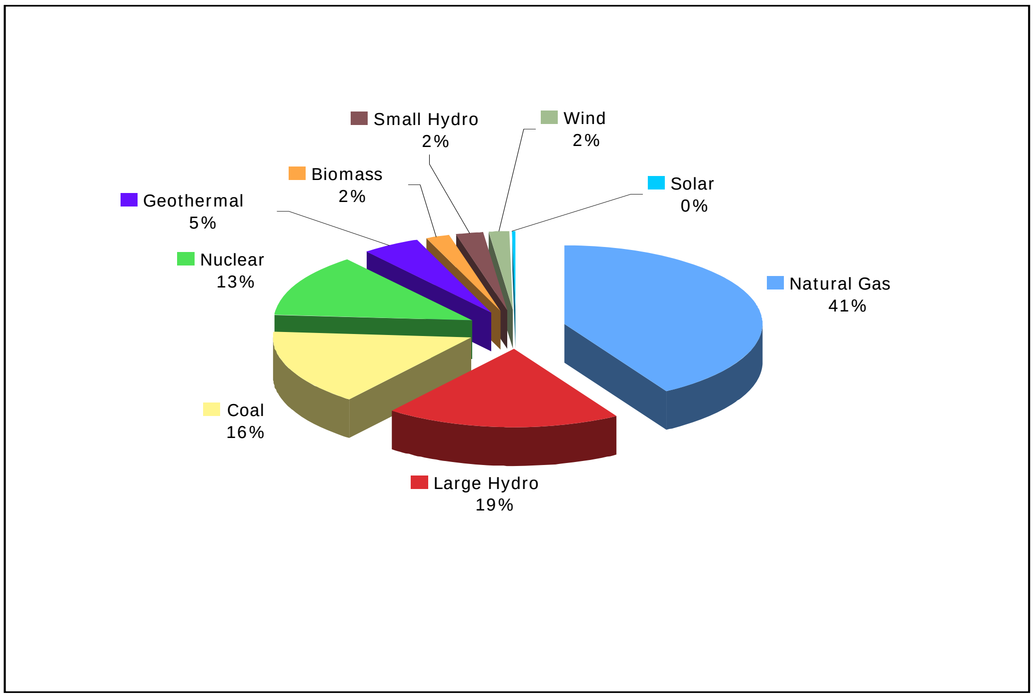

Figure 2: California's Electricity Mix 2006

Source: California Energy Commission, 2007c.

Hydroelectric Generation

Hydroelectric power plants contribute about 20 percent of the electricity generated by California's in-state power plants and are an important component of the state's power portfolio (Franco 2005). The hydroelectric capacity in California is over 14,000 MW (Aspen Environmental Group and M.Cubed 2005). Hydropower's ability to be dispatched quickly on hot summer afternoons to meet peak load, its low cost, and near-zero emissions are particularly valuable characteristics. Much of California's hydropower system is part of a broader multi-use system, with power generation facilities at dams that also serve water supply, flood control, recreation, and other beneficial uses. This is also the case for the Pacific Northwest and the Colorado River Basin, which supply hydropower to California. Because of these potentially competing needs, hydropower production may be preempted or at least constrained under changing climate conditions.

Hydropower generation is sensitive to the amount, timing, and geographical pattern of precipitation as well as temperature (which affects the share of precipitation that falls as rain or snow and the timing of mountain snowmelt). Reduced stream flows are expected to jeopardize hydropower production in some areas. It is also expected that less water will be available for hydroelectric generation in the spring and summer months, when demand is highest. In addition, there is a high likelihood that changes in precipitation and runoff patterns will not only jeopardize hydropower production in some areas but also lead to changes in broader water policies. Earlier snowmelts, particularly if coupled with heavy stream flows, could result in water being diverted from hydropower facilities to avoid damage to the dams and released from reservoirs to avoid flooding. Earlier snowmelt will increase the demand for reservoir space for flood control. Thus, the already existing conflict between water supply, flood control, and hydropower production will likely be exacerbated by climate change.

Two studies evaluated hydropower generation in the state under different climate scenarios. One study concluded that under a "wet" type of climate change, with significantly increased precipitation, there would be substantial increases in the annual amount of electricity generated in hydroelectric power plants in the state (Lund et al. 2003). On the other hand, if precipitation remained the same or decreased slightly, there would be substantial reductions in the amount of electricity generated, and the decreases would be more pronounced during the summer. This scenario would translate into reductions of about 30 percent in annual hydroelectricity generation by the end of this century. The second study estimated a loss of hydropower generation of about 10 percent per year by the end of this century for a relatively dry scenario (Vanrheenen et al. 2004).

The Pacific Gas and Electric (PG&E) Company has been evaluating the impact of climate change on hydroelectric generation for several years (Freeman 2003, 2007, and 2008; personal communication with Wendy Pulling, June 25, 2008). PG&E is concerned that if a rising snowline trend continues, then generation loss is likely to occur with increasing frequency, overshadowing the benefits of having runoff shift to earlier in the winter period (Freeman 2008).

Even relatively small changes in in-state hydropower generation result in substantial extra expenditures for electricity, which then needs to be purchased from other sources. For example, a 10 percent decrease from the current average in-state level of hydropower generation would result in an additional $350 million per year in net replacement costs (Franco and Sanstad 2006)[5]. Out-of-state sources of hydropower are also likely to become less available or more costly. Currently, hydropower imports from the Pacific Northwest provide 7 to 10 percent of California's peak load on high load days (between 4,000 to 7,000 MW of power) (Aspen Environmental Group and M.Cubed 2005). At some point in the future, California may not be able to count on large transfers of hydropower from this region, given the expected increase in local demand and the decreased ability to generate electricity in the summer months in the Pacific Northwest. For example, the Northwest Power and Conservation Council released its fifth power plan in May 2005 and indicated that climate change may have a significant impact on hydropower in the Pacific Northwest (Northwest Power and Conservation Council 2005). A more recent analysis of the potential impact of climate change on hydropower generation in the Pacific Northwest shows that the average annual hydropower production could potentially decrease by as much as 15 percent by 2020 and 30 percent by 2050 compared to baseline hydropower production (Markoff and Cullen 2008). Similar problems may affect hydroelectricity supplies from the Colorado River, although its contribution to California is significantly less than the contribution from the Pacific Northwest.[6]

Other Renewable Energy Sources

Since the early 2000s, California has placed an increased emphasis on the development of renewable energy sources other than hydroelectric power, such as solar, wind-based, biomass, and geo-thermal generation.[7] Excluding large hydroelectric generation, renewable energy production accounted for approximately 11 percent of total electricity production in California in 2007 (California Energy Commission 2007b).[8] This share is expected to increase to 20 percent by 2010 under the state's renewable energy policy. Because renewable energy depends directly on ambient natural resources such as hydrological resources, wind patterns and intensity, and solar radiation, it is likely to be more sensitive to climate variability than fossil energy stems. Renewable energy systems are also vulnerable to damage from extreme weather events because of their exposure to the natural elements (e.g., wind for windmills and solar radiation for solar panels). The issues vary for different renewable energy sources.

Solar energy. Photovoltaic (PV) electricity generation and solar water heating are suitable for most of California, with current deployment primarily in off-grid locations and rooftop systems. Solar radiation – the energy source for these systems - may be affected by climate change. Preliminary results from one study found that in most of the U.S., increased CO_2 concentrations were associated with increased cloudiness, resulting in decreased levels of daily global radiation availability in the range of 0 to 20 percent (Pan et al. 2004). The most noticeable decrease was in the western U.S. during fall, winter, and spring.

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[5] This assumes a price of $0.10 per kWh.

[6] The Hoover Dam provides 626 MW of power to California (CEC 2003)

[7] As described below, under the Renewable Portfolio Standard (RPS), first adopted in 2002, utilities are required to increase the share of renewables to 20 percent by 2010.

[8] Geothermal (4.7%), biomass (2.1%), small-scale hydroelectric (2.1%), wind (1.8%), and solar (0.2%) (CEC 2007d)

Wind energy. The use of wind energy is growing rapidly in California. Wind power generation is susceptible to variations in ambient temperatures, humidity and precipitation. The primary determinants of wind power availability are wind speed statistics (e.g., mean wind speeds and gustiness). Wind speeds are subject to natural variability on a wide range of time scales, and they may be affected by climate change. One modeling study found that the U.S. will see reduced wind speeds of 1.0 to 3.2 percent in the next 50 years, and 1.4 to 4.5 percent over the next 100 years (Breslow and Sailor 2002). Another model suggested reductions in mean wind speeds on the order of 10 to 15 percent (Breslow and Sailor 2002). Considering that wind power generation is a function of the cube of the wind speed, these decreases in wind speed correspond to potential reductions in wind power generation on the order of 30 to 40 percent.

Yet there remains a great deal of uncertainty regarding how wind fields will change in the future. For example, in one study linking general circulation model output to local weather in a doubling of carbon dioxide scenario, the windier conditions were found in one part of California (Santa Clara and Amador counties) while less windy conditions were reported in another region (Humboldt County) (Fried, Torn and Mills 2004). Increased variability in wind patterns could create additional challenges for accurate wind forecasting for generation and dispatch planning, for the siting of new wind farms, and for the integration of wind with the utility grid (Bull et al. 2007).

Biomass-based energy. Biomass from trees, municipal waste, and crop residues is found in abundance in California and represents a significant renewable energy resource. California's current use of bioenergy as a source of electric power represents a small fraction of what is technically feasible: approximately 30 million dry tons of technically recoverable solid biomass resources each year (enough to power some 3 million homes) (California Energy Commission 2006a). Given the state's goals to increase the use of biomass-based energy, climate change impacts on biomass are of concern (Bull et al. 2007). For example, for wood and forest products, there may be short- or long-term impacts from timber kills and long-term impacts from changes in tree growth rates. For agricultural biomass, there may be changes in food crop residue and growth rates of crops produced specifically for energy production.

Thermoelectric Generation

Despite the recent emphasis on renewable sources, California still relies heavily on thermoelectric power generation, particularly gas-fired plants (roughly 41% of in-state generation) and nuclear plants (13%). Thermoelectric generation is water intensive; on average, each kWh of electricity generated via the steam cycle requires approximately 25 gallons of water (Bull et al. 2007). Power plants (136,000 million gallons per day (MGPD)) rank only slightly behind irrigation (137,000 MGPD) in terms of freshwater withdrawals in the United States (US Geologic Survey 2004).[9] Interestingly, in California, freshwater withdrawals for power plants are significantly lower (352 MGPD) with irrigation (30,500 MGPD) representing almost 80 percent of total freshwater withdrawals. If changing climatic conditions alter historical patterns of precipitation and runoff, this may complicate operations of existing thermoelectric power plants as well as the design and site selection of new units.

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[9] Power plants consume a substantially lower share of water withdrawals than other sectors, however, with much of the water going back into the system after it is used by the plants.

Elevated water temperatures may affect thermoelectric generation. For California's nuclear power plants that use once-through cooling with ocean water, the cooling water supply should not be a problem. However, if ocean water temperatures rise, then these power plants may have difficulty in meeting existing water temperature discharge limits (Personal communication with Joe O'Hagan, California Energy Commission, July 3, 2008).[10] The thermal discharges have long been considered to be potentially the most severe impacts of once-through cooling systems (California Energy Commission 2005d). For gas-fired power plants that use once-through cooling, the discharge water impacts are also of concern (Personal communication with Joe O'Hagan, July 3, 2008).

Impacts on Electricity Sector Infrastructure

Two key aspects of electricity sector infrastructure are the siting of power plants along the coast and the transmission and distribution (T&D) network. Although both types of infrastructure face potential climate-related impacts, the issues appear to be more significant for the T&D network.

For power plants located along the coast, concerns have been raised about possible effects of sea level rise and coastal storm surges. However, neither issue appears to be particularly threatening in California. In contrast to other coastal states, increased storm surges are not expected to affect California's coastal power plants, with the exception of the Diablo Canyon nuclear facility.[11] Theoretically, rising sea level might make also it more difficult for power plants to get the fresh water they need for once-through cooling. In 2005, 21 California coastal power plants (generating capacity of 23,910 megawatts (MW)) that use once-through seawater for cooling were located along the entire length of the State from Humboldt Bay to San Diego Bay (Figure 3).[12] However, it appears that very few existing coastal plants are at risk. With increased awareness of possible sea level change, the construction of new power plants along the coast will be designed to account for this possible impact.

The transmission and distribution system may be affected to different degrees by several aspects of climate change – sea level rise, increased temperatures, and increased frequency and size of wildfires. At currently predicted rates, sea level rise is expected to have very minimal consequences on existing T&D lines over the next century. Given the likely relatively slow increase in sea level, raising transmission lines would not be difficult, but could be costly (Personal communication with Merwin Brown, California Institute for Energy and Environment, July 23, 2007).

For future T&D lines, planners can take into account sea level change by constructing higher lines or, where possible, moving the lines to others areas.

[10] These discharge-related issues are commonly referred to as 316(a) impacts because they are regulated by the US Environmental Protection Agency under Section 316(a) of the Clean Water Act.
[11] The Diablo Canyon cooling water intake often gets clogged due to debris from storm surges, forcing the plant to shut down. Although the plant itself is well above sea level, greater impacts on the intake may occur with sea level rise, increasing the frequency and duration of power reductions (Aspen Environmental Group and M.Cubed 2005; O'Hagan 2007).
[12] There are many small power plants along the coast that use cooling towers or do not require water for steam condensation (O'Hagan 2007).

Figure 3. Major coastal power plants that use once-through cooling of seawater, 2005

Source: California Energy Commission, 2005d

Note: Since 2005, at least one plant has been taken off-line (Hunters Point Power Plant, in 2006). Several new PG&E plants will use dry cooling (without water) (personal communication with W. Pulling, June 25, 2008).

The trend towards increased temperatures is not expected to significantly affect the transmission and distribution of electricity in the long term (Personal communication with Merwin Brown, July 23, 2007.) The amount of current a line can carry is determined in part by the ambient air temperature: the higher the temperature, the lower the maximum current. Theoretically, higher temperatures would mean lower levels of peak power capacity for the T&D system. On the other hand, because of the relatively slow pace of temperature increase expected, the conservative engineered margins used could absorb additional thermal load.

However, in the short term, sudden increases in temperatures (e.g., heat waves) may affect the T&D system. For example, in the July 2006 heat wave in California, over 80,000 customers in the Los Angeles Department of Water and Power's service territory lost power for days as 860 distribution line transformers (worth about $1 million) malfunctioned or stopped working (Bernstein 2006). Similarly, in Northern California, 1.2 million PG&E customers lost power in the July 2006 heat wave as 1,150 distribution line transformers failed (Jurgens 2006). PG&E reported that heavy electricity use heated the transformers and warmer-than-normal air failed to cool them: this tripped circuit breakers, broke fuses and burned the insulation, causing short circuits inside the transformers.

The increased frequency and intensity of wildfires expected with climate change may have a significant impact on the transmission and distribution of energy. For example, on October 21, 2007, the Acton Fire in Southern California caused the Southwest Powerlink transmission system to go out of service. The following day, the state's electrical grid operator – Cal-ISO – declared an emergency when the Santiago Fire in Orange County caused two more high-voltage transmission lines to trip off-line. To reduce stress on the power grid, Cal-ISO asked two utilities (San Diego Gas & Electric (SDG&E) and Southern California Edison (SCE)) to reduce their electrical load by a total of 500 MW. By October 23, the fires had knocked out multiple transmission lines in the San Diego area, causing Cal-ISO to request voluntary energy conservation in San Diego. Over the course of that week, more than 24 transmission lines were knocked out of service, and by October 24, San Diego was being served by only one 230 kV transmission line. At the same time, two units of the San Onofre nuclear power plant had been temporarily out of service for maintenance reasons, and a complete loss of off-site power would have caused the nuclear plant itself to automatically trip off-line. In order to maintain systemwide reliability, SDG&E started planning for rolling blackouts, which did not occur as the Southwest Powerlink was brought back into service. All in all, nearly 80,000 SDG&E customers (of a total of 1.4 million) lost power in San Diego, more than 1,500 utility poles were burned, and at least 35 miles of overhead wire were damaged (San Diego Gas & Electric 2007).

2. Institutions and Regulatory Structure: Energy and Climate

The energy sector involves many actors who will need to respond to the challenges posed by climate change. This includes state institutions that oversee energy planning decisions and facilities, water resource institutions that manage the state's hydroelectric facilities, as well as the electric utilities and other private sector actors. In addition, local government decisions can have a large effect on the demands placed on the energy system – a central tool for reducing the vulnerability of the system to increases in summer temperatures.

State Energy Agencies

California has had a long history (over 30 years) in public planning and decision-making on energy matters. The California Energy Commission (CEC) and the California Public Utilities Commission (CPUC) have been the key policy leaders in deciding which energy supplies (power plants and distributed generation) get built and which energy programs (energy efficiency, demand response, renewable energy, distributed generation) get funded and implemented.

In addition to setting general policy and energy targets and goals for public utilities, the CEC is responsible for developing and implementing the state energy building codes and appliance standards. The CEC has also been playing a leading role in California's research efforts on climate change, through its own Public Interest Energy Research (PIER) Program and the California Climate Change Center, a virtual, multi-site research center launched in 2003 (Franco et al. 2003 and Franco 2005). These efforts are aiming to develop the tools and data necessary for in-depth policy relevant analyses of climate-related issues for numerous sectors in addition to energy.[13]

The CEC's PIER program is also very active in conducting research on energy efficiency and renewable energy technologies and services. The CPUC also recently established its own research program on solar energy. While the California Air Resources Board (ARB) is the lead state agency in implementing AB 32, this agency has deferred to the CEC and the CPUC for providing ARB information and recommendations in the energy field.

Water Resource Planning Institutions

The operation of the hydroelectric system is of key concern to the CEC and the Department of Water Resources (DWR) in the planning of water and energy resources. While approximately 36 percent of hydroelectric generation is controlled by the investor-owned utilities, approximately 27 percent of generation is owned by water project operators (the U.S. Bureau of Reclamation's Central Valley Project and DWR's State Water Project), and approximately 35 percent is owned by municipalities, with the remaining hydropower capacity owned by irrigation districts.

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[13] For more details, see http://www.climatechange.ca.gov/research/index.html

DWR and the U.S. Bureau of Reclamation (USBR) have formed a working team to address water resources-related issues of climate change. This team will coordinate with other state and federal agencies in providing and regularly updating information to the decision making processes on potential risks and impacts of climate change, flexibility of existing facilities to accommodate climate change, and possible mitigation measures (e.g., Brekke 2007).

Investor-Owned Utilities

California's three investor-owned utilities – PG&E, SCE and SDG&E - are responsible for acquiring and delivering 68 percent of the electricity to the state's business and residential customers (California Energy Commission 2007c). These companies 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. They have been involved in planning for capacity additions, assuring system reliability, and selecting sites for long-lived capital facilities. They are concerned that relatively small changes in temperature (and demand) can affect their total capacity needs, especially in peak periods.

Given the importance of hydroelectric generation, any changes to this resource are of utmost concern. For example, PG&E's water management team is aware that climate change is occurring (e.g., reduction of mountain snowpack and more intense winter runoff events) and is planning for how to best work with runoff change in terms of best hydroelectric scheduling practice (Freeman 2003, 2007). PG&E is investigating improved methods for data collection and analysis that will help its adaptation capabilities (Freeman 2003). In one research project, PG&E is evaluating how aquifers (an important source of water for hydroelectric generation) can be recharged with land-based cloud seeding for increasing daily outflow from springs in all years, including anticipated future multi-decadal aquifer outflow droughts (Freeman 2007). The company is also assessing the susceptibility of its transmission and distribution network to sea level rise and increased risks of flooding in areas such as the Sacramento-San Joaquin Delta. In addition to their ongoing work on evaluating the risks of increased fires and heat storms, PG&E is conducting an institutional risk management review process, where climate change has been identified as one of the "enterprise risks." Through this process, PG&E will be tracking the scientific analysis of climate change in California and using that science as a starting point for potentially developing appropriate tools, methodologies, programs, and policies (personal communication with W. Pulling, December 20, 2007 and June 25, 2008). PG&E is currently at the initial stages of this risk analysis.

Local Governments

Local governments can express their legally enforceable policies through required general plans and zoning codes (California Energy Commission 2007a). Although state law does not require general plans to address energy, some cities and counties have adopted an "energy element," which specifies local policies regarding energy use and efficiency. By 2006, 56 general plan included energy elements (California Energy Commission 2007a). Some local governments have also enacted specific ordinances to promote energy efficiency or renewable energy: e.g., retrofit conservation ordinances and solar access ordinances. Furthermore, the publicly owned utilities (owned by municipalities and special districts), which provide electricity to 22 percent of the population (California Energy Commission 2007c), play an important role in promoting energy efficiency, renewable energy, and distributed generation, similar to investor-owned utilities.

Although the state has very limited land use authority, the policies it develops in regard to new infrastructure, utility funding, environmental review, and housing allocation are all leverage points that the state can use to assist local governments in growing in an energy-efficient and climate-friendly manner. Most recently, the state Attorney General has used the California Environmental Quality Act (CEQA) as a lever to require local government to consider climate change in their general plans.

Laws and Regulations Considering Climatic Factors

AB 32 was signed into law by Governor Schwarzenegger on September 27, 2006. This Act commits the state to reduce global warming pollution back to 1990 levels by 2020 through a concerted effort to deploy clean energy technologies and other emission reduction strategies. The coal and natural gas burned to generate electricity and the natural gas used directly in homes and businesses represent approximately 36 percent of the state's GHG emissions (California Energy Commission 2006b). Accordingly, the California Climate Action Team has identified numerous strategies to reduce emissions from the energy sector, including energy efficiency, renewable energy, and cleaner power plants to reduce emissions from the electricity and natural gas sectors.[14] The ability to meet the AB 32 goals may be jeopardized if there is reduced hydroelectric generation or increased use of carbon-based back-up generation in extreme heat events.

A number of key energy legislation and decisions (in addition to building codes and appliance standards) have been enacted in recent years that, while not designed to address climate change, will affect how the energy sector will respond to AB 32 and how the sector is able to adapt to climate change (Table 1).

For the most part, this portfolio of measures will simultaneously work to reduce the production of greenhouse gases (mitigate) and to improve California's ability to adapt to the increased pressures on the energy sector from climate change. In contrast, one piece of recent legislation is likely to pose tradeoffs between these two goals. SB 1368, signed into law in 2006, sets GHG emissions standards for electricity imports into California, in an effort to limit the carbon footprint of the state's overall electricity use. These import restrictions could limit California's flexibility to respond to peak demand increases, which may already be reduced because of a loss of in-state hydropower. The constraint might be particularly felt if California's future hydroelectric imports are also reduced because of climate impacts in the Pacific Northwest and the Colorado River basin.

[14] "Cap and trade" – whereby emissions producers are "capped" at certain levels of emissions and allowed to trade emissions permits - is one of the general mechanisms being discussed as a way of enhancing the efficiency of reductions.

Table 1 - Climate-related energy legislation and programs

Year	Policy	Description
2002	Renewable Portfolio Standard (SB 1078)	Requires 20 percent of electricity generation be renewable by 2020
2003	Energy Action Plan	Joint effort by the CPUC, CEC, and the California Power Authority to create a unified energy policy for California. Emphasized energy efficiency and called for acceleration of the RPS.
2004	Executive Order S-20-04	"Green Building Initiative" that requires the state government to reduce its own electricity demand 10 percent by 2010 and 20 percent by 2015. All new, renovated, and build-to-suit leased state buildings will meet LEED standards.
2006	Million Solar Roofs	$2.9 billion incentive program for homeowners and building owners to install solar electric systems.
	Executive Order S-06-06	Established biomass production and use targets for California
	SB 1368	Sets GHG emission standards for electricity imported into California
2007	AB 1470	Incentives for installation of 200,000 solar water heaters by 2017.
	AB 2021	Requires municipal-owned utilities to prepare 10-year energy efficiency goals and use load ordering similar to the investor-owned utilities
2008	Green Building Standards Code	Green Building Standards Commission adopts green building standards for residential and commercial construction, with mandatory compliance by 2010.

3. Adaptation Strategies

The preferred adaptation strategy for California's electricity sector should consist of a portfolio of strategies, including mitigation, adaptation, technological development (to enhance both adaptation and mitigation), and research (on climate science, impacts, adaptation and mitigation). Adaptation and mitigation should follow the guiding principle of "resilience" – enhancing the capacity of the system to operate under a range of future environmental and socio-economic conditions that can be anticipated as possible and plausible but that cannot be predicted with certainty (Franco and Sanstad, 2006).

Accordingly, the energy sector can adapt to climate change vulnerabilities and impacts by anticipating possible impacts and taking steps to increase its resilience: e.g., by diversifying supply sources and investing in technological change to further expand its portfolio of demand and supply options (Intergovernmental Panel on Climate Change 2007). Given its impressive investment resources and experience with risk management, the energy sector has the potential to be a leader in adaptation initiatives, whether related to reducing risks associated with extreme events or coping with more gradual changes such as water availability (Intergovernmental Panel on Climate Change 2007).

On the other hand, adaptation actions are unlikely to approach their full potential for cost-effective risk reduction without deliberate investments of policy, management, and financial resources. While many energy sector strategies are relatively inexpensive, some involve high capital costs, and social acceptance of climate-change response alternatives that might imply higher energy prices could be limited. Finally, adaptation prospects are likely to depend considerably on the availability of information about possible climate change effects to inform decisions about adaptive management. Making that information available to energy policymakers will be a key effort in California's adaptation response.

Reducing Peak Demand Increases

The electricity system can respond to increases in peak demand in two primary ways: by reducing the magnitude of increased peak demand through energy efficiency programs and by increasing the resiliency of the energy production system to respond to these peaks. Fortunately, California's state and local government institutions and utility companies have extensive programs (information, education at all levels, ranging from kindergarten to university, marketing, and financial incentives) to promote the use of high efficiency air conditioners. In addition, alternative technological solutions to air conditioners (e.g., the use of natural cooling) are being studied in the public sector (e.g., CEC's PIER program). For example, in some areas of California where air conditioners are used for only a few hours in the summer (during hot, peak demand days), these households do not need to use an air conditioner if the house is designed and built with energy efficiency principles in mind (e.g., thermal mass, use of natural cooling, well insulated, sealed ducts, evaporative coolers,[15] etc.).

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[15] In the future, advanced multiple stage evaporative coolers have the potential to reduce annual electricity consumption by 80 percent (Personal communication with Marshall Hunt, UC Davis Western Cooling Efficiency Center, December 9, 2007). While these units do use water, onsite water use is

Complementing the air conditioning strategy is the use of higher levels of insulation (e.g., ceiling, wall and floor) and higher levels of window glazing in both the new and existing housing stock. Fortunately, California's building code (Title 24) has had a long history in making the new residential and commercial building stock more energy efficient. The existing stock is also getting more attention: for example, the CEC issued a report on recommended strategies to increase energy efficiency in existing buildings (California Energy Commission 2005a). Another strategy for adapting to the increased energy demand resulting from higher temperatures is the planting of trees to shade homes and buildings, the painting of reflective surfaces for roofs and pavements, and the construction of roofs that reflect heat to reduce the heat island effect in urbanized areas.

In the non-residential sector, customers in California have been investing in energy efficiency measures that not only save energy but also help to reduce peak demand: for example, insulation of the building shell (ceilings, walls, basements), adjustable speed drive motors for air-conditioning and processes, high efficiency chillers, and more efficient lighting.

Public information programs can also play a large part in mitigating the effects of energy demand increases. Some of the most direct strategies have been phone trees to alert people about possible heat waves, public education programs, cooling centers, and heatwave early warning and response systems to reach the most vulnerable (Kovats and Ebi 2006; Palecki et al. 2001; Weisskopf et al. 2002; Ebi et al. 2004). With respect to energy use and demand, the state's Flex Your Power program and utility programs have alerted consumers on when to turn off (or reduce their use of) selected appliances (including air conditioning) during peak periods and to run this equipment on off-peak periods.

California's utilities have been the leaders nationally in promoting energy efficiency (Vine et al. 2006). Since 1975, the energy savings from the utilities' energy efficiency programs and from the state's building and appliance standards have supplanted the need for a minimum of 24 new, large-scale (500 MW) power plants (California Energy Commission 2005c). In addition to involving local government, the utility programs include manufacturers, retailers, distributors, and energy service companies (ESCOs). Since 2000, PG&E has been focused on climate change issues. In addition to advocating for the regulation of GHG emissions at the federal level, they have been reporting their GHG emissions as a charter member of the California Climate Action Registry since 2004 (personal communication with W. Pulling, June 25, 2008). More recently, they introduced the Climate Smart™ Program that provides a voluntary option for PG&E customers to reduce their personal impact on climate change. PG&E calculates the amount needed to make the GHG emissions associated with the customer's personal or business energy use "neutral" and will add this amount to their monthly energy bill; 100 percent of the Climate Smart payment goes directly to funding new GHG emission reduction projects in California.[16]

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almost offset with kWh savings that saves the water that it takes to produce kWh. In addition, water use for cooling can be easily offset with plumbing fixtures, distribution layout, landscape choices, and super-low water use appliances. Finally, low cost water storage units with the ability to use rainwater are also being evaluated for widespread use.

[16] See http://www.pge.com/about_us/environment/features/climatesmart.html

The financial sector has been actively involved in energy efficiency by promoting energy-efficient mortgages (EEMs). The EEMs offer homebuyers bigger loans or discounts if they make energy-efficient improvements, or if their new home meets certain efficiency standards. As an example, Citigroup Inc.'s mortgage division offers $1,000 off the closing costs on EEMs, Bank of America Corp. offers $1,000 off the closing fees for Energy Star qualified homes, JPMorgan Chase & Co.'s mortgage division offers $500 off the closing costs for homes insulated with a high-efficiency spray foam, and the Indigo Financial Group allows consumers to borrow more money to finance energy-efficient upgrades (Muñoz 2007).

The demand response programs are most effective when there is real-time pricing. Real-time pricing is being addressed in regulatory proceedings at the CPUC, and the infrastructure is being laid with the installation of advanced (smart) utility meters that provide information about what energy is costing at particular times during the day. SDG&E has a one-year trial program designed to measure the financial impact of time-of-use programs. SCE has been field-testing advanced meters and plans to start large scale meter installations in January 2009 through June 2012. And PG&E has been installing advanced meters since 2007 and hopes to install 10 million advanced meters by 2012.

Finally, planning at the local and regional level can be conducted to anticipate storm and drought impacts, improve forecasting of the impacts of global warming on renewable energy sources at regional and local levels, and establish action plans and policies that conserve both energy and water. For example, the Cities of San Francisco, Santa Cruz, and Berkeley have each added an environmental expert to their staffs specifically to help reduce GHG emissions, and the San Diego Foundation is working with local and regional government in looking at climate change impacts in San Diego over the next 40 years.

Improving the Generation System's Ability to respond to Peak Demands

For energy production, the adaptability of the system will be enhanced if future installations can be designed with built-in flexibility to accommodate the span of potential climate impacts. Possible adaptation measures include technologies that minimize the impact of increases in ambient temperatures on power plant equipment and technologies that conserve water use for power plant cooling processes. To meet the increased energy demand for air conditioning, onsite or locally-based renewable energy systems (e.g,. as part of a "microgrid") may become particularly interesting: for example, the installation of a small wind generator next to a building or the placement of photovoltaic arrays on exterior parking structures. Energy sources in the future may also be integrated increasingly with buildings (e.g., zero energy new homes): for example, new roofs and walls with materials incorporating photovoltaic cells. Sources of more electricity on hotter days could include pumped storage,[17] new plants to increase storage capacity, or thermal energy storage[18] in buildings (typically less expensive than pumped storage).

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[17] Pumped storage is a hydroelectric source of power in which electricity is generated by the use of water that has been pumped into a reservoir or a holding tank at a higher altitude (height).

[18] Thermal energy storage refers to a number of technologies that store energy in a thermal reservoir for later reuse. In the context of this discussion, the principal application is the production of ice or chilled water at night, which is then used to cool buildings during the day.

Regarding the hydroelectric system, the management of water reservoirs can be substantially improved with the use of modern probabilistic seasonal and short-term hydrological forecasts and numerical decision support tools. These management tools will result in an improved capacity to better cope with long-term increased climate variability and change (Georgakakos et al. 2005; Carpenter and Georgakakos 2001; Yao and Georgakakos 2001). Reservoir operation strategies are further discussed in the accompanying report on water resource management (Hanak and Lund, 2008).

Enacting Mitigation Policies that Enhance Adaptation Potential

As noted above, California has been a leader in implementing energy legislation and policy that affect how the public and private sector will manage climate change. In the coming years, California is expected to continue this leadership role. Local governments in California have also been national leaders in preparing for climate change by implementing policies that primarily have a mitigation focus but will also provide adaptation benefits (Table 2 describes San Francisco's efforts). For example, building energy efficient buildings will reduce the amount of energy needed, and streamlining the solar photovoltaic permit process will increase the amount of renewable energy. In a warmer climate, less reliance on the utility grid (through either reduced energy use or more use of onsite renewable energy) is an effective adaptation strategy, since the grid will be more vulnerable to potential brownouts and blackouts.

The League of California Cities (LCC) and many individual cities in the state have endorsed the U.S. Conference of Mayors Climate Protection Agreement, which commits signatories to meet the Kyoto Protocol targets (reduction of emissions by 7 percent below 1990 levels by 2012).[19] Some local governments have even gone further. For example, the City of Berkeley's voters passed a measure in November 2006 that pledges an 80 percent reduction in GHG emissions by 2050, comparable to the California goals set forth in Governor Schwarzenegger's Executive Order in 2005. Both the LCC and the California State Association of Counties (CSAC) have adopted guiding principles on climate change (League of California Cities, 2008; California State Association of Counties, 2007).

Table 2. Recent Greenhouse Gas Emissions Mitigation Policies by the City of San Francisco

- 2002 – The City passed a resolution committing to reduce carbon emissions by 20 percent below 1990 levels by 2012 – this goal goes beyond the Kyoto Protocol objectives.
- 2004 – The City required all new municipal construction and major renovation projects to achieve a LEED Silver certification from the U.S. Green Building Council.
- 2006 – The City streamlined the solar photovoltaic permit process – permits can be issued over the counter, without the delays of in-house reviews
- 2006 – The City established a priority permitting process for LEED Gold certified building projects.

One concrete step that local governments can take is to waive fees for solar installations. Two years ago, none did; now at least 14 jurisdictions hand out building permits for solar power to homeowners for free (Rogers 2007). Cities such as San Jose, Walnut Creek and Novato

[19] http://www.usmayors.org/climateprotection/agreement.htm

have also streamlined their rules so much that their planning departments now issue most permits in a few minutes, a process that once took weeks.

Another initiative that local governments can take is to pass energy ordinances that require more energy-efficient building practices than required by the state (i.e., CEC). For example, the City of Santa Barbara recently passed an energy ordinance that tightens energy standards by 10 percent every five years and makes buildings 20 percent more energy efficient than state standards (Licata 2007).

Increasing RD&D to Support Energy Sector Response

While existing technologies are available for California to use as part of its adaptation response, there is a need to develop a portfolio of robust energy efficiency technologies as part of a major research, demonstration and development (RD&D) effort. Unfortunately, for several decades, there has been a disturbing trend away from investment in energy technology – both by the federal government and the private sector (Nemet and Kammen 2007). In fact, the U.S. invests about $1 billion less in energy RD&D today than it did a decade ago (which was also low compared to earlier investments).

Fortunately, in California, key agencies have realized this necessity and have committed funds to support RD&D, much of which can be linked to climate change mitigation and adaptation. For example, the CEC's PIER Program has conducted (and continues to conduct) in-depth climate-related studies that will be of particular interest for the energy sector, including :

- Development and exploration of probabilistic California climate projections for impact and adaptation studies
- Development of higher resolution regional model tools to explore effects of climate change and land use change
- Demonstration of probabilistic seasonal forecasts, to improve the management of water reservoirs in the state
- Installation of climate reference stations to track and, if possible, detect climatic changes in the state
- Enhancements to the CALVIN water system model to investigate potential adaptation measures under a wide variety of scenario (see Hanak and Lund, 2008).

The funding authorization for the electricity portion of the PIER program of $62.5 million per year sunsets at the end of 2011 – just four short years from now. Support of PIER and other similar R&D programs needs to be continued to determine 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 (Tierney 2007). This could include identification of important climate change-related factors (e.g., trends in changing wind patterns, in heating and cooling degree days), along with efforts to collect and analyze different data than in the past. Accessing and analyzing such information will be important for assuring that demand and load forecasts remain reasonable for future conditions as heating and cooling degree days change.

In April 2008, the CPUC issued a decision establishing the California Institute for Climate Solutions (CICS) (California Public Utilties Commission 2008). The mission of the CICS is to (1) administer grants to facilitate mission-oriented, applied and directed research that results in practical technological solutions and supports development of policies to reduce GHG emissions or otherwise mitigate the impacts of climate change in California; (2) speed the transfer, deployment and commercialization of technologies that have the potential to reduce GHG emissions or otherwise mitigate the impacts of climate change in California; and (3) facilitate the coordination and cooperation among relevant institutions to most efficiently achieve mission-oriented, applied, and directed research. The budget, funded by ratepayer funds, is $60 million per year over a ten-year period. The implementation of the CICS is currently pending, awaiting a review by the State Legislature.

Table 3 highlights particular research needs for the energy sector in California (some of which is already being implemented but needs more funding). In addition, more research must be conducted on risk management 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. For example, one would create forecasts of long-range energy capability and demand and then assess the ability of energy facilities to supply and distribute energy under changing, and often extreme, weather conditions. DWR is already conducting scenario planning for extreme events, and examining the location of facilities and their ability to withstand storms and other severe weather. In California, other organizations that need to conduct such analyses include the CPUC, the CEC, ARB, and coastal zone management agencies; regional transmission operators; utilities and other energy companies; and state emergency management agencies. For all of these agencies, information sharing for systems operations, equipment and materials strengths, emergency preparedness, research needs, and technological issues will be key.

Table 3. California energy sector research needs

1. Climate change effects on a relatively fine-grained geographic scale (temperature and precipitation changes and severe weather events)
2. Implications of extreme weather events for energy system resiliency (strategies for reducing and recovering from impacts)
3. Strategies and improved technologies for adding resilience to energy supply systems (regional interconnection capabilities and distributed generation)
4. Detailed relationships between temperature (including temperature extremes) and patterns of electricity consumption and demand in California
5. Potentials, costs, and limits of adaptation for supply and use infrastructures
6. 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
7. Implications of changing regional patterns of energy use for regional supply institutions and consumers (including water suppliers and operators)
8. Effects of changing conditions for renewable energy production (wind and solar)
9. Linkages and feedbacks among climate change effects, and implications for adaptation and mitigation
10. New energy efficiency technologies and services for reducing space cooling, involving cross-disciplinary research and development efforts to generate innovation and including both component and system energy efficiency improvements and integration
11. Behavioral issues affecting individual and organizational climate change adaptation.
12. Analytical methods for incorporating appropriate levels of uncertainty in key climatic, technological and socioeconomic trends
13. Robust policy strategies for developing and managing the electric power system
14. More effective integration of the investment, finance, and risk management communities into the research and development process to help identify opportunities and barriers and evaluate the potential solutions for market success

Source: Franco and Sanstad (2006), Wilbanks et al. (2007), and Mills (2008)

4. Constraints to Adaptation

Although California's various institutions have made significant advances in developing tools that will help the electricity sector adapt to the effects of climate change, some important barriers remain. Foremost among these is the cost of implementing energy efficiency measures and investing in renewables. Institutional barriers can also play a significant role in slowing down the pace of new technology adoption in businesses and within the energy sector itself. Finally, there may be political and behavioral barriers to adoption of new technologies and practices.

Financial and Economic Barriers

One of the biggest constraints to adaptation is cost. Many energy efficiency measures are cost-effective, and many of these measures have simple paybacks ranging from one to four years. In contrast, wind and solar energy projects require more capital and will require longer paybacks. And for water resource managers, new water storage facilities are very expensive and will most likely require a financing mechanism supported by California taxpayers (e.g., an infrastructure bond). For example, raising Shasta Dam by 6.5 feet could increase the long-term Central Valley energy production by up to 10 GWh/year, and raising it by 18.5 feet could increase it to 40 GWh/year – the capital cost estimates for these enhancements would range from $280-480 million (DWR 2006).[20]

Most importantly, the focus for many residents will be on short-term costs of adaptation rather than on lifetime costs that account for savings achieved through lower operation and maintenance costs. For example, the initial cost of buying a high efficiency air conditioner is a barrier to some consumers, even though the long-term operating costs will be reduced over time and even though the payback times range from three to seven years. Also, as noted earlier, the cost of operating an air conditioner will be a burden for specific groups (elderly and low income); they will face the challenge of paying for cool air or paying for food. Accordingly, an adaptation strategy will need to emphasize a long-term perspective and ensure that the needs of the elderly and low income groups are accounted for.

Institutional Barriers to Business Decisions

Investment in energy efficiency and renewable energy is relatively simple in the residential sector: usually, only one or two people are involved in the decision to adopt these measures. In the nonresidential sector (commercial and industrial), the decision-making process is more complex due to multiple actors with different perspectives (e.g., plant manager, chief financial officer, chief executive officer, etc.). In addition, the cost of the measure will affect this relationship: relatively inexpensive measures will need fewer approvals than more expensive measures. As a result, a new, better adapted power plant or transmission and distribution line will take years to get approved and built, and, in some cases, legislation or regulation will be needed. Similarly, if new management policies and procedures are needed, then human and

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[20] These costs include pumping and operations and maintenance costs, and the wide range of costs reflects the wide range of storage options, conveyance facilities, etc.

financial capital will be required to make these policies and procedures work. Because climate change adaptation solutions will require the cooperation and coordination of different specialists and agencies, problems in coordinating across departments and agencies could arise. Fortunately, in the energy sector, coordination across agencies is occurring, and new initiatives will most likely be cooperative ventures among the public and private sectors.

Political Barriers

In general, the most significant political barrier to creating policies and measures for climate change adaptation is the difficulty in getting the attention of politicians and policymakers. They are faced with numerous other social issues (crime, education, health, foreign policy, other environmental issues, etc.) that require their attention and may have higher priority. Fortunately, in the energy sector, climate policy is a high priority among key stakeholders (for instance, the Governor, State Legislature, state agencies, and the private sector). Nevertheless, information, education, and marketing strategies need to continue and be supported to make more people aware of the need for adaptation measures, so that more politicians understand that this is an important priority for their constituents.

Informational, Social, Attitudinal, and Behavioral Barriers

Three key informational issues need to be addressed. First, the scientific uncertainties surrounding the timing and extent of climate change impacts appear to be a major factor affecting people's willingness to support policies and programs addressing climate change (although this is changing, as noted below). Second, while the global impacts are starting to become clearer, the local impacts remain uncertain. And third, the long-term benefits of adaptation are largely local to regional in scale, but the costs are more immediate and often borne by individuals (i.e., pay now to help future generations). As a result, there is a critical need to develop information, education, and marketing strategies to make more people aware of the need for adaptation measures. Increased awareness should increase the positive attitudes towards social change, leading to changes in individual and organizational behavior, as well as leading to the engagement of stakeholders in responding to climate change.

It appears that Californians are more likely than the rest of the nation to see global warming as a threat, but also are more optimistic that GHG emissions can be cut while creating jobs and expanding the economy, according to a statewide poll (Field Research Corporation 2007). In 2007, more than 80 percent of Californians believed that global warming poses a serious or very serious threat. While 43 percent said global warming requires immediate action, another 32 percent said that some action should be taken. Another survey by the Public Policy Institute of California (2007) reported similar findings and also noted that over 80 percent of respondents thought it was necessary to take steps right away to counter the effects of global warming (Baldassare et al., 2007).

Summary and Conclusions

California's public and private energy institutions have already made great strides in improving the state's energy efficiency, and they will play a leadership role in reducing greenhouse gas emissions under the terms of AB 32 and related energy policies. Their high awareness of climate-related risks, and the accumulated experience in coping with market risks and changing conditions, also puts California's energy institutions in a position to play a leadership role on the adaptation front.

Adaptive capacity can be increased by broadening the options for reducing society's vulnerability and increasing resilience to climate variability and change (Moser and Luers 2008). To improve decisionmakers' ability to cope with and adapt to climate change, three critical dimensions of adaptation must be strengthened: awareness, analytic capacity, and action. In the electricity sector, it is fortunate that all three ingredients - awareness, analytic capacity, and action – have been, and are continuing to be, addressed by public and private entities.

Three key agencies – the CEC, the CPUC, and, more recently, ARB – have promoted the awareness of climate change and implications for energy use and demand, improved their analytical capabilities and disseminated the information from these activities, implemented energy policies, and helped to promulgate energy legislation that addresses climate change. The investor-owned utilities which serve most of California's electricity needs have also been actively promoting the awareness of climate change as well as showcasing energy efficiency and renewable energy in their own facilities, as well as supporting educational efforts internally and externally. They have also been developing analytical tools to assess the vulnerability of hydropower facilities and the transmission and distribution system to climate change and will be closely examining other aspects of climate change as part of risk management.

To date, however, the "adaptation" part of the message to the public has been missing. Perhaps it is premature for the public to get involved in adaptation per se, given the amount of mitigation efforts underway that will provide key benefits. Given other public priorities, this missed opportunity may only be addressed under certain circumstances: as Wilbanks (2006) point out, adaptation strategies would need to be the greatest in connection with possible increases in the intensity of extreme weather events and possible significant changes in water supply regimes. Unfortunately, when these events and changes occur, it may be too late to implement adaptation strategies that require significant financial resources or that take time to implement. These strategies need to be conducted well in advance of such events. However, in general, energy efficiency measures and services can be implemented relatively quickly and inexpensively.

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