The Electric Power Industry and Climate Change: Power Systems Research Possibilities

Final Project Report

Power Systems Engineering Research Center

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Final Project White Paper

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Power Systems Engineering Research Center

This is a project report from the Power Systems Engineering Research Center (PSERC). PSERC is a multi-university center conducting research on challenges facing a restructuring electric power industry and educating the next generation of power engineers. More information about PSERC can be found at the center's website: http://www.pserc.wisc.edu.

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Executive Summary

The interaction of the electric power industry with climate is manifested in both the effect that severe weather has on the power system and the contribution of electric power to the production of greenhouse gases (GHG) and other pollutants. It is estimated that the United States is the source of one-fourth of the world's GHG emissions and that the electric power industry accounts for one-third of these. Within the total GHG emissions, CO_2 emissions account for more than 80 percent of the overall U.S. contribution, and 38 percent of this amount is derived from the electric power sector.

In response to increasing concerns over global climate change, this white paper identifies possible research needs for PSERC to pursue that are related to interactions between the power industry and global climate change. The technologies that can aide in the mitigation and adaptation to climate change trends have to be enabled by the power system infrastructure. Contributions could come through researching and clarifying the following: (i) power infrastructure capability to respond to climate change and extreme weather events; (ii) relative impact of climate change issues on system operating strategies (e.g., system dispatch), system configurations (e.g., network islanding and microgrids), and expansion plans; (iii) system effects of an expanded use of renewable and alternative energy technologies; and (iv) impacts of market rules and policy mandates on the operations of the power system and sustainability and, subsequently, on the national economy.

Accordingly, this white paper identifies possible research areas in the following categories:

- Interaction between the production of greenhouse gases and the production, consumption, and delivery of electricity.
- Extreme weather statistics and events, and the potential impact on power system blackouts and component failures.
- Electricity market issues that relate to climate change.
- Federal, state and other local policies on climate change that affect the electric power industry.
- Long-range planning of the electric power and other industries with respect to climate change and sustainability.
- Themes from previous PSERC research, including developing analysis tools, understanding risk and uncertainty, promoting interregional coordination, analyzing market design and behavior and integrating new technologies into the power system.

Through lists of possible research areas, this paper demonstrates that PSERC researchers are well positioned to contribute to research needs in the broad, interrelated areas of power system-climate change interactions. The next steps will be to continue this discussion at PSERC meetings and to integrate these issues into future research solicitations.

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1. Introduction

1.1 Background

The interaction of the electric power industry with climate is manifested both in the effect that severe weather has on the power system and through the contribution of electric power to the production of greenhouse gas (GHG) and other pollutants. It is estimated that the United States is the source of one-fourth of the world's GHG emissions and that the electric power industry accounts for one-third of the nation's GHG emissions. Within the total GHG emissions, CO_2 emissions account for more than 80 percent of the overall U.S. contribution, and 38 percent of this amount comes from the electric power sector [Morgan, 2005].

This white paper identifies possible research areas for PSERC to pursue related to the power industry-climate change interaction. The research team for this project recognizes that the scope of this topic is tremendous, with many aspects falling outside the expertise of PSERC researchers. However, there is also significant overlap between these issues and PSERC in terms of interest, ability, and significance to PSERC members. PSERC industry and university members represent a large segment of the power industry and are in a unique position to contribute to the preparedness of the power industry with respect to extreme weather events, the national climate change discussion in academia and industry, and policy and market development at federal, state and local levels. PSERC could contribute by researching and clarifying the following: (i) power infrastructure capability to respond to climate change and extreme weather events; (ii) relative impact of climate change issues on system operating strategies (e.g., system dispatch), system configurations (e.g., network islanding and microgrids), and expansion plans; (iii) system effects of an expanded use of renewable and alternative energy technologies; and (iv) impacts of market rules and policy mandates on the operations of the power system and sustainability and, subsequently, on the national economy.

This white paper does not propose that PSERC itself will perform research on climate or health sciences but rather that, through this white paper, PSERC will begin discussion of identifying research areas that PSERC might pursue. This discussion will help to clarify where PSERC researchers are qualified and interested in contributing to research relating to interactions between electricity production and climate change.

1.2 Overview of the Problem

The sources of greenhouse gas, GHG, emissions, the cause of global climate change, are from both natural (biogenic) and human (anthropogenic) sources. A brief overview of emissions from land use, agriculture, transportation, and electric power is provided below.

Land Use Patterns and Agriculture
Land use plays an important role in GHG emissions and carbon sequestration in the United States. Land use types that affect GHG emissions and sequestration include forest land, grassland, pasture, rangeland, cropland, wetland, and urban land. The effects of land

use on natural emissions estimates are complicated by distinguishing between anthropogenic and biogenic emissions [EIA].

In 2000, agriculture was responsible for 14 percent of the GHGs, divided among the following categories:

- 38 percent fertilizers (nitrous oxides released during nitrification and denitrification).
- 31 percent livestock (methane as a waste product of digestion by livestock).
- 11 percent wetland rice cultivation (methane produced from flooded fields that prevent the decomposition of organic matter).
- 7 percent manure management methods (methane emitted from anaerobic decomposition of manure stored in an insufficiently oxygenated environment).
- 13 percent burning savannah and agricultural residues (non-carbon dioxide emissions).

Agricultural practices also produce carbon dioxide via soil and biomass management practices that disturb natural carbon sinks. In addition, agriculture is responsible for emissions in other sectors, including deforestation, production of fertilizers, use of equipment that requires an energy source, and transportation of agricultural inputs and outputs [HM-Treasury].

Transportation

The share of total emissions from transportation rose from 17 to 24 percent between 1990 and 2004, an increase of 41 percent, or 2.5 percent per year on average. Emissions from international aviation and shipping rose by 86 and 45 percent, respectively, and accounted for 22 percent of transportation emissions in 2004 [Transport].

Electric Power

The electric power industry accounts for one-third of the nation's GHG emissions. It is claimed that the power sector accounts for 38 percent of the nation's overall carbon dioxide emissions, equivalent to 2.2 billion metric tons. In 2000, carbon emissions from generating 10,000 TWh of electricity from fossil fuels were as high as 2.3 million tons of carbon, which accounts for approximately 35 percent of total anthropogenic carbon emissions. This amount could increase to 40 percent in 2020 [WorldEnergy].

Society's Response to Global Climate Change Issues

Analyses of climate change issues and our response frequently refer to the need and ability for adaptation and mitigation. These themes are introduced here in terms of issues that are relevant to the electric power industry in general and PSERC in particular.

In terms of electric power systems and climate change, adaptation includes the hardening of power system equipment and developing new operating system strategies in response to system upgrades and to changing weather patterns. Modern power systems have been designed during a period of relatively stable weather, and these design assumptions may be strained by new weather patterns. The extreme weather of relevance includes directly destructive events such as hurricanes and ice storms as well as extremes of heat and cold that affect both individual equipment failure and system operations.

The power system must also respond to new market rules, proposed laws and regulations, expanded energy conservation, energy efficiency, use of renewable energy sources, and demand-side participation programs—the power industry is confronted with the need to adapt to current and anticipated market structures and government mandates relating to climate change and sustainability.

Mitigation refers to the need to lessen the negative impacts of climate change on society and the economy, as well as mitigating the power industry's production of pollutant emissions. This area of power system-climate interaction focuses on reducing the production of GHGs through combustion and energy conversion processes.

1.3 White Paper Organization

This white paper is divided into the following five topics, presented in sections 2 through 6. Each of these sections summarizes background information on the significance of the topic to the electric power industry, policy makers, and society and identifies possible research areas of interest to PSERC academic and industry members.

- Section 2: Interaction between the production of greenhouse gases, GHG, and the production, consumption, and delivery of electricity, considering technologies for generation, transmission and distribution, renewable energy and sustainability, as well as strategies for system planning and operation.
- Section 3: Extreme weather statistics and events, and the potential impact on power system blackouts and component failures.
- Section 4: Electricity market issues that relate to climate change.
- Section 5: Federal, state and local policies on climate change, to the extent that they affect the electric power industry.
- Section 6: Long-range planning of the electric power and other industries with respect to climate change.

The references are also divided into five subsections according to the five topics listed above. Conclusions are presented in section 7. The Appendix presents a brief discussion of previous PSERC projects and their relevance to research on the interactions of the electric power industry and climate change.

2. Interaction of the Production of GHGs and Electric Power

2.1 Introduction

The public and the electric utility industry are showing greater interest in environmental issues, including global climate change. This section discusses the interaction between the production of greenhouse gases and the production of electricity. An overview of the greenhouse effect and specific chemical compounds is presented in section 2.2, followed by global mitigation efforts, in section 2.3. Section 2.4 discusses emission-reduction technologies, including both direct reduction of pollutant emissions and alternative generating technologies. Finally, possible impacts on the transmission grid are discussed in section 2.5, and section 2.6 concludes with a list of possible research areas.

2.2 The Greenhouse Effect and Greenhouse Gas Emissions

It is widely known in scientific circles that life on Earth would not be possible without the greenhouse effect. The greenhouse effect plays a crucial role in maintaining the Earth's average temperature at about 59º F (15º C). Without the greenhouse effect, the Earth's average temperature would be about 60º F colder. Key naturally occurring greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and water vapor.

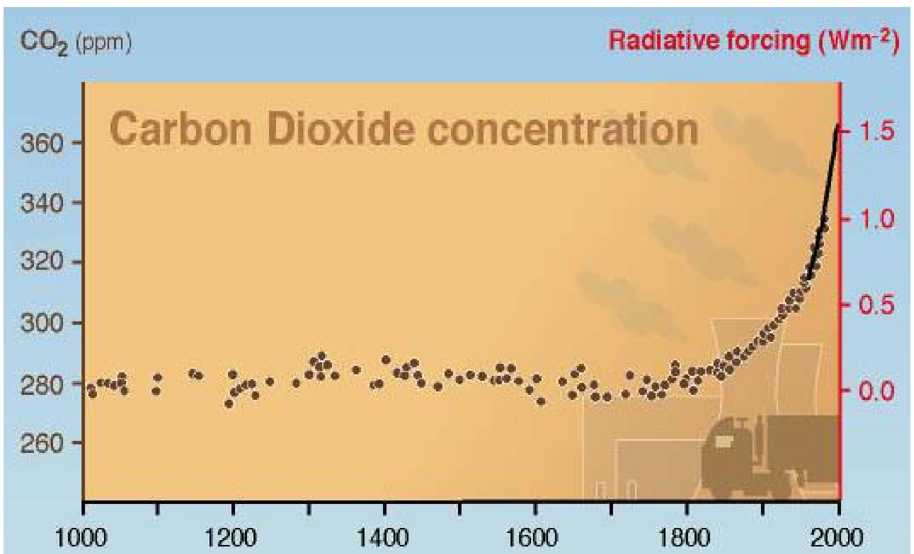

Figure 2.1 Indicators of Human Influence on the Atmosphere [1a]

The greenhouse effect occurs when some of the radiation from the sun that reaches the Earth's surface through the atmosphere is prevented by atmospheric gases from being reflected back into space. This is similar to what occurs within a glass-enclosed space, such as a car or a greenhouse. On a global basis the greenhouse effect causes a rise in the Earth's temperature until there is a balance between incoming and outgoing radiation.

Studies have shown that water vapor and CO_2 are responsible for most of the Earth's greenhouse effects. Through a process known as the carbon cycle, the concentration of CO_2 in the atmosphere is regulated. The carbon cycle involves the movement of CO_2 between the atmosphere, the land and the oceans, with natural processes such as photosynthesis playing a dominant role.

The past century or two has seen a marked increase in the concentration of GHGs in the atmosphere. This change has been attributed, in part, to the industrial revolution and the tremendous increase in fossil fuel consumption. This has perturbed the normal carbon cycle, resulting in a gradual increase in atmospheric CO_2 concentration from approximately 280 parts per million (ppm) prior to 1800 to about 379 ppm today, as shown in Figure 2.1. As a result, the current thinking is that increased CO_2 in the atmosphere traps more radiation, resulting in a gradual increase in the Earth's average temperature. If the effects of other significant greenhouse gases, such as methane (CH_4) (from the production of coal, natural gas, and oil) and nitrous oxide (N_2O) (from the combustion of fossil fuels), are also included, the measured warming effects of GHGs are increased.

2.2.1 United States CO_2 Gas Emissions

The production of CO_2 from the consumption of fossil fuels is commonly reported, either in terms of millions of metric tons (MMT) of CO_2 equivalent or MMT of carbon equivalent. Since carbon comprises 12/44 of the mass of CO_2, the two values are related by this ratio. In this white paper, all results are presented in terms of MMT of CO_2 equivalent, rather than MMT of carbon.

Worldwide, the emission of CO_2 from the consumption of fossil fuels was estimated to be slightly more than 25,000 MMT, with United States' emissions at about 5,800 MMT. This makes the U.S. responsible for approximately 23 percent of world energy-related CO_2 emissions. In a more recent 2005 study, CO_2 emissions in the U.S. and its territories were estimated at 6,008.6 MMT, an increase of 208.6 MMT from 2003 [1]. Of this number, the amount related directly to the production of electricity was 2,375.0 MMT, or about 38 percent of the U.S. total. The electric power sector, as defined in [1], includes all utilities, non-utilities, and combined heat and power facilities whose primary business is the production of electric power.

In 2005, coal, natural gas, and petroleum combined generation was responsible for producing about 71.4 percent of the total net energy generated by the U.S. electric power industry [4]. Figure 2.2 summarizes the net energy generated by the electric power industry in the U.S. for the year 2005.

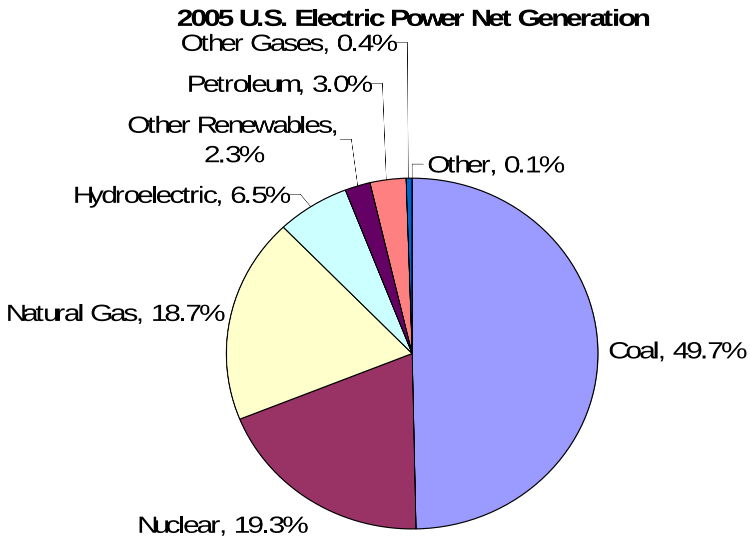

Figure 2.2 U.S. Net Generation in the Year 2005

Table 2.1 U.S. CO_2 Emissions from the Electric Power Sector [1]

Fuel	**MMT of CO_2 in 2005**
Petroleum	100.3
Coal	1,944.2
Natural Gas	318.9
Other	11.5
Total	**2,375.0**

Table 2.1 summarizes U.S. CO_2 emissions from the electric power sector in the year 2005. As both the table and the figure depict, coal generation provides about 50 percent of our electric energy and is responsible for about 82 percent of electricity-related CO_2 emissions. The production of 1 megawatt hour (MWh) of electric energy with coal results in the release of about 0.97 metric tons of CO_2 (almost a 1 to 1 ratio). The next highest CO_2 contributor is natural gas, which provides about 19 percent of the total electric energy and 13.4 percent of CO_2 emissions from the electric power sector. For natural gas, CO_2 emissions per MWh are about 0.42 metric ton (MT). For petroleum, the third highest source of total CO_2, the value is 0.82 metric ton per MWh. Figure 2.3 summarizes this data. It is also important to note that the production of electricity using either nuclear, hydro, wind, or solar results in essentially zero CO_2 emissions.

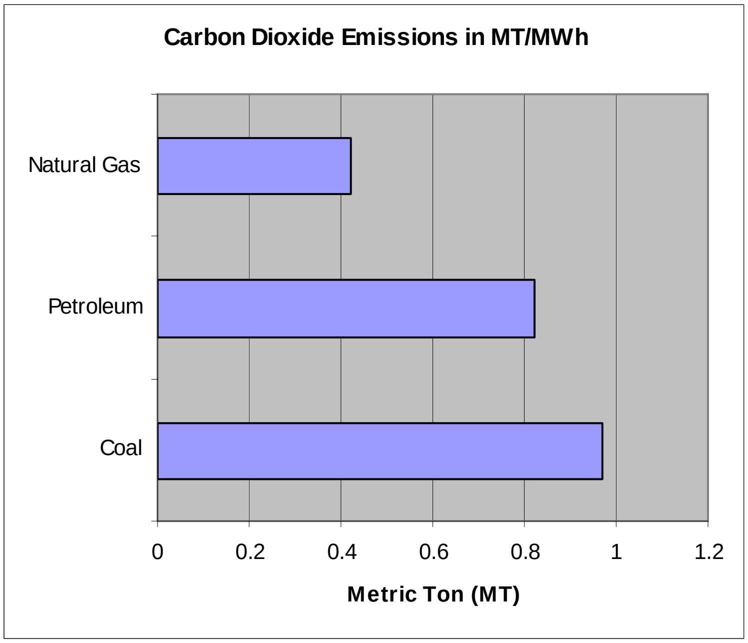

Figure 2.3 CO_2 Emissions in MT/MWh by Type of Fossil Fuel

To put these numbers in perspective, it can be enlightening to compare them to the carbon storage capability of a forest. In the United States, the average forest contains 158,000 pounds of organic carbon per acre, or about 72 metric tons per acre [31]. This corresponds to the carbon in about 263 metric tons of CO_2. However, only 31 percent of this carbon is in the trees, with most of the remainder in the soil. But the rate of yearly carbon accumulation depends upon the trees, so the average yearly sequestration is only about 0.57 metric ton of carbon or the equivalent of 2.1 metric tons of CO_2 [31]. Relating these numbers back to MWh production from coal, a single acre of forest can annually sequester the CO_2 produced by the generation of about 2.2 MWh. Hence, to continually sequester all the CO_2 produced by a 500-megawatt coal-fired power plant with a 75 percent capacity factor would require about 1.5 million acres of forest, or about 2,333 square miles. There are currently 193 million acres of national forest and grasslands.

2.2.2 Other GHG Emissions by the U.S. Electric Power Sector

The combustion of fossil fuels also produces other greenhouse gases such as methane (CH_4) and nitrous oxide (N_2O), and indirect greenhouse gases NOx, CO, and NMVOCs (non-methane volatile organic compounds) [3]. NOx and N_2O are related to air-fuel mixes and combustion temperatures and also are a by-product of some of the combustion control pollution equipments. N_2O, CO, and NMVOCs attack ozone in the atmosphere, increasing the ultraviolet light entering the Earth's atmosphere. It is important to mention that N_2O has 310 times the effect of CO_2 for producing global warming, and CH_4 has 21 times the effect [3]. This means that, while their emission quantity is considerably less than those of CO_2, they still could have, in the big picture, an important role in the greenhouse effect.

The electric power industry produces different amounts of some of these greenhouse gases. Tables 2.2 and 2.3 summarize the emissions of CH_4 and N_2O.

Table 2.2 U.S Methane (CH4) Emissions from the Electric Power Sector [1]

Fuel	Thousand Metric Tons of CH_4 in 2005	Thousand Metric Tons of CH_4 in CO_2 Equivalent in 2005
Fuel Oil	1	14
Coal	13	288
Natural Gas	1	13
Other	Less than 500 metric tons	Less than 500 metric tons
Total	**15**	**315**

Table 2.3 U.S Nitrous Oxide (N2O) Emissions from the Electric Power Sector [1]

Fuel	Thousand Metric Tons of N_2O in 2005	Thousand Metric Tons of N_2O in CO_2 Equivalent in 2005
Fuel Oil	1	216
Coal	29	8,635
Natural Gas	1	165
Other	1	196
Total	**32**	**9,212**

As presented in Table 2.2, coal produces about 87 percent of all CH_4 generated by the electric power industry. But this number is just 0.06 percent of the total CH_4 emissions in the U.S. for 2005 (total of 26.6 MMT of CH_4). The remaining CH_4 comes primarily from nonelectric power-related energy sources (11 MMT of CH_4) and from agricultural sources (7.96 MMT of CH_4). From Table 2.3, coal is responsible for 91 percent of the total N_2O emissions from electric power. However, since the estimated N_2O emissions in the U.S were about 1,238.4 thousand metric tons for 2005, the electric power industry also plays a very insignificant role in the production of N_2O emissions (about 2.6 percent). Hence, while the emission of other greenhouse gases in the production of electric power is not zero, it is quite small compared to the impact of CO_2. Even when one considers that CH_4 causes 21 times the greenhouse effect of CO_2 and N_2O causes 310 times the greenhouse effect of CO_2, correspondingly, their greenhouse impact would be small.

A final pollutant emission of interest is sulfur hexafluoride (SF_6), a greenhouse gas with a global warming potential 23,900 times greater than CO_2 and an atmospheric life of 3,200 years. One pound of SF_6 has the same global warming impact of 11 tons of CO_2, and in 1995, it was found to make up about 0.3 percent of the atmosphere. The electric power industry uses roughly 80 percent of all SF_6 produced worldwide. Significant leaks occur from aging equipment and gas losses during equipment maintenance and servicing. Currently, over 70 utilities participate in a voluntary program to reduce SF_6.

The most important conclusion from this section is that coal is responsible for the majority of greenhouse gases, most importantly CO_2, generated by the U.S. electric power sector. Either reduction in the utilization of coal as a fuel to generate electricity or an increase in the sequestration of the resultant CO_2 could significantly reduce the amount of greenhouse gases that the U.S. is emitting into the atmosphere.

2.3 Global Emissions Mitigation Efforts

On this subject, it is important to mention the Kyoto protocols [5] and what some of the signatory nations are doing, as well as a summary of what is being done in the United States.

2.3.1 Kyoto Protocols and Other Countries Efforts

The Kyoto protocol is an agreement between more than 160 countries to reduce the emissions of greenhouse gases by at least 5 percent below the 1990 levels during a commitment period of 2008 to 2012 [5]. The percent amount is different for every country and is based on the amount of emissions at the base year, usually 1990. The U.S. signed the protocol but never ratified it. The amount of reduction assigned for the U.S., based on the 1990 base years, was 7 percent.

Most of the European Union (EU) countries, including the United Kingdom (UK), have ratified the protocol. Some of them are beginning to make progress in reducing GHG emissions. However, it should be noted that many of the EU countries have very low or even negative population growth rates.

2.3.2 U.S. Domestic Emissions Mitigations Efforts

Several initiatives have been proposed to treat the important issues of GHG emissions in the United States [1]. Most of these initiatives are voluntary. One is the Global Climate Change Initiative that sets a national goal for the U.S. to reduce GHGs by 18 percent between 2002 and 2012. Other efforts encourage the development of strategies and technologies to limit or reduce the emissions of GHG. With respect to the power industry, the Department of Energy has a Voluntary Reporting of Greenhouse Gases Program. This program currently has 537 participating electric power and cogeneration projects, whose total emissions reduction in the long run were reported to be 167.6 MMT of CO_2 for the year 2005 [7].

The Energy Policy Act of 2005 has a stated purpose of achieving energy self-sufficiency within the United States, Canada, and Mexico [8] by 2025. This bill provides for research and development programs in subjects such as renewable energy, including the following: solar energy, wind energy, geothermal energy, ocean and wave energy, and combinations of these technologies with other energy technologies. The bill also provides for research and development of distributed energy to improve the reliability and efficiency of these technologies, as well as integration with the grid connectivity. On the topic of emissions from burning fossil fuels, the bill directs the Secretary of Energy to conduct research in the development of technologies such as precombustion technologies and the reduction of CO_2 for pulverized coal combustion units, among others.

All of these initiatives are showing some movement in the U.S. to reduce GHG emissions, not only for the electric energy sector but also for the entire country. One example of this movement is the California state initiative to reduce by 25 percent the state CO_2 emissions by 2020. Also, many cities in the U.S have voluntarily ratified the Kyoto protocols and are planning to reduce GHG emissions by the year 2020.

2.4 Technologies to Reduce GHG Emissions in the United States

To reduce the amount of greenhouse gas emissions in the United States, it is important to understand the available technologies. This section summarizes some of these technologies and strategies.

2.4.1 Carbon Capture and Sequestration

The combustion of fossil fuels is responsible for the majority of CO_2 emissions produced in the U.S., with 40 percent of these emissions, primarily from coal, coming from the electric power industry. To address this, the Department of Energy with the Carbon Sequestration Program is pursuing the goal of producing new coal-fired power plants with almost 90 percent lower CO_2 emissions. Through a process called carbon capture and sequestration (CCS), carbon is captured from these plants and stored in a repository where it will remain permanently.

As mentioned in section 2.2, carbon is sequestered naturally through the carbon cycle, and could be enhanced through programs to eliminate clear cutting and promote reforestation. For technology based solutions, there are basically three options to capture CO_2, referred to as post-combustion, pre-combustion, and oxygen combustion (oxy-combustion).

- In the post-combustion process, CO_2 is captured after the fuel is burned. The combustion exhaust from the boiler, called the flue gas, is mostly oxygen, CO_2, and other impurities, such as nitrogen and traces of sulfur. The separation process is made by the injection of a solvent, typically amine-based, that reacts with the CO_2 [18][19].
- The pre-combustion process consists of converting the combustion fuel into a gaseous mixture of hydrogen (H), CO_2, CO, and other light hydrocarbons [19][20]. This technology, often referred to as coal gasification, is being proposed for coal-fired power plants.
- In the oxygen combustion process, the energy fuel is burned with pure oxygen. This reaction produces a flue gas with a high concentration of CO_2 (about 80 percent) that can be cooled down in a condenser. Then the CO_2 can be separated from the water, making the CO_2 ready for sequestration [17][19].

After the CO_2 is captured, the next dilemma involves the fact that it must remain sequestrated for many centuries. There are currently three leading alternatives to this sequestration: geological formations, terrestrial ecosystems, and the oceans. These options are discussed further in references [17] and [21].

Carbon sequestration is a promising technique to reduce GHG in the atmosphere, but it is not without issues that need serious consideration. One of these is the issue of how CO_2

should be transported from the source to the sequestration location. One approach would be to build a direct pipeline. Alternately, it could be more economically viable to construct new power plants near the carbon sink site and invest in the transmission infrastructure to deliver power to the system.

2.4.2 Indirect GHG (NO_x and SO_2) Emissions Reduction Strategies and Technologies

Many strategies and technologies are currently being used by the electric power industry to reduce the effect of indirect greenhouse gases emissions, albeit for reasons other than their potential impact on global warming. Typically, when an emissions cap is placed on electricity producers, the least expensive reduction option available is chosen to meet the cap [9]. For the reduction of NO_x, one alternative is simply to reduce the number of high-emission plants. Normally, adding combustion controls to existing plants would reduce NO_x emissions. Modifications usually consist of installing low-NO_x burners or adding post-combustion technology, such as selective catalytic, or noncatalytic, reduction (SCR) equipment. SCR works by adding ammonia (NH_3) and some catalyst, which produces a chemical reaction in which the final products are water and nitrogen. New technologies are being developed to install SCR equipment in the pre-combustion stage [10].

In the case of sulfur dioxide (SO_2), there are also several alternatives. These range from simply varying the utilization of low-sulfur fuel to reducing the use of high-emitting plants. The most common alternative is adding flue gas desulphurization (FGD) to the plants. FGD has shown a reduction in the number of emissions, but many power companies still have not installed them. Based on the Annual Energy Outlook 2006, most utilities have plans to install them by the year 2030 [11].

2.4.3 Dispatchable Zero-Emissions Sources: Hydropower & Nuclear Energy

GHG emissions can be reduced by supplementing or replacing fossil fuel energy sources with ones that produce no GHG emissions, such as hydropower. However, most hydro-resources that could be economically developed have already been developed, with little if any growth in net electric energy production from hydropower for decades.

The other major dispatchable energy source that produces essentially no GHG emissions is nuclear energy. In 2005, nuclear energy provided slightly more than 20 percent of our total electric energy. How much of our future electric energy needs could be supplied by nuclear power is a political rather than a strictly technical question, with key issues being what to do with the nuclear waste and public safety perceptions. Adequate nuclear fuel exists for hundreds of years of nuclear plant operation even at generation levels significantly above those seen today. The Annual Energy Outlook 2006 [11] estimates a slight increase between now and 2030 in nuclear capacity from 100 to 109 gigawatts (GW). This projected increase in nuclear capacity would be the result of upgrading existing plants (3 GW) and an additional 6 GW from new plant constructions. This estimate comes as a direct response to the 2005 U.S. Energy Policy Act [8] that provides for incentives to stimulate the development of new advance technologies of nuclear plants. However, if CO_2 emissions need to be drastically curtailed, nuclear energy provides an alternative that can replace a large percentage of existing GHG-emitting technologies.

If nuclear energy is greatly expanded, this raises the question of where to locate these new power plants and hence how they would impact the transmission grid. One interesting technology would be to locate Generation IV high-temperature reactors underground in salt deposits in large nuclear parks of perhaps 5 to 10 GW per location. Such a scenario would call for the development of an extremely high capacity transmission grid, such as the SuperGrid concept described in [32].

2.4.4 Wind Energy

Another generation technology that has no GHG emissions is wind energy. While some wind energy is harvested using small turbines, most energy in the United States comes from large "wind farms" or "wind power plants," in which a number of turbines of capacity up to 2 MW are placed together (with current turbine technology closer to 5 MW). Currently, wind-generation capacity in the United States is 9,500 MW, with plans for 7,000 MW of new capacity. Figure 2.4 presents a summary of the wind-energy capacity installed in the U.S. and the planned wind capacity for the year 2006 [13]. In 2005, wind energy provided only about 0.38 percent of our total electric energy, with this percentage expected to triple by 2010.

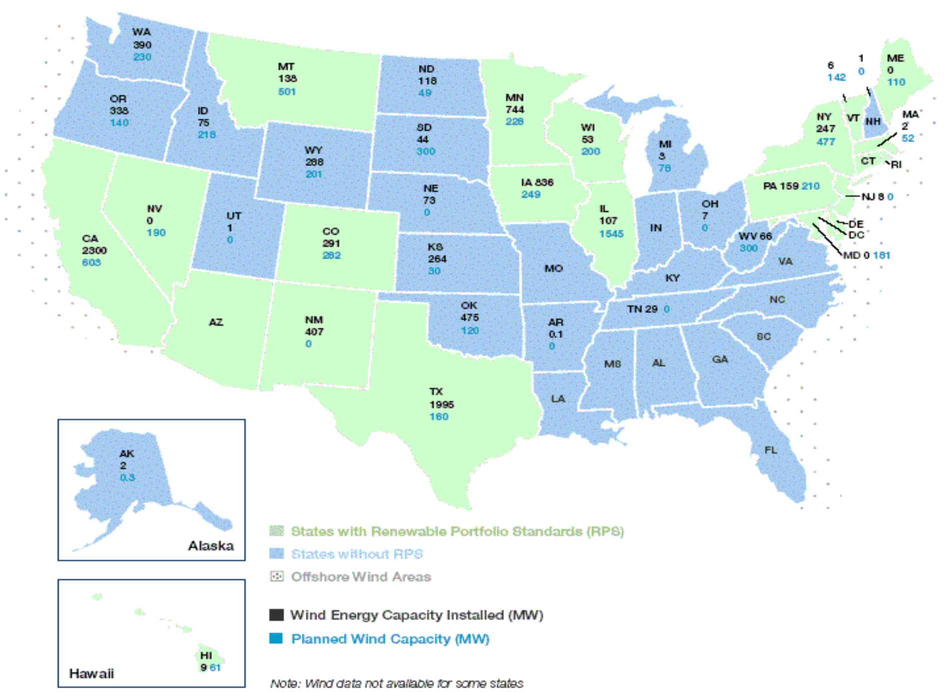

Figure 2.4 Summary for 2006 of Installed and Planned Wind Capacity [13]

While the potential for wind energy is promising, there are several significant issues that need to be considered. A key problem with wind energy is its intermittency, resulting in the capacity credit for wind being significantly less than the total installed capacity (often 25 to 40 percent). Most U.S. wind farms are built on sites where the average wind is more than 6.7 m/s above 10 m height. Typically, they are built in Class 6 sites (around 7 to 8.5 m/s). Current technologies can operate cost-efficiently in Class 4 wind sites with the help of federal support such as the Production Tax Credit (PTC) [12]. The PTC would support the entity in charge of the wind farm with the operational cost of generating electricity in such a wind-speed range.

To overcome the concerns of wind intermittency, better wind-speed forecasts could provide better estimates of the hourly availability of wind power. In California, wind forecasting is being implemented to predict winds almost a day in advance [13]. Energy storage paired with wind is another option for addressing wind intermittency [15][16]. Examples include the utilization of flywheels, super-capacitors, batteries, and systems based on superconducting magnetic energy storage (SMES). Pumped hydrostorage is a very attractive energy storage technique, but it requires the availability of large, nearby water reservoirs at different elevations.

Another significant issue associated with wind is that locations with the strongest wind resources tend to be remote. Hence, the development of wind would require investment for the construction of new transmission infrastructures, something that is currently being pursued by groups such as the Southwest Power Pool (SPP). Since the output of a turbine increases exponentially as wind speed increases, the placement of wind turbines where wind is adequate is very important. The key problem is that the transmission grid in the U.S. was not designed to deliver energy over large distances [13] without reactive power compensation indicating the need for upgrading the transmission system. Currently the developer of a wind project is responsible for any transmission upgrades needed, increasing the cost of the project and sometimes making the project too expensive to be economically possible. This issue needs more investigation, specifically on how to solve the transmission infrastructure problem.

2.4.5 Solar Energy

Solar insulation is the Earth's primary energy source, and an increased use of solar energy has been proposed as an important renewable energy source for decades. Several technologies that convert solar energy to electrical energy have been developed, all of which have virtually no GHG emissions.

One of these technologies is the photovoltaic cell (PV), which generates DC electricity that is converted to AC with the use of a DC-to-AC inverter. While the use of PV cells is ubiquitous, powering many calculators, for example, its current energy contribution is minimal, representing at most 0.01 percent of all electric energy (0.36 billion kWh). Although the potential penetration of PV panels could be significant, with estimates of up to 420 billion kWh if every home in the U.S. has a 3 kW PV panel installed on its roof [22], such a solution is far from being economically feasible. As with wind energy, solar radiation is also an intermittent resource. Also, PV systems are quite expensive, with PV electricity generation having an average cost between 15 and 32 ¢/kWh. One of the greatest concerns for the Department of Energy (DOE) and other entities is to reduce the cost per kWh of the electricity generated by PVs. Increasing the efficiency of the PV, which is usually lower than 18 percent on commercially available products, could reduce the kWh cost of electricity. Research is being conducted to increase the efficiency of PV panels.

A second method for converting solar energy to electricity is the concentrating solar thermal (CST) power plant. CST produces electricity by converting the energy of the sun into heat using mirrors. That heat is used to generate steam, which is later transferred to a turbine generator to produce electricity. This type of technology has being used in California, generating about 354 MW. The problems with these plants are the high cost of operation and the necessity for efficient energy-storage technologies. Also, they need open and large amounts of territory to install the number of mirrors needed to generate enough heat to produce steam. Today, research is focused on increasing CST plant efficiency to around 25 percent and also on the creation of good energy-storage technologies. Currently, there are plans for constructing these types of plants in Nevada (65 MW) and Arizona (1 MW). In order to successfully use these types of technologies, more research is needed, especially to improve their performance. These plants are primarily used locally to help the system during peak hours of demand, which is the only period for which they are economically feasible.

2.4.6 Geothermal and Ocean Energy

One other possible source of energy with low GHG emissions is the use of geothermal energy. This technology uses geothermal hot water or steam reservoirs deep in the earth. The water or steam is used to turn a turbine using a binary plant or is taken from the steam source itself. In the binary plant, the water or steam is used to heat clean water to produce steam inside a heat-exchanger, which at the same time is used to drive a turbine. The binary plant process does not produce any emissions, but the process of taking the steam directly from the source generates a small amount of GHG. In total, the geothermal production of electricity generates 2,200 MW, mostly in California (The Geysers area). Currently, resources are estimated at over 20,000 MW, mostly in the western states [23].

Another source of renewable energy is the ocean. This technology uses the energy of waves to drive linear generators or pumps connected to a generator. These technologies are relatively new but may have potential. Currently, research is being done to create a generator to be used in the sea. This technology does not generate GHG but has a direct ecological impact on sea life. Also, if implemented correctly, it would require substantial investment in a transmission infrastructure.

2.4.7 Plug-in Hybrid Vehicles

Plug-in hybrid vehicles are a technology targeted as a solution to the transportation sector's need to reduce greenhouse gas emissions. Widespread use of plug-in hybrids would serve to transfer the production of these emissions from the transportation sector to the electric power sector. Wide-ranging issues relating to which generating technologies would be used in charging these vehicles, the likely need to reinforce the transmission system to meet increased demand, the need to understand the effect on the daily load profile of vehicle charging, and the possibility of using charged batteries as distributed storage to meet system needs, all raise significant research questions.

2.4.8 Demand-Side Participation

The widespread inclusion of active and responsive load in system operations, along with active participation of the demand side in electricity markets is recognized as an important, and essentially absent, element in the electric power industry. Technologies that facilitate customer involvement in the power industry are increasingly available and are likely to improve system efficiency, reduce demand, and subsequently reduce the use of fossil fuel-based technologies. This subject is discussed further in sections 4.2.3 and 6.1.1.

2.4.9 MicroGrids

Many of the generating technologies discussed above are likely to be in remote locations, where the investment in transmission infrastructure may not be economically possible. One solution that could be explored is the implementation of microgrids. Microgrids are a cluster of power sources (usually less than 500 kW), storage systems, and loads that can be controlled independently of the ISO or other grid operator. The most notable of these proposed approaches is the CERTS Microgrid Concept [24], based on the aggregation of cogeneration systems, other generators such as microturbines, fuel cells, and reciprocating engines, and controllable loads. The generators are of small capacity and often produce low GHG emissions. The microgrid would provide power and also heat, improving overall system efficiency inside the microgrid. The generators and loads could be programmed with control characteristics to provide energy to the microgrid under different operating conditions using an Energy Management System (EMS). The CERTS microgrid concept along with numerous related versions of microgrids could represent a solution for interconnecting renewable technologies, such as wind and solar energy, which are in remote locations. The overall concept applied to these renewable technologies would be the same as in the CERTS concept: a cluster of loads and sources capable of generating energy and not requiring control operations from the grid operator. Currently this microgrid concept is under research and is in the process of validation on a testbed [25].

2.5 Greenhouse Gas Reduction, Its Impact on the Transmission Grid, and Future Research Challenges

Many of the technologies and solutions that offer the possibility of reducing greenhouse gases present additional challenges. One of the most noticeable is the direct impact on the transmission grid. Many of these technologies would be located in remote locations requiring additional transmission infrastructure. Any expansion or change in the utilization of these technologies for generating electricity would require an increase in the transfer capability of the transmission lines. The necessity of delivering great quantities of energy to and from different parts of the country is imperative not only in the case of an extraordinary atmospheric event but also to meet the future projected demand.

2.5.1 Transmission Grid Impacts

This white paper raises many issues that are directly related to the transmission grid. First, many of the new clean technologies need to be established in remote locations because of the nature of the technology itself. A site for wind turbines or solar panels could not be developed where the natural source of the energy would not be adequate to maximize its output efficiency. Also, new nuclear plants may need to be located remotely to reduce public safety concerns.

For most of the past decades, transmission planning has been done to satisfy the local requirements of an area and in accordance with the North American Electric Reliability

Corp. (NERC) regulations for the interconnection of the system. In recent years, with restructuring and deregulation efforts, the Federal Energy Regulatory Commission (FERC) through Orders 2000 and 890 has placed transmission planning directly on the transmission operators with the creation of regional transmission organizations (RTOs) to coordinate markets and ensure the reliability of the nation [26]. This regionalizes transmission planning, with the requirement that any new transmission expansion would need the approval of the RTO for that region. A major issue is what is the objective of transmission planning in this new regime? There is some discussion, for example, that to support wind projects, the transmission capacity must be expanded in advance with the cost being socialized in part, at least until the additional generation capacity is added.

Entities such as the Department of Energy and Electric Power Research Institute (EPRI) have seen the necessity to transform and modernize the transmission grid system to meet twenty-first-century needs. Natural load growth alone of 2 to 3 percent, regardless of energy source, will require approximately 20,000-30,000 MW of added generation per year, which in turn will require upgrading and modernizing the transmission grid. The DOE has identified three important elements that the new grid should include: (i) a national electricity "backbone," (ii) regional interconnections, and (iii) local distribution [27][28]. The DOE also presents a vision of incorporating the environmental issue of GHG gases, land use, and water impacts while maintaining reliability standards. The EPRI approach is more ambiguous in that it not only sees the necessity of modernizing the electric grid, but one of its principal goals is the development of clean-energy technologies to reduce GHG emissions and pollution [29]. In both scenarios, the environmental issue would be an active component at the moment of designing a new infrastructure and establishing policies to operate the system.

It is important for the new electric grid to be able to deliver energy large distances from any part of the country. This would require the integration of technologies such as low-impedance superconducting cables and High Voltage Direct Current (HVDC) systems [32]. This is essential to reducing possible new congestion bottlenecks that would occur with the addition of new technologies to the current network portfolios. Also, it would provide the freedom to maintain reliability in case of extreme weather events that could affect any part of the country. For example, a very intense winter storm along the eastern coast that directly affects the generation or transmission of electricity in that region would need energy from the central, southern, or western states of the country. The new electric grid should withstand such extreme conditions at any moment by being able to shift energy to that region if needed.

Another vital element would be the creation of regional or local networks. The creation of RTOs is a first step to achieving this goal, but today many issues concerning their formation are still ongoing and need prompt solutions. These regional networks should be responsible for maintaining real-time monitoring of the region. The development of new network management and monitoring systems would improve system efficiency and reliability by reducing the possibility of bottlenecks and responding quickly to extreme situations. It is in these regional networks that microgrids could be incorporated. The new environmental constraints would increase the utilization of distributed generation including renewable resources. Many of these technologies would be established in remote locations with an automated control system separating them from the rest of the system when necessary.

It will be important to establish policies and rules to determine which technologies of the available generation portfolio will be most useful to maintain not only reliability but also environmental constraints.

2.6 Possible Research Areas

- Develop a model to simulate the new transmission grid and system operation scenarios to verify that these proposals could be realizable in real life, thus helping future research projects find the most accurate and efficient methods to modernize the electric system.
- Develop and analyze methods to improve energy conservation and efficiency.
- Analyze the effects on system load shape, transmission system expansion, system dispatch, and new control needs in response to an increased use of plug-in hybrid vehicles, including a study of metering, two-way inverters, and possible distributed storage resources from hybrid vehicles (building upon the work in the ongoing PSERC project, P-10).
- Analyze the impact of an expansion of nuclear energy, in terms of impacts on the transmission system and power system operation, and in GHG reductions.
- Analyze system impacts and control needs of a significant penetration of large, remote wind farms, in terms of impacts on the transmission system, power system operation, and in overall GHG reductions.
- Analyze the system impacts, penetration level, and control needs of a high penetration of distributed photovoltaic systems in the distribution system.
- Analyze the expanded use of microgrids and network islanding organized to incorporate local as well as remote (renewable) energy resources.
- Analyze the effects of energy efficiency and demand response programs on load models, particularly for system stability analyses.
- Analyze the comparative impacts (e.g., on cost and system operations) of transporting carbon to a sequestration location, versus locating a power plant at the sequestration site.
- With respect to SF_6, analyze the effects of the following: (i) the industry conducting annual inventory emissions of SF_6 using an emissions inventory protocol, and (ii) the industry establishing strategies for replacing older, leakier pieces of equipment.
- Investigate the potential for distributed energy technologies, such as photovoltaics, cogeneration, energy efficiency and demand response, to be used in strategies that address climate change. Investigate obstacles, such as interconnection policies, to increased use of distributed technologies.

3. Extreme Weather, Blackouts, and Component Failures

3.1 Introduction

Electric power systems are usually designed during periods of relatively stable weather and loading patterns. However, these design assumptions may be strained by extreme weather due to climate change. The extreme weather of interest includes directly destructive events such as hurricanes and ice storms as well as extremes of heat and cold, which affect both individual equipment failure and system operations. The effects of climate change will combine with the effects of other changes such as population migration and changes in water availability. Since power systems need to be designed and operated with respect to extremes of weather and peak loading, it is necessary to quantify likely changes in the statistics of these extremes due to changes in climate. In this section, we evaluate the prospects for estimating the frequency and impact of equipment and system failures. A readable account of the climate science supporting the extreme weather trends and predictions is in [Houghton04].

3.2 Extreme Weather

This section discusses the predicted extreme weather trends that will directly impact electric power systems in the United States and Canada. Over the next 20 years, the average global surface temperature is expected to rise about 0.2 degree Celsius per decade [IPCC07WG1]. Over the next 100 years, the average global surface temperature is expected to rise between 0.2 to 0.4 degree Celsius per decade, depending on the human response to climate change [IPCC07WG1]. We expect this slow average temperature increase to have a slight direct impact on power systems. The key issue is the increase in the variability of temperature, precipitation, and other weather extremes.

The IPCC 2007 report [IPCC07WG1] identifies the following trends and expects them to continue for the next 100 years. The likelihood of these future trends exceeds 90 percent, according to expert judgment.

- Warmer and more frequent hot days and nights, and more frequent heat waves.
- Increased proportion or frequency of heavy precipitation.
- Warmer and fewer cold days and nights.

Also predicted with likelihood greater than 66 percent are changes in hurricane intensity, that is, hurricanes are likely to have stronger winds and more precipitation.

It is clear that these changes in weather extremes can impact the power system infrastructure, but assessing the nature of this impact requires quantifying the rate of change of the weather extremes and comparing this to the rate of change of the power system infrastructure. The power system infrastructure changes on a time scale of decades. (The typical lifetime of a power plant is 30 to 50 years and a transformer decades; a new transmission line can take about a decade to plan.) If extreme weather changes occur on a timescale slower than decades, then the power system can adapt to the extreme weather changes by having specially designed expansion and equipment according to the current weather extremes. On the other hand, if the extreme weather changes significantly on a timescale of decades, then either the power system will require uprated designs and more upgrades and maintenance, or the power system reliability will decrease.

We now discuss how to extract quantitative estimates of the rate of change of weather extremes from the climate change literature. We are interested in the changes per decade over the next hundred years. Some of the characteristics of climate change and prediction affecting this are as follows:

- Many studies of the impact of climate change assume either a given average temperature increase or a doubling of the atmospheric carbon dioxide concentration.
- The time over which a given average temperature increase or doubling of the atmospheric carbon dioxide concentration occurs depends on the human response to climate change. This is accounted for by considering several different scenarios of human response. The time for a one degree Celsius average temperature increase ranges from about 25 to 50 years (using best estimates in Table SPM-2 in [IPCC07WG1]). The estimated date for the atmospheric carbon dioxide concentration reaching double its preindustrial level of 280 ppm ranges from approximately 2050 to 2100 (estimated from [Houghton04, Fig 6.2]).
- There is considerable inertia in climate change in that the global average temperature will continue to rise even if carbon emissions are sharply reduced.

We consider an example of extracting data from a climate study. Interpolation of climate model data in [Houghton04, p. 158] suggests that a four degree Celsius warming in the Sacramento River basin in California would reduce the average September runoff by about 50 percent and increase the average January runoff by 40 percent. If the regional temperature increase follows the global average temperature increase, the four degree Celsius increase would occur in 100 to 200 years. This is proportional to a 2.5 to 5 percent reduction in September runoff per decade and a 2 to 4 percent increase in January runoff per decade. This calculation gives a rough value of the change per decade to gain an appreciation of the magnitude of the rate of impact on hydro resources. However, the regional temperature change will differ from the global average temperature change, and estimates for planning and decision-making should use the regional predictions of temperature change. Regional models of climate change exist and are improving, but the global average temperature models are more accurate than regional models. The IPCC report [IPCC07WG2] will summarize quantitative projections of climate change for North America updated to reflect the most recent literature.

3.3 Extreme Loading of Power System

Growth in the demand and change in load patterns may create major bottlenecks in the delivery of electric energy. This would cause power system stress as operational conditions approach thermal and mechanical ratings of power system elements such as transmission lines, transformers, circuit breakers, etc. These conditions may contribute to deterioration of dielectric materials, operating mechanisms, supporting structures, and cooling/insulating liquids used in power apparatus. As a result, overall wear and tear impacts may be greater, leading to increased vulnerability to faults and/or breakdowns.

The effects from climate change will be exacerbated by other unusual changes not caused by climate change but whose effects combine with the effects of climate change. For example, population migration in the U.S. will affect loading patterns significantly, particularly in the West and South. When combined with the change in temperature and increase in inclement weather conditions in the same areas, two issues need to be considered when assessing impacts on the power systems:

- A significant increase in population in the areas most affected by climate change puts additional stress on the system due to an increase in demand. This increase is the result of not only the existing population using more (peak) electricity but also the increasing peak load from population migration patterns.
- A significant increase in population in areas with high risk for weather-related disasters brings a new dimension to planning for emergencies and related strategies for electricity service restoration. Climate change will affect more citizens if the electricity service disruption is caused by this change.

3.4 Overall Impacts on Power Systems

The warmer and more frequent hot days will increase the peak load in summer-peaking regions at the same time as stressing power system components. Thermal limits on components are more restrictive on hot days. If components are not derated to allow for this, they may fail more frequently, age faster, and require more maintenance and earlier replacement. Control equipment may require recalibrating to derate the equipment. Problems have occurred with transformers designed to cool off at night being unable to cool down sufficiently during warm nights and therefore begin the next day with higher starting temperatures.

If more extreme wind gusts occur, they would cause tower and conductor damage and more faults due to galloping and trees falling. If an increase in hurricane intensity occurs, it would be necessary to uprate designs and to consider shifting more resources to emergency planning and restoration. This is particularly true if population migration brings more citizens to areas that are prone to power outages due to extreme weather conditions. The more population movement to the given area,, the more careful planning for emergencies and recovery is needed.

River water runoff is very sensitive to changes in climate, and small changes in temperature and the amount of precipitation can have a significant influence [Houghton04, pp. 158–59]. (Higher temperatures increase water evaporation and decrease runoff.) A regional temperature rise of a few degrees can increase winter runoff and decrease summer runoff. Arid regions may experience higher variability in precipitation. The increase in heavy precipitation may stress the systems to control river flow. There may be an increase in large floods [Milly02; Allen02] with the consequent risk of damage to the electricity infrastructure. All these effects would affect hydro energy resources and scheduling.

It is possible that drought (affected by climate change) combined with exhaustion of aquifers (unrelated to climate change but important in water resources) could lead to population shifts that change load patterns.

3.5 Effect of Catastrophic Wildfires

Climate change is thought to contribute to catastrophic wildfires in the western United States, Alaska, and Canada as a result of longer, warmer growing seasons. Once trees have died back, the landscape is prone to intense crown fires rather than surface fires that are more easily suppressed. Drought that enhances insect populations and subsequent wildfires directly dries other fuels, leaving forests of healthy, living trees that are more vulnerable to crown fires. In addition, years of fire suppression have greatly increased understory fuels in the dry, lower-elevation forests of the western U.S., turning normal surface fires into crown fires [Forest Service]. Increased fire activity could have significant repercussions for the transmission system infrastructure.

3.6 Estimating Effect on Blackouts

Estimating overall blackout risk is an ongoing and emerging topic in PSERC projects, and it may become feasible to use these emerging methods to estimate the effects of climate change on overall reliability. The likelihood of blackouts of various sizes is thought to be mainly affected by the size of the initial disturbance to the power system (such as caused by extreme weather) and the extent to which the disturbance propagates via cascading failure. The size of the initial disturbance when the weather is more extreme is probabilistic, and it would be necessary to quantify the statistics of the extreme weather parameter, such as wind speed, and relate it to the initial damage to the power system. Some extreme weather events such as a heat wave would also tend to load the power system so as to increase the propagation of cascading failure.

3.7 Estimating Effect on Component Design and Maintenance

The existing power system infrastructure in the United States is valued at $800 billion. Replacing such an infrastructure with new components having ratings required to sustain climate and load changes is unrealistic. Hence, an incremental strategy for making improvements is more likely to prevail. Three approaches may have some promising impact:

- Condition-based maintenance strategy aimed at estimating the remaining life based on online measurements, prevailing system operating conditions, and history of thermal/mechanical stresses.
- Retrofitting and reinforcing existing infrastructures with more robust construction and control solutions that can better respond to extreme weather and load patterns.
- Automated restoration procedures that can bring the system back faster after the extreme weather causes damage and service interruptions.

The above-mentioned strategies may lead to new requirements for designing power system information infrastructure as well as power apparatus. It may also lead to the development of new techniques for estimating the combined impacts of climate and load extremes that are more complex than the ones used to date.

3.8 Possible Research Areas

- Combine climate predictions of extreme weather with blackout risk assessment techniques under development by PSERC to estimate the impact of climate change on blackout risk.
- Explore power system monitoring and control techniques more amenable to self-healing properties, particularly under harsh weather conditions and increased load demand.
- Find climate change prediction studies for regions of North America, and use these to estimate the rate of change of power system design parameters such as temperature, wind, and precipitation extremes so that component design parameters can be uprated and loading forecasts changed as necessary.
- Design a better service restoration methodology in case of natural disaster such as hurricanes, high wind and rain, and snow storms.
- Analyze the likelihood and impact of increased wildfires on the western power grid and transmission system equipment.

4. Market Mechanisms

4.1 Introduction

There is widespread consensus regarding the scientific understanding of climate change, with considerably less agreement concerning the appropriate response(s). Market mechanisms such as a cap-and-trade policy, carbon taxation, renewable portfolio standards and price-responsive load are those that feature most prominently in the climate change literature. Although emissions trading has emerged as the frontrunner, methods to effectively combine multiple market mechanisms are also important to explore.

4.2 "Cap-and-Trade" Emissions Trading

Cap-and-trade emissions reduction programs have emerged as the leading market mechanism to address emissions reductions. First introduced to the electric power industry for controlling SO_2 emissions, cap-and-trade programs establish emissions limits, or caps, along with permits to produce specified amounts of a pollutant that can be traded among producers. Such a trading system allows a fixed environmental goal to be achieved over a specified period of time, while incorporating flexibility that ensures that reductions occur where the cost of reduction is the lowest, thereby minimizing the overall cost. (A concise discussion of this mechanism can be found at [UCS 2005].)

Some areas of the United States already have experience with trading mechanisms in the form of regional efforts, such as the Regional Greenhouse Gas Initiative [RGGI] and the Chicago Climate Exchange [Chicago], as well as national experience with SO_2-trading programs and the NO_x emissions trading program administered by the EPA in the eastern United States. Lessons can also be learned from international trading schemes, such as the European Union Emissions Trading Scheme [Pew 2006]. The Pew Center on Global Climate Change, in February 2006, released an Agenda for Climate Action that defines a series of fifteen recommendations, two of which are: (i) the creation of a mandatory GHG reporting system as a basis for an economy-wide emissions trading program, and (ii) implementation of a large-source, economy-wide cap-and-trade program for GHG emissions [Pew 2006]. The Congressional Budget Office analyzed distributional effects of carbon allowance trading in 2000 [CBO 2000], and released a report in April 2007 discussing the current debate in Congress on mandating a national cap-and-trade program for CO_2 emissions [CBO 2007].

The GHG emissions trading market design is a complex endeavor since there are a number of design elements affecting distribution, efficiency, and overall efficacy of the program. Key design elements include a timetable, sectoral coverage, initial distribution of allowances (or permits), banking of allowances, opt-outs, opt-ins and pooling, monitoring and verification, compliance, and permit auction mechanisms [EU-ETS 2005]. The growing number of GHG markets for auctioning and trading permits, each with significant variation in design elements, results in GHG markets having an increasingly fragmented nature. This fragmentation and potential incompatibility of markets is a concern because it hinders trading between and/or the expansion of these markets. The distribution of allowances and permits also has important implications for the acceptance and ultimate success of the programs. A combination of these design elements, examining a mix of allocation methods and auctions that could evolve over time, is discussed in [Palmer 2006].

4.3 Carbon Tax

A carbon tax is a tax on sources that emit CO_2 into the atmosphere. In the *Wall Street Journal* Monthly Economic Forecasting Survey, February 2007, 85 percent of economists were found to believe that the government should encourage the development of alternatives to fossil fuels, and 54 percent believe a carbon tax raising the price of purchasing fossil fuels would be the most economically sound method of encouragement [WSJ 2007]. In late January 2007, the CEOs of ten major American corporations met and called on President Bush to create mandatory ceilings on U.S. GHG emissions, demonstrating corporate support for action in limiting pollutant emissions [Mufson 2007].

Economist support for a carbon tax stems from the fact that these taxes could yield a "double dividend" by reducing carbon emissions and simultaneously reducing costs of preexisting tax distortions through revenue recycling (the term used if the revenue from a carbon tax were to be used to reduce other taxes, which, in turn, could increase employment and investment and thus lead to economic gain). As yet, it is not certain how revenues from such a measure would be used or if they would be used productively [Parry 2003]. Caution is necessary when implementing such a tax, since counter-measures such as granting tax breaks to industries most affected or reducing fuel taxes could undermine its effects.

An advantage cited is the transparency of the carbon tax compared with the complex permit allocation process associated with grandfathered permitting [Parry 2003]. One element of carbon taxes compared with more general emissions trading is that the tax is applied only to carbon dioxide, which, though the most important GHG, is not the only one. In January 2007, a Carbon Tax Center was launched to educate and inform policy makers about the benefits of an equitable, rising, carbon tax [Carbon 2007]. Lessons can also be learned from studying carbon taxes implemented in Sweden, Finland, the Netherlands, and Norway, all of which were introduced in the 1990s.

4.4 Demand-Side Response

One way to reduce GHG emissions is to reduce consumption, which could be achieved via demand response. Demand-response programs can be either price-based or incentive-based. Price-based programs include real-time pricing, critical-peak pricing, and time-of-use tariffs, all of which vary electricity prices to reflect the changing value and cost of electricity during different time periods. For incentive-based demand response programs, customers are paid to reduce their loads at times requested by the program sponsor, triggered either by a threat to grid reliability or high electricity prices. Examples are the following:

- The New York Energy $mart Program is a partnership between the New York State Energy Research and Development Authority and the Public Service Commission. One of their many programs includes submetering, which provides building owners with financial assistance to install advanced metering, energy management, and load control equipment in order to take advantage of time-of-use rates and to assist the grid during times of emergency [GetEnergy].

- Through several ERCOT programs, customers can receive payments for providing load curtailments. Customers participate through a retail electricity provider, and programs include the following: load curtailment offer bids into the Balancing Energy Market, load acting as a resource with bids into different ancillary service markets, and voluntary load reduction, in which customers receive payment for discretionary load curtailment in response to an hourly market clearing price [EERE].
- A report released in March 2005 by the California Demand Response Business Network [DRBizNet] discusses new tools for managing peak demand. The systems used to support demand response are integral to the success of these initiatives. DRBizNet, in collaboration with the California Energy Commission (CEC) and the California Institute for Energy and the Environment (CIEE), are developing software to streamline those processes involved in operating a demand-response system. Features include customer enrollment, meter management, and settlement processing. The report estimates that deploying such a real-time demand-response network could increase the benefits of demand response by a factor of ten, at a cost one-tenth of the current system [DRBizNet].
- In the Toronto Hydro's Peaksaver AC program, both business and residential customers can have a switch installed on a central air conditioner to which a signal can be sent to reduce electric consumption. To alleviate business concerns, business customers are allowed to opt out of an activation two times each summer [Toronto].
- Critical peak pricing programs in California offer customers three price levels for peak, off-peak, and a 'critical peak' period, for which customers are notified when this 'critical' period price is in effect [CPP].

In 2004, potential demand response capability was approximately 20,500 megawatts, 3 percent of total U.S. peak demand; however, actual delivered peak demand reduction was about 9,000 megawatts, 1.3 percent of peak [DOE 2006]. The U.S. DOE report, *Benefits of Demand Response and Recommendations*, which follows the Environmental Policy Act, lays out a number of interesting recommendations on expanding and implementing demand-response capabilities nationwide. Recommendations and relevant areas for analysis from this report include the following:

- A study of program design elements that influence effectiveness, such as eligibility criteria, curtailment terms, incentive payments, and procedures to measure and verify demand reductions, to be incorporated into new and existing programs.
- A voluntary and coordinated public-private partnership effort to strengthen demand response analysis capabilities, with the goal of establishing universally applicable methods and practices for quantifying the benefits of demand response.
- Public-private partnerships to examine how much demand response is needed to improve the efficiency and reliability of wholesale and retail markets.

- Resource planning initiatives to review existing demand response characterization methods and improve existing planning models.

4.5 Renewables Portfolio Standards

Renewables portfolio standards (RPS), policies that mandate a specified megawatt amount or percentage of electricity that is supplied to originate from a renewable resource, are increasingly being adopted by state governments (see Figure 4.1). In many states the motivation for mandating RPS stems from economic interests such as promoting local industry and avoiding importing fuel. However, decreasing greenhouse gas emissions is also part of the motivation behind mandating RPS in most states. Many states are continuing to increase their renewable energy requirements; those changes as they apply to prior legislation can be found in the DOE *Annual Energy Outlook 2006* [EIA 2006].

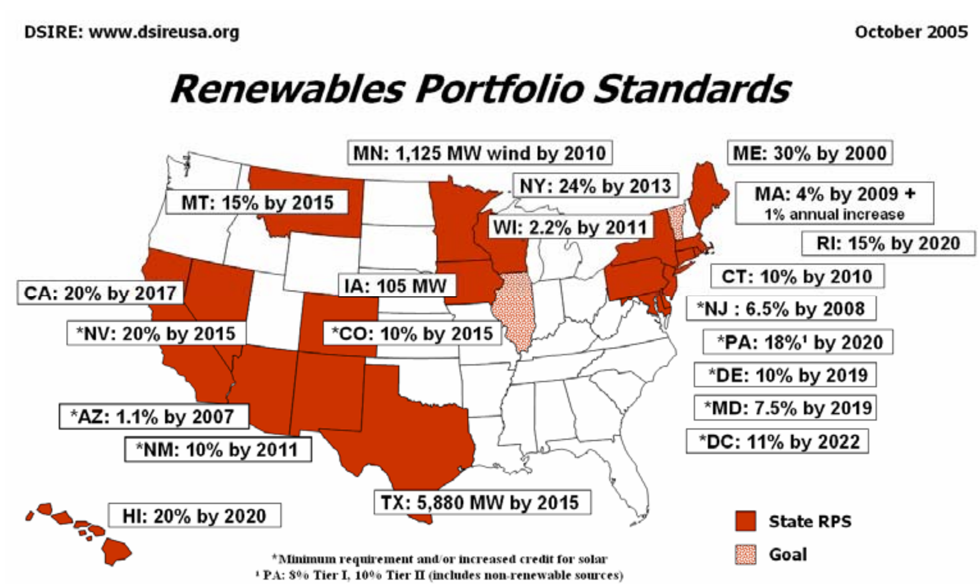

Figure 4.1 State Requirements in Renewable Portfolio Standards [DSIRE]

Many RPS include market mechanisms to allow trading of both renewable energy generation, quantified in renewable energy certificates (RECs), and emissions permits, quantified through cap-and-trade mechanisms, as defined above. The individual REC and cap-and-trade markets are neither well-coordinated between the states nor coordinated across these similar but distinct mechanisms. Both the Northeast and Southwest are developing *de facto* regional markets for both mechanisms, yet without specific coordination, there is the risk of double-counting the benefits of various measures and general chaos in attempts to design well-functioning markets.

State programs currently in place vary greatly state by state, with some of the key similarities as follows:

- *Tier I & Tier II Technologies:* Connecticut, the District of Columbia, Maryland, New Jersey, and Pennsylvania have different "tiers" or "classes" of renewables.

Tier or Class I typically includes solar, wind, geothermal, tidal, and small hydroelectric. Tier II is often waste to energy and other hydropower facilities. Tier II resources are increasingly phased out each year, replaced by the increased use of Tier I facilities, ensuring a transition to the lowest polluting technologies.

- *Solar & Wind Emphasis:* Many states also have their own unique requirements for how much energy must come from particular sources. Arizona requires that solar energy make up 60 percent of total renewables; solar energy must be 4 percent in Colorado, and 2.12 percent in New Jersey by 2021; in Illinois, 75 percent must come from wind energy. Differences in the composition of the portfolios vary greatly from state to state [DSIRE].

As success with state-level RPS continues, interest in *national* renewable portfolio standards for electricity production is increasing. Senator Boxer may pursue implementation of a Federal RPS [Morello 2007], with additional support coming from Senator Bingaman and resistance from Secretary Bodman [Kaplan 2007]. Research groups such as Resources for the Future (RFF) and the Pew Center on Global Climate Change advocate the implementation of a national RPS program. Their analyses have found that RPS, when compared to other policies, is likely to be the most effective at lowering greenhouse gas emissions [RFF 2004]. Recommendations on how national RPS should be implemented vary, but the success of state programs encourages the development of federal RPS based on these state-level programs [Rabe 2006].

4.6 Possible Research Areas

- Research the effect of conflicts and/or inconsistencies between regional cap-and-trade markets, as well as interactions between cap-and-trade policies and renewable portfolio standards requirements.
- Develop new planning and risk management tools, focusing on the risk introduced by uncertainty in climate change and government policies designed to address climate change issues.
- Analyze the effect on system and market operations if automated control systems are installed at customer locations. What would be an optimal control and communications architecture? How would local control strategies be integrated into system control and market operation strategies? Analyze the effect of new tools for managing peak demand.
- Develop optimal bidding strategies for multi-period electricity markets with uncertainty in GHG policies and mandates (e.g., mandated caps on emissions, cap-and-trade mechanisms, mandated percentage use of renewable energy technologies).
- Analyze the potential for market power, assuming that there are emissions restrictions that affect the ability of different players to bid into markets and to exercise market power.
- Analyze the potential for and benefits of co-optimizing markets for pollutant emissions permits and electricity.

- Optimize renewable energy usage in rural electric power systems.
- Analyze the possible impacts of RPS in terms of identifying which thermal generation is displaced, allowing for an analysis of the RECs and quantification of GHG reductions. Account for the time-dependent nature of renewable energy generation on GHG reduction.
- If there were to be a carbon tax, analyze the impact of various uses of tax revenues with the goal of identifying the most efficient (such as subsidies for R&D of renewable energy technologies)
- Investigate smart metering relative to automated load response and the monitoring of renewable energy generation (for renewable energy certificates), and include analyses of the type and extent of information required by the system and by customers/independent generators.

5. Federal, State and Local Government Policies

5.1 Federal Policies

The first federal action related to GHG emissions came in the 1990 Clean Air Act, which requires electric generating facilities subject to the acid rain provisions of the Act to also monitor CO_2 emissions. Monitoring can be done by actual measurement or by fuel analysis [Yacobucci]. In 1992, Title XVI, Global Climate Change of the Energy Policy Act of 1992, directed the Secretary of Energy to assess the global warming mitigation and adaptation recommendations in the 1991 National Academy of Sciences report, "Policy Implications of Greenhouse Warming" [NAS]. The 1992 act also established a voluntary system of reporting GHG emissions, DOE's Voluntary Reporting of Greenhouse Gases Program, for those not covered by the 1990 rules. Both monitoring systems are still in place in 2007 [EIA].

Further 1992 action on climate change came with full ratification of the United Nations' Framework Convention on Climate Change (UNFCCC), a nonbinding commitment to reduce atmospheric greenhouse gases. The treaty itself did not set limits on GHGs but instead provided for later protocols that would set actual limits. This resulted in the December 1997 Kyoto Protocol to the UNFCCC, which committed signatories to legally binding reductions in emissions of six GHGs, including, most significantly for the electric power industry, CO_2. The U.S. goal would have been a 7 percent reduction below 1990 levels between 2008 and 2012. The Kyoto Protocol was signed by the Clinton Administration in November 1998 but was never submitted to the Senate for consent. In 2001, the Bush administration disengaged from the protocol [Fletcher].

Since 1992, all three presidential administrations have relied on voluntary limits to CO_2 emissions, and no direct federal limits have been established. Limits are in place for methane (CH_4) emissions from landfills, and EPA rules on ozone-depleting substances list global warming as one of the risk criteria for evaluating alternatives. Energy conservation initiatives indirectly reduce GHG emissions by reducing total energy use. These include appliance and commercial building efficiency standards, automotive fuel economy standards, and the conservation and renewable energy provisions of the 1978 Public Utilities Regulatory Policies Act (PURPA) [Yacobucci].

Four bills that would impose mandatory limits on GHGs have been introduced in the 110th Congress, which convened on January 4, 2007. All direct the EPA to impose absolute caps on emissions from electric power generation and decrease cap levels in subsequent years. Programs would begin as soon as 2010. All propose a tradable allowance system similar to that used now for acid rain reduction [Parker].

5.2 Carbon Capture and Sequestration—Federal and Industry Support

Carbon capture and sequestration or storage, introduced in section 2.4.1 of this paper, refers to the process of capturing and storing CO_2 that is emitted from electric generators and industrial processes. With continued reliance on coal for energy, CCS offers an important technology for reducing GHG emissions. This section (5.2) discusses the broad interest among policy makers in CCS and thus highlights the likelihood of future policies that promote CCS.

As one recent example, the Stern Review on the Economics of Climate Change (Sir Nicholas Stern is director of the United Kingdom Government Economics Service and Adviser to the Government on the economics of climate change and development) included CCS when it examined the future costs of climate change, *assuming* that new technologies and legislation for the mitigation of GHG would be in place [Stern]. The Pew Center on Global Climate Change recommends increased federal research and development into CCS and finds it likely that the technology will be needed in the near future [Pew 2006]. Another report recommends mandatory research and development of a one percent of all value-added tax, by all parties involved in the electricity industry [Morgan]. The United Nations Foundation advised banning construction of new coal-fired power plants that are not equipped for CCS [UN].

Industry groups are supportive of CCS as well, with the Edison Electric Institute stating in February that they would support CCS legislation [Foster]. There are six different CCS regional partnerships in the United States: West Coast Regional Carbon Sequestration Partnership (WESTCARB), Southwest Regional Partnership on Carbon Sequestration (SRPCS), Big Sky Partnership on Carbon Sequestration, The Plains CO_2 Reduction (PCOR) Partnership, Midwest Geological Sequestration Partnership (MGSC), and Southeast Regional Carbon Sequestration Partnership (SRCSP). Each has different capabilities and specific objectives depending on the region's geology. Overviews and links to each can be found at the National Energy Technology Laboratory website [NETL].

One area of concern is that CCS technology is quite expensive. For pulverized coal plants, the cost of retrofitting CO_2 capture to these facilities could add at least 70 to 100 percent to the cost of electricity [NETL]. The industry will benefit from researching the most cost-effective CCS technologies and also developing policies and/or financial instruments to clarify who will be expected to bear the costs. Some discussion of the costs of CCS can be found at the Big Sky Partnership on Carbon Sequestration website, www.bigskyco2.org, and the National Energy Technology Laboratory website [NETL].

5.3 State and Local Policies

In the absence of federal limits on GHGs, a number of states and even some municipal governments have implemented GHG limits. Electric generators in nine states will be subject to mandatory limits beginning in 2009 under the Regional Greenhouse Gas Initiative (RGGI). RGGI is a "cooperative effort by Northeastern and Mid-Atlantic states to reduce carbon dioxide emissions" [RGGI]. Connecticut, Delaware, Maine, Massachusetts [Sullivan], New Hampshire, New Jersey, New York, Rhode Island [Carcieri], and Vermont are now participating, and Maryland will join by June 30, 2007. RGGI is a mandatory cap-and-trade program with emissions trading. A model rule was issued in August 2006. The model rule is intended to be the basis for state rules, which are to be in place by the end of 2008. Under the model rule, emissions will be capped at current levels starting in 2009 and continuing through 2014. Then by 2019, allowable emissions will decrease by 10 percent. The rules will apply to all fossil fuel-fired generators with nameplate capacity exceeding 25 MW.

While RGGI addresses only electric power generators, the California Global Warming Solutions Act of 2006 (AB 32) caps GHG emissions from all sources at 1990 levels by

2020 (see more below). Both markets and other compliance mechanisms will be considered [AB32 Fact Sheet]. In addition, the governors of California and New York have agreed to link the California and RGGI emissions trading markets [Executive Order S-17-06].

California is also a participant in another regional initiative, announced by the governors of Washington, Oregon, Arizona, New Mexico, and California on February 26, 2007 [WRCAI]. This initiative will, within six months, set a regional goal for GHG emission reduction. It will be implemented with a regional emissions market and monitoring program that will cover multiple sectors and be designed within 18 months.

Other states have implemented some form of limits on GHG emissions, and all states with limits are listed in Appendix 4. Municipal governments have also created limits. On November 8, 2006, for example, Boulder, Colorado, created a GHG emissions tax on electric generators that seeks to reduce GHG emissions to 7 percent below 1990 levels by 2012 [Initiative 202]. New bills are now being considered in various state legislatures in their 2007 sessions, and the list of states with mandatory GHG reduction programs is likely to continue growing.

5.4 California Assembly Bill 32 (AB32)

The state of California is the largest contributor of GHG in the nation, and the twelfth largest in the world, with annual emissions comparable to those of Australia [Eilperin]. California Assembly Bill 32 was approved by the governor and filed with the Secretary of State on September 27, 2006 [AB32]. The key purpose of this bill is to mandate reduction in state emission levels to those of 1990 by 2020. By 2050, it will reduce emissions to 80 percent below 1990 levels.

The mandatory reporting and verification of statewide GHG emissions will begin no later than January 1, 2008, the date by which the California Air Resources Board must adopt regulations that will monitor and enforce compliance with the program. The regulation will require monitoring of all electricity consumed in the state, including transmission and distribution line losses from electricity generated within the state or imported from outside the state. This applies to all retail sellers of electricity.

By January 1, 2009, the California Air Resources Board will prepare and approve a scoping plan that will identify and make recommendations on emission reduction measures. In this plan, the state board will identify options for emission reduction measures from all verifiable and enforceable voluntary actions, including, but not limited to, carbon sequestration and best management practices. By January 1, 2011, the state board will adopt statewide GHG emission limits and emission reduction measures that will become operative beginning on January 1, 2012. The reduction measures may include market-based compliance mechanisms such as GHG emission exchanges, banking credits, and other transactions as defined by legislation.

On or before June 30, 2007, the state board must publish a list of early voluntary GHG reduction actions that can be implemented prior to the mandatory measures that will come into effect January 1, 2011. Entities that have voluntarily reduced their GHG emissions prior to the mandatory implementation in 2011 must receive “appropriate credit for early voluntary reductions.”

5.5 Possible Research Areas

- Analyze the effect of system operations from changing dispatch patterns that result from production caps (the result of emissions caps) and changes in merit order (from changes in production costs), as a result of emissions regulations.
- Analyze the impact on both existing generating plants and the power system from possible government regulations constraining the dispatch of specific types of generators.
- Analyze the effect of bills such as AB32 on power system operations.
- Analyze the effect of inconsistent/conflicting regional emissions policies (in conjunction with an analysis of inconsistent/conflicting regional permit markets) in contrast to uniform, national policies.
- Create an up-to-date document of all major government, state and local initiatives affecting the utility industry.

6. Long Range Industry Planning

6.1 Electric Power Industry's Long-Range Plans for Adapting to Global Climate Change

As reported by EPRI, the McKinsey Quarterly, and numerous electric power generation and transmission companies, the electric power industry is making long-range plans along several fronts to adapt to global climate change. These include (but are not limited to) the following:

- Demand reduction and conservation.
- Improvement of the efficiency of the electricity infrastructure.
- Renewables (wind, solar, biomass, bio-fuel) and distributed generation.
- Nuclear generation.
- CO_2 reduction, capture, and sequestration.

The McKinsey Quarterly predicts that effective use of these technologies can result in a reduction of CO_2 emissions from the current 9.4 gigatons to 7.2 gigatons worldwide by 2030. These figures include an increase in demand of roughly 78 percent during this period.

6.1.1 Demand Reduction and Conservation

Demand reduction and overall conservation is expected to be a part of the long-range strategy for most electric power utilities. As an example, Duke Energy Corporation Chief Executive Jim Rogers stated that Duke will find 600 MW or more of decreased power demands by creating more energy efficiency programs [Energy Central, 2007b]. Fifteen states are working with the EPA to increase end-use efficiency. These states are also developing strategies to increase distributed generation, renewable energy, and other clean sources of energy [Energy Central, 2007c].

6.1.2 Improvement of Efficiency of the Electricity Infrastructure

Driven by the industry's directives, EPRI plans on conducting research and development to improve the efficiency of the electricity infrastructure. Their definition of infrastructure includes generation, transmission, and distribution. EPRI also is supporting demand side management to minimize the need for peaking units with high greenhouse gas emissions.

6.1.3 Renewables

Electric power utilities throughout the United States and abroad are actively pursuing alternative forms of renewable energy, including concentrated solar, photovoltaic, wind, tide, and geothermal (these technologies were introduced in section 2 of this paper). Examples of this are numerous throughout every region of the United States. As one example, producers in Maine and eastern Canada are planning to substantially increase wind- and tide-driven generation and to build generation fired by wood waste from paper and lumber mills. This power is to be transported via an undersea cable to the Boston area [Howe, 2007]. One major challenge is accessing renewables, which are often found in areas that are remote to the existing electric power grid. The California Independent System Operator is currently seeking financing to construct transmission lines to remote locations in order to provide green power to the grid [CAISO, 2007].

6.1.4 Nuclear Generation

The largest sector of planned generation seems to belong to nuclear energy. Nuclear power (introduced in section 2.4.3) is increasingly presented as climate change friendly and is finding support from many sectors including some environmental groups, political organizations, and the federal government. In response to one power producer's plan to build 11 new pulverized coal-fired power plants, U.S. Secretary of Energy Samuel Bodman stated that "the ultimate solution to the need for more power lies with nuclear generation," although he also conceded that he "favors coal technology, so long as it is 'clean'" [Piller, 2007].

The electric power industry is perhaps the most ardent supporter of this proven technology. For example, Duke is planning on building two nuclear reactors, which would increase their capacity by 15 percent without increasing CO_2 emissions. Although it has been recognized that the mining of uranium results in CO_2 emissions [Energy Central, 2007b], it is not clear if this form of mining is more injurious to the environment than mining of the equivalent amount of coal. Duke is not the only company looking at nuclear power. Six major U.S. power providers are preparing requests for combined construction and operating licenses to the Nuclear Regulatory Commission (NRC) to allow construction to begin within the next five years. "The nuclear power industry believes the first new U.S. order is only two years away" [Guinnessy, 2007]. While nuclear energy may be a long-term solution for some power producers, the traditional long delays, due to licensing and construction, makes nuclear undesirable for regions where growth demands new generation in the short term, although there is some sentiment for streamlining the licensing process.

Abroad, some nations are considering building their first reactors, and other countries are considering building additional reactors. Two 1,600 MW pressurized water reactors being built in Europe are slated for completion in 2008 and 2012. Prime Minister Tony Blair is expected to announce six to eight new reactors for the United Kingdom this spring [Guinnessy, 2007]. Bruce Power of Canada has committed $3.6 billion USD to rebuild two reactors, which have stood idle for almost a decade. China plans to construct 30 nuclear reactors by 2020. China also views nuclear power as a major export opportunity and is completing its second of four planned reactors in Pakistan. India has nine plants of its own under construction [Guinnessy, 2007]. The Ontario Power Authority proposed plans to build 12 new nuclear plants in order to phase out their older coal-fired units [Guinnessy, 2007]. "Worldwide, a total of 25 reactors are currently under construction" [Sovacool, 2007]. Another 24 are slated for refurbishment.

Nuclear development has been further spurred by technology advancements. The gas pebble bed modular reactor (PBMR), which is less expensive to build and safer than previous designs, has an extended service life of 60 years. It has been suggested also that heat from some nuclear plans be used in the production of hydrogen.

6.1.5 CO_2 Reduction, Capture, and Sequestration

Generation from fossil fuels is not expected to disappear in any foreseeable future and utilities are planning for the likely phasing in of CO_2 emissions caps and trading regulations. Puget Sound Energy (PSE) has joined the Chicago Climate Exchange (CCX), the United States' only existing (voluntary) greenhouse gas emissions registry, reduction, and trading program [Energy Central, 2007d]. PSE has committed to work with CCX on greenhouse gas emissions and reduce the environmental impact of their energy generation facilities. Duke Energy Corporation Chief Executive Jim Rogers states that Duke is planning to mothball 600 MW of its dirtiest coal-fired power plants [Energy Central, 2007b].

In an unusual move by the private investment industry, private investors have been influence by environmental groups in their plans to buy out TXU energy corporation. By guaranteeing reverses in TXU's focus on conventional coal generation, they have potentially avoided protest by environmental groups [Energy Central, 2007e]. Continuing public concerns over an expanded use of nuclear power however, may refocus attention on this issue.

Generation companies are looking at CO_2 capturing and sequestration, discussed above in sections 2.4.1 and 5.3. The California Energy Commission and DOE have undertaken a partnership to "determine long-term capturing and sequestering methods." The West Coast Regional Carbon Sequestration Partnership (WESTCARB) is currently planning a 3,500 foot well in the California Delta in order to store CO_2 in a deep saline aquifer. The project is slated to be completed sometime in 2007. This project is a direct result of the DOE's CO_2 sequestration program [Hoffman, 2006]. The WESTCARB, or WCRCSP partnership has a budget of $3.5 million USD and includes six western states and part of Canada [DOE, 2007].

Arizona Public Service is currently testing a program at its Red Hawk Power facility, wherein the emissions from a combined cycle power plant are plumbed through a lake in order to feed algae, which is then harvested for fuel.

Carbon sequestration is also being explored world wide. The Total Energy Company has begun the engineering study phase of a carbon sequestration project at a power plant in Lacq, France. This project is slated to cost roughly $79 million USD and consists of a pipeline that transfers CO_2 from the plant to a depleted natural gas field in the town of Rousse, 30km from Lacq. The project is expected to become operational in late 2008 and eventually capture 150 metric kilotons of CO_2 [Energy Central, 2007a].

6.2 Other Industries' Long-Range Plans for Adapting to Global Climate Change

As with the electric power industry, most industries are planning for changes in their operating environment due to global climate change. The financial incentives motivating industry to make plans come from four main pressure points:

- Anticipated environmental regulations.
- Opportunity to increase market share or offer a new product.
- Prevention of financial losses
- Avoidance of litigation.

6.2.1 Anticipating Environmental Regulations

In addition to the electric power industry, the industries furthest along in adapting to global climate change are the ones anticipating emissions regulations and adapting to keep their market share. All of the players in the automotive industry are aggressively pursuing "plug in" hybrid vehicles—which could be charged during the evening when the power grid's load factor is low. These vehicles could produce 60 percent less carbon each year (assuming only a modest 20-mile electrical range) [Woolsey, 2006], depending upon which generating technologies are used to charge the vehicles. This adaptation presents an opportunity for the electric power industry since it is expected to increase the load served and increase the base load. It also presents a challenge in areas where transmission congestion already exists. The precise effect of plug-in hybrid vehicles on load shape is unknown, and the new load shapes may have unforeseen consequences for equipment, such as transformers.

The aeronautical industry is searching for technologies that will produce sustainable transportation options. The industry recognizes that "radical technological steps will be demanded of the industry" for various reasons, including "climate change, long-term fuel supply, traffic congestion, and noise pollution" [Denning et al., 2003]. Various alternatives are being considered, such as more efficient wing designs [Denning et al., 2003] and more efficient engines [Wulff et al., 1997], which would allow for longer ranges, higher payloads, higher cruising speeds, and greater fuel efficiency [Wulff et al., 1997].

A group of corporations has partnered with environmental organizations to form the United States Climate Action Partnership (USCAP) in an effort to create a carbon-emissions cap and/or trading program in the United States [Sissel, 2007]. USCAP members include BP, General Electric, and DuPont. The USCAP states in its first report that "Each year we delay action to control emissions increases the risk of unavoidable consequences that could necessitate even steeper reductions in the future, at potentially greater economic cost and social disruption" [USCAP, 2007].

A number of petroleum companies are planning to continue their core business. "There is no significant alternative to oil in coming decades," says ExxonMobil CEO Rex Tillerson, "and ExxonMobil will continue to make oil and natural gas its primary products." ExxonMobil, along with many petroleum producers, will make the vast majority of its investments in oil and gas exploration in the near future [Silverstein, 2007].

6.2.2 Opportunities to Increase Market Share

For some industries, global climate change produces new opportunities. The financial industry is developing carbon-reduction portfolios for investors. The European Bank for Reconstruction and Development and the Dexia Group announced an equity fund that will invest in energy-efficiency projects including heating and energy [EBRD, 2000]. In addition to regular returns, the fund also offers investors carbon-emission credits that could be traded in European markets [EBRD, 2000]. Carbon credits have not passed the notice of larger firms. In 2006, Morgan Stanley announced a five-year program of investments in carbon credits and emissions reduction totaling approximately $3 billion

[Morgan Stanley, 2006]. Morgan Stanley will sell the credits through its Commodities Trading Department to companies that must reduce their carbon emissions to comply with the Kyoto Protocol [Morgan Stanley, 2006].

Many industries are offering carbon-neutral goods or services to consumers. In January of 2007, DHL announced "GoGreen," a carbon-neutral delivery service. DHL shipping pledged to use alternative and renewable technologies, including biodiesel delivery trucks, and claimed that its service would offset the CO_2 emissions involved in transportation and delivery [DHL, 2007]. This is by no means the first such announcement; in 2004, HSBC Holdings plc announced a program of energy use reduction, increased purchases of green power, and offsets through carbon credits in the European markets, in an effort to become carbon-neutral within three years. HSBC's chief executive, Stephen Green, said that he expects that the program will cost $7 million in its first year [HSBC, 2004]. HSBC is the largest bank in the world in terms of assets [Riley et al., 2006]. A similar announcement in late 2006 from insurance company Aviva included a statement from its chief executive, Richard Harvey: "We believe climate change to be the most important environmental issue facing the world. . . . We continue to encourage other companies to reduce their CO_2 emissions . . . ." Aviva's plans include investment in renewable energy generation and increased energy efficiency [Aviva, 2006].

In January of 2007, GE and AES Corporation announced a partnership meant to reduce greenhouse gas emissions [Selko, 2007a]. The companies intend jointly to pursue reductions in methane and carbon emissions and renewable power generation, in order to cater to corporations interested in reducing their environmental impacts [GE, 2007].

Some companies stand to gain from an increased focus on energy efficiency. DuPont is marketing thermal mass building materials designed to stabilize a room's temperature and reduce the need for air conditioning and heating. It is promoting these materials as a technology that will enable the construction of more sustainable and energy-efficient buildings [DuPont, 2007]. An increased focus on alternative fuels has spurred the planning and construction of hundreds of biofuel production plants such as one in Mississippi, which is able to produce 6,000 gallons per day [Selko, 2007b].

Honda Motor Company, responding to strong sales in hybrids and other fuel-efficient vehicles, has announced a $600 billion investment in a new factory that will produce "20% fewer emissions of CO_2 greenhouse gas compared with the level of 2000," according to president Takeo Fukuda. At the same time, the factory will produce 200,000 vehicles annually [France-Presse, 2006].

6.2.3 Preventing Financial Losses

Some industries are adapting their business to minimize or reverse anticipated losses due to global climate change. The insurance industry, which has traditionally set rates based on historical data, is now in the business of forecasting how global climate change is likely to change their risk. Actuaries, using new methods, will be proposing higher rates to accommodate higher risk. In a report released by a national coalition of investors, Ceres, it was found that "losses from weather-related insurance claims are rising faster than premiums, the population, and economic growth." The report concludes that governmental agencies, along with financial and insurance industries, have "failed to adequately study the problem and evaluate potential impacts" [American Chemical Society, 2006]. In an attempt to curb the losses stemming from increased claims due to environmental conditions, the state insurance plan of Massachusetts has substantially raised rates in order to cover future natural disaster losses [American Chemical Society, 2006]. Increasing costs may need to be passed on to consumers. Allstate Insurance indicated in 2006 that it intends to increase premiums in response to rising reinsurance costs [McQueen, 2006]. This avoids a financial loss but runs the risk of driving away customers.

The banking industry is looking at how the potential rise in sea level will affect some of their mortgagors. The Union Bank of Switzerland anticipates that if its clients' properties are damaged by rising sea levels, there may no longer be enough collateral to cover their loans. Even if the properties are repossessed, the bank will not be able to recover its losses [Hansen, 1996].

The risk and uncertainty presented by global climate change concerns investors. Rob Feckner, president of the board of California Public Employees' Retirement System (CalPers) has said that "Companies need to provide accurate and timely disclosure of the risks associated with climate change." CalPERS, with $208 billion in assets, is the largest public pension fund in the United States, and its demands are echoed by pension funds and other large, risk-averse investors [Ceres, 2006].

6.2.4 Avoid Litigation

The desire to reverse/minimize losses, maintain/increase market share, or meet anticipated government regulations is the motivation for most companies to adapt to global climate change. The other adaptive pressure comes from lawsuits. Although unlikely, some industries may be found liable for their contribution to global climate change. General Motors, Ford, Toyota Motors North America, Honda North America, DaimlerChrysler, and Nissan North America are being sued by the Attorney General of California based upon a complaint that the companies are producing a product that causes economic and environmental harm to California. The companies are responding that the suit is "without merit" and planning on responding by filing for "dismissal as soon as practicable" [Ford Motor Company, 2006].

6.3 Possible Research Areas

- Develop efficient and fast computational methods that operate in real time to analyze the trade-offs between profits and power system security and reliability. Security concerns should include voltage stability and short, mid, and long term stability. These tools should be tailored to account for the intermittency of alternative forms of energy.
- Analyze the efficiencies of market structures where carbon trading is allowed between the electric power industry and other GHG producing industries, such as transportation (e.g., automotive, aeronautical) and forestry.
- With the growth of population in the West and throughout the country, and the expected decreased rainfall due to climate change, thereby decreasing water

available for hydro-generation at a rate of 5 percent or more per decade, evaluate the consequences on system stability and responsiveness that is lost by reducing hydro-generation.

- Develop technology, system control methods, and market designs to improve power-system efficiency and demand-side management.
- Evaluate various market designs for aiding in GHG control.
- Because the holy grail of power system control is the completely automated control center, and due to the intermittency of alternative forms of energy and their wide dispersal that thereby require the future control of the system to have a faster response time than power system operators are capable of today, design smart technologies that can automatically control the power system locally while accounting for regional and national needs.
- Evaluate both the technical and economic impacts of the implementation of a "hydrogen economy" on the electric power industry.

7. Conclusions

7.1 Summary of Possible Research Areas

Concern over global climate change and its effects on human society, sustainability and national economies is increasing. There are multiple sources of GHGs, both biogenic and anthropogenic. The electric power industry, though not the cause of the majority of these emissions, is the source of a considerable fraction which could increase if technologies such as plug-in hybrid vehicles are successful in transferring emissions currently attributed to the transportation sector over to the electric power sector. As part of the ongoing national and international discussions of climate change, PSERC members are interested in developing potential research areas that address the interactions between the electric power industry and global climate change debate.

Following the themes introduced in sections 2 through 6 of this white paper, lists of possible research areas are repeated below. The subsequent steps for PSERC members in utilizing this white paper are to continue the discussion of power system—climate change interactions at PSERC meetings, and to integrate these issues into future research solicitations.

7.2 Interaction between the Production of GHGs and of Electric Power

- Develop a model to simulate the new transmission grid and system operation scenarios to verify that these proposals could be realizable in real life, thus helping future research projects find the most accurate and efficient methods to modernize the electric system.
- Develop and analyze methods to improve energy conservation and efficiency.
- Analyze the effects on system load shape, transmission system expansion, system dispatch, and new control needs in response to an increased use of plug-in hybrid vehicles, including a study of metering, two-way inverters, and possible distributed storage resources from hybrid vehicles (building upon the work in the ongoing PSERC project, P-10).
- Analyze the impact of an expansion of nuclear energy, in terms of impacts on the transmission system and power system operation, and in GHG reductions.
- Analyze system impacts and control needs of a significant penetration of large, remote wind farms, in terms of impacts on the transmission system, power system operation, and in overall GHG reductions.
- Analyze the system impacts, penetration level, and control needs of a high penetration of distributed photovoltaic systems in the distribution system.
- Analyze the expanded use of microgrids and network islanding organized to incorporate local as well as remote (renewable) energy resources.
- Analyze the effects of energy efficiency and demand response programs on load models, particularly for system stability analyses.

- Analyze the comparative impacts (e.g., on cost and system operations) of transporting carbon to a sequestration location, versus locating a power plant at the sequestration site.
- With respect to SF_6, analyze the effects of the following: (i) the industry conducting annual inventory emissions of SF_6 using an emissions inventory protocol, and (ii) the industry establishing strategies for replacing older, leakier pieces of equipment.
- Investigate the potential for distributed energy technologies, such as photovoltaics, cogeneration, energy efficiency and demand response, to be used in strategies that address climate change. Investigate obstacles, such as interconnection policies, to increased use of distributed technologies.

7.3 Extreme Weather, Blackouts and Component Failures

- Combine climate predictions of extreme weather with blackout risk assessment techniques under development by PSERC to estimate the impact of climate change on blackout risk.
- Explore power system monitoring and control techniques more amenable to self-healing properties, particularly under harsh weather conditions and increased load demand.
- Find climate change prediction studies for regions of North America, and use these to estimate the rate of change of power system design parameters such as temperature, wind, and precipitation extremes so that component design parameters can be uprated and loading forecasts changed, if necessary.
- Design a better service restoration methodology in case of natural disaster like hurricanes, high wind and rain, and snow storms.
- Analyze the likelihood and impact of increased wildfires on the western power grid and transmission system equipment.

7.4 Electricity Market Issues

- Research the effect of conflicts and/or inconsistencies between regional cap-and-trade markets, as well as interactions between cap-and-trade policies and renewable portfolio standards requirements.
- Develop new planning and risk management tools, focusing on the risk introduced by uncertainty in climate change and government policies designed to address climate change issues.
- Analyze the effect on system operations if automated control systems are installed at customer locations. What would be an optimal control and communications architecture? How would local control strategies be integrated into system control strategies? Analyze the effect of new tools for managing peak demand.
- Develop optimal bidding strategies for multiperiod electricity markets with uncertainty in GHG policies and mandates (e.g., mandated caps on emissions,

cap-and-trade mechanisms, mandated percentage use of renewable energy technologies).

- Analyze the potential for market power, assuming that there are emissions restrictions that affect the ability of different players to bid into markets and to exercise market power.
- Analyze the potential for and benefits of co-optimizing markets for pollutant emissions permits and electricity.
- Optimize renewable energy usage in rural electric power systems.
- Analyze the possible impacts of RPS in terms of identifying which thermal generation is displaced, allowing for an analysis of the RECs and quantification of GHG reductions. Account for the time-dependent nature of renewable energy generation on GHG reduction.
- If there were to be a carbon tax, analyze the impact of various uses of tax revenues with the goal of identifying the most efficient (such as subsidies for R&D of renewable energy technologies)
- Investigate smart metering relative to automated load response and the monitoring of renewable energy generation (for renewable energy certificates), and include analyses of the type and extent of information required by the system and by customers/independent generators.

7.5 Federal, State and Local Government Policies

- Analyze the effect of system operations from changing dispatch patterns that result from production caps (the result of emissions caps) and changes in merit order (from changes in production costs), as a result of emissions regulations.
- Analyze the impact on both existing generating plants and the power system from possible government regulations constraining the dispatch of specific types of generators.
- Analyze the effect of bills such as AB32 on power system operations.
- Analyze the effect of inconsistent/conflicting regional emissions policies (in conjunction with an analysis of inconsistent/conflicting regional permit markets) in contrast to uniform, national policies.
- Create an up-to-date document of all major federal, state and local governmenet initiatives affecting the utility industry.

7.6 Long-Range Industry Planning

- Develop efficient and fast computational methods that operate in real time to analyze the trade-offs between profits and power system security and reliability. Security concerns should include voltage stability and short, mid, and long term stability. These tools should be tailored to account for the intermittency of alternative forms of energy.

- Analyze the efficiencies of market structures where carbon trading is allowed between the electric power industry and other GHG producing industries, such as transportation (e.g., automotive, aeronautical) and forestry.
- With the growth of population in the West and throughout the country, and the expected decreased rainfall due to climate change, thereby decreasing water available for hydrogeneration at a rate of 5 percent or more per decade, evaluate the consequences on system stability and responsiveness that is lost by reducing hydrogenation.
- Develop technology, system control methods, and market designs to improve power-system efficiency and demand-side management.
- Evaluate various market designs for aiding in GHG control.
- Because the holy grail of power system control is the completely automated control center, and due to the intermittency of alternative forms of energy and their wide dispersal that thereby require the future control of the system to have a faster response time than power system operators are capable of today, design smart technologies that can automatically control the power system locally while accounting for regional and national needs.
- Evaluate both the technical and economic impacts of the implementation of a "hydrogen economy" on the electric power industry.

7.7 Building Upon Themes of Previous PSERC Research

- Incorporate climate change analysis into optimal power flow and unit commitment tools.
- Analyze methods to adapt system operations and control to changes imposed by environmental regulations in the form of constraints on generation location, operation, and type (e.g., fuel type, distributed resources, nondispatchable renewable energy technologies).
- Analyze the effect of emissions constraints upon resource location and scheduling.
- Develop tools to improve understanding and operations in an environmentally constrained system.
- Develop tools to identify, gather, and analyze data and parameters relating to emissions and environmental control technologies as they become important decision variables and constraints in system operations.
- Analyze and model risk and uncertainty associated with topics addressing power system-climate change interactions.
- Expand and continue projects on market design, as climate change issues and environmental restrictions add more complexity to optimal market design, including the need for interregional coordination and seams issues.

References

Introduction

[EIA] website: http://www.eia.doe.gov/oiaf/1605/gg98rpt/land.html

[HM-Treasury] website: http://www.hm-treasury.gov.uk/media/7CB/0E/annex7g_agriculture.pdf

[Transport] website: http://www.transportenvironment.org/docs/Publications/2006/2006-07_ghg_emissions_transport_eea_analysis_2004.pdf

[WorldEnergy] website: http://www.worldenergy.org/wec-geis/publications/reports/pgp/environmental/electric.asp

[Morgan] Morgan, G., L. Lave, and J. Apt, "The US Electric Power Sector and Climate Change Mitigation," Pew Center on Global Climate Change, June 2005, Available [online]: http://www.pewclimate.org/docUploads/Electricity%5FFinal%2Epdf

TASK 1: EPI and CC

[1a] Intergovernmental Panel on Climate Change, working group I, Climate change 2007: the physical science basis, summary for policymakers, February 2007. website: http://www.ipcc.ch/WG1_SPM_17Apr07.pdf with the full report available online at http://ipcc-wg1.ucar.edu/wg1/wg1-report.html

[1] Energy Information Administration (EIA), "Emissions of Greenhouse Gases in the United States" 2005, DOE/EIA-0573(2005). website: http://www.eia.doe.gov/oiaf/1605/ggrpt/pdf/057305.pdf

[2] Energy Information Administration (EIA), International Energy Outlook 2006, DOE/EIA-0484(2006), Washington, DC, June 2006. website: http://www.eia.doe.gov/oiaf/ieo/pdf/0484(2006).pdf

[3] Environmental Protection Agency (EPA), Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004, 2005. website:http://www.epa.gov/climatechange/emissions/downloads06/06_Complete_Report.pdf

[4] Energy Information Administration (EIA) / Electric Power Annual 2005, DOE/EIA-0348(2005). website: http://tonto.eia.doe.gov/FTPROOT/electricity/034805.pdf

[5] Kyoto Protocols to the United Nations Framework Convention on Climate Change, United Nations Framework Convention on Climate Change, United Nations, 1998. Available [online]: http://unfccc.int/resource/docs/convkp/kpeng.pdf

[6] T.J., Hammons, "Greenhouse gas emissions from power generation in Europe," *IEEE 39th International Universities Power Engineering Conference 2004*, Vol. 2, pp. 837-844, Sept. 2004.

[7] Energy Information Administration (EIA) / Voluntary Reporting of Greenhouse Gases Program, September 2006, DOE/EIA-0608(2005/S).

website: http://www.eia.doe.gov/oiaf/1605/vrrpt/summary/pdf/0608(2005-s).pdf

[8] Energy Policy Act of 2005, Washington, DC, 2005. Available [online]: http://www.doi.gov/iepa/EnergyPolicyActof2005.pdf

[9] Energy Information Administration (EIA), Analysis of Strategies for Reducing Multiple Emissions from Electric Power Plants: Sulfur Dioxide, Nitrogen Oxides, Carbon Dioxide, and Mercury and a Renewable Portfolio Standard, July 2001, SR/OIAF/2001-03.
website: http://www.eia.doe.gov/oiaf/servicerpt/epp/pdf/sroiaf(2001)03.pdf

[10] T. Valdés-Solís, G. Marbán, and A. B. Fuertes, "Low-temperature SCR of NO_x with NH_3 over carbon-ceramic supported catalyst," *Elsevier Applied Catalysis B: Environmental*, pp. 261-271, Nov. 2003.

[11] Energy Information Administration (EIA), Annual Energy Outlook 2006, February 2006, DOE/EIA-0383(2006).
website: http://tonto.eia.doe.gov/FTPROOT/forecasting/0383(2006).pdf

[12] DOE Energy Efficiency and Renewable Energy, Wind Power Today, DOE/GO-102006-2319, May 2006. website: http://www.nrel.gov/docs/fy06osti/39479.pdf

[13] Transmission and Wind Energy: Capturing the Prevailing Winds for the Benefit of Customers, National Grid, September 2006.
website: http://www.nationalgridus.com/non_html/c3-3_NG_wind_policy.pdf

[14] A Framework for the Offshore Wind Energy Development in the United States, Massachusetts Technology Collaborative, U.S. Department of Energy, and GE, September of 2005.
website: http://www.masstech.org/offshore/final_09_20.pdf

[15] R. Takahashi, L. Wu, T. Murata, and J. Tamura, "An application of flywheel energy storage system for wind energy conversion," *2005 IEEE International Conference on Power Electronics and Drives Systems*, Vol. 2, pp. 932-937, Nov. 2005.

[16] J. McDowall, "Integrating energy storage with wind power in weak electricity grids," *Elsevier Journal of Power Sources*, pp. 959-964, Nov. 2006.

[17] National Electric Technology Laboratory, Carbon Sequestration Technology Roadmap and Program Plan 2006, June 2006. website: http://www.netl.doe.gov/publications/carbon_seq/project%20portfolio/project_portfolio2/2006%20Roadmap.pdf

[18] D. W. Bailey and P. H. M. Feron, "Post-combustion decarbonisation process," *Oil & Gas Science and Technology*, Rev. IFP, Vol. 60 (2005), No. 3, pp. 461-474.

[19] U.S. Department of Energy Office of Fossil Energy, "CO_2 Capture and Storage in Geological Formations," January 2002.

[20] L. I. Eide and D. W. Bailey, "Precombustion decarbonisation processes," *Oil & Gas Science and Technology*, Rev. IFP, Vol. 60 (2005), No. 3, pp. 475-484.

[21] National Electric Technology Laboratory and Kansas Geological Survey, National Carbon Explorer Atlas (NATCARB). website: http://www.natcarb.org/

[22] DOE Energy Efficiency and Renewable Energy, Solar Energy Technologies Program Multi-Year Program Plan 2007-2011. website: http://www1.eere.energy.gov/solar/pdfs/set_myp_2007-2011_proof_1.pdf

[23] C. F. Kutscher, "The Status and Future of Geothermal Electric Power," National Renewable Energy Laboratory, DE-AC36-99-GO10337, 2000.

[24] R. H. Lasseter, "MicroGrids," *IEEE Power Engineering Society Winter Meeting*, Vol. 1, pp. 27-31, Jan. 2002.

[25] D. K. Nichols, J. Stevens and R. H. Lasseter, "Validation of the CERTS Microgrid Concept the CEC/CERTS Microgrid Testbed," *IEEE Power Engineering Society Meeting*, Montreal, Canada, June 2006.

[26] U.S. Department of Energy, National Transmission Grid Study, May 2002. website: http://www.oe.energy.gov/DocumentsandMedia/TransmissionGrid.pdf

[27] DOE Office of Transmission and Distribution, Grid 2030, July 2003. website: http://www.oe.energy.gov/DocumentsandMedia/Elec_Vision_2-9-4.pdf

[28] DOE Office of Transmission and Distribution, National Electric Delivery Technologies Roadmap, January 2004. website: http://www.oe.energy.gov/DocumentsandMedia/ER_2-9-4.pdf

[29] EPRI, Electricity Technology Roadmap, Product Number: 1010929, 2003.

[30] DOE Energy Efficiency and Renewable Energy and U.S. Department of the Interior Bureau of Land Management, "Assessing the Potential For Renewable Energy on Public Lands," February 2003 website: http://www1.eere.energy.gov/femp/pdfs/33530.pdf

[31] Institute for Lifecycle Environmental Assessment, "Carbon Storage and Accumulation in U.S. Forests," website: http://www.ilea.org/birdsey/carbon.html

[32] P.M. Grant, C. Starr, and T.J. Overbye, "A power grid for the hydrogen economy," *Scientific American*, vol. 295, pp. 58-65, July 2006.

TASK 2: Extreme Weather

[Allen02] M. R. Allen and W. J. Ingram, "Constraints on future changes in climate and the hydrologic cycle," *Nature*, vol. 419, September 2002, pp. 224-232.

[Forest Service] [Online May 2007] website: http://www.fs.fed.us/research/fsgc/climate-change.shtml

[Houghton04] J.T. Houghton, *Global Warming: The Complete Briefing*, Third Edition, Cambridge University Press, Cambridge UK 2004.

[IPCC01WG2] Intergovernmental Panel on Climate Change, working group II, IPCC Third Assessment Report, Climate change 2001: Impacts, adaptation and vulnerability. Available [Online] http://www.ipcc.ch/ and http://www.grida.no/climate/ipcc_tar/wg2/index.htm

[IPCC07WG1] Intergovernmental Panel on Climate Change, working group I, Climate change 2007: the physical science basis, summary for policymakers, February 2007. Available [Online] http://www.ipcc.ch/WG1_SPM_17Apr07.pdf

[IPCC07WG2] Intergovernmental Panel on Climate Change, working group II, IPCC Fourth Assessment Report, Climate change 2007: Impacts, adaptation and vulnerability. Available [Online] http://www.ipcc.ch/SPM13apr07.pdf

[Milly02] P.C.D. Milly, R.T. Wetherald, K.A., and Dunne, T.L. Delworth, "Increasing risk of great floods in a changing climate," *Nature*, vol. 415, January 2002, pp. 514-517.

TASK 3: Market Mechanisms

[Carbon 2007] Carbon Tax Center, www.carbontax.org

[CBO 2000] Dinan, Terry and Diane L. Rogers, "Who Gains and Who Pays Under Carbon Allowance Trading?: The Distributional Effects of Alternative Policy Designs." Congressional Budget Office, June 2000, Available [online]: http://www.cbo.gov/ftpdocs/21xx/doc2104/carbon.pdf

[CBO 2007] Congressional Budget Office, "Trade-Offs in Allocating Allownaces for CO_2 Emissions," April 25, 2007, Available [online] http://www.cbo.gov/ftpdocs/80xx/doc8027/04-25-Cap_Trade.pdf

[Chicago] Chicago Climate Exchange, website: http://www.chicagoclimatex.com/

[CPP] Critical Peak Pricing Programs in California: PG&E http://www.pge.com/biz/demand_response/critical_peak_pricing/index.html; SCE http://www.sce.com/RebatesandSavings/LargeBusiness/CPP/

[DOE 2006] U.S. Department of Energy. "Benefits of Demand Response in Electricity Markets and Recommendations for Achieving Them," February 2006. Available [online] http://eetd.lbl.gov/EA/EMP/reports/congress-1252d.pdf

[DRBizNet] California Demand Response Business Network, No. 500-01-043, DR04-01, March 20 2005, website: http://www.ucop.edu/ciee/dretd/wrkshps/documents/ws0405_exec_sum.pdf

[DSIRE] The Database of State Incentives for Renewables and Efficiency (DSIRE) website: http://www.dsireusa.org/library/includes/seeallincentivetype.cfm?type=RPS&currentpageid=7&back=regtab&EE=1&RE=1

[EERE] U.S. Department of Energy, Energy Efficiency and Renewable Energy, "Energy-Efficiency Funds and Demand Response Programs, Texas," Available [online] http://www1.eere.energy.gov/femp/program/utility/utilityman_em_tx.html

[EIA 2006] Energy Information Administration (EIA), Annual Energy Outlook 2006, February 2006, DOE/EIA-0383(2006). Available [online]: http://tonto.eia.doe.gov/FTPROOT/forecasting/0383(2006).pdf

[EU-ETS 2005] Pew Center on Global Climate Change. "The European Union Emissions Trading Scheme (EU-ETS) Insights and Opportunities," 2006. Available [online] http://www.pewclimate.org/docUploads/EU-ETS%20White%20Paper.pdf

[GetEnergy] New York State Energy Research and Development Authority (NYSERDA) Energy Smart Program, Available [online] http://www.GetEnergySmart.org

[Kaplan 2007] Kaplan, Alex, "Energy Policy: White House Hosts 'Big Four' On Energy To Talk Strategy" *Environment and Energy Daily*, February 27 2007. Available [online] http://www.eenews.net/eenewspm/2007/02/27/archive/1/?terms=ethanol

[Morello 2007] Morello, Lauren, and Darren Samuelsohn, "Boxer to aim for 'Significant Legislation' on Warming This Year," *Environment and Energy Daily*, February 13, 2007. Available [online] http://www.eenews.net/EEDaily/2007/02/13/#2

[Mufson 2007] Mufson, Steven, "CEOs Urge Bush To Limit Greenhouse Gas Emissions," *Washington Post*, January 23, 2007, Page A06.

[Parry 2003] Parry, Ian. "Fiscal Interactions and the Case for Carbon Taxes over Grandfathered Carbon Permits." Resources for the Future. Discussion paper 03-46 December, 2003. Available [online] http://www.rff.org/Documents/RFF-DP-03-46.pdf

[Palmer 2006] Palmer, Karen, Burtraw, Dallas, and Kahn, Danny. "Simple Rules for Targeting CO2 Allowance Allocations to Compensate Firms," Resources for the Future Discussion Paper 06-28. June 2006. Available [online] http://www.rff.org/Documents/RFF-DP-06-28.pdf

[Pew 2002] Rosenzweig, Richard, Varilek, Matthew, and Janssen, Joseph. "The Emerging International Greenhouse Gas Market," Pew Center on Global Climate. March 2002. Available [online] http://www.pewclimate.org/docUploads/trading%2Epdf

[Pew 2006] Pew Center on Global Climate Change, "Agenda for Climate Action," February 2006. Available [online]: http://www.pewclimate.org/docUploads/PCC%5FAgenda%5F2%2E08%2Epdf

[Rabe 2006] Rabe, Barry, "Race to the Top: The Expanding Role of State Renewable Portfolio Standards," The Pew Center on Global Climate Change, June 2006 website: http://www.pewclimate.org/docUploads/RPSReportFinal%2Epdf

[RGGI] Regional Greenhouse Gas Initiative, http://www.rggi.org/

[RFF 2004] Palmer, Karen and Dallas Burtraw, "Electricity, Renewables and Climate Change," Resources For the Future, Washington, DC., May 2004, website: http://www.rff.org/rff/Documents/RFF-RPT-Renewables.pdf

[RFF 2005] Darmstadter, Joel, "Stimulating Renewable Energy: A 'Green Power' Initiative, New Approaches on Energy and Environment: Policy Approaches for the President," Resources for the Future, 2005, website: http://www.rff.org/rff/RFF_Press/CustomBookPages/NewApproachesonEnergyandtheEnvironment/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=15623&CFID=6157082&CFTOKEN=97353403

[Toronto] Toronto Hydro Peak Saver Program, PowerWISE: website: http://www.torontohydro.com/electricsystem/powerwise/peaksaver/index.cfm

[UCS 2005], http://www.ucsusa.org/publications/catalyst/page.jsp?itemID=27226959; and http://www.ucsusa.org/global_warming/solutions/climate-stewardship-act.html

[WSJ 2007] Wall Street Journal, "Monthly Economic Forecasting Survey: February 2007," website: http://online.wsj.com/public/page/2_0891.html

TASK 4: Government Policies

[AB32] California. AB 32, Nunez. Air Pollution: greenhouse gases: California Global Warming Solutions Act of 2006. Available [online] http://www.law.stanford.edu/program/centers/enrlp/pdf/ab_32_bill_20060927_chaptered.pdf

[AB32 Fact Sheet] - California Global Warming Solutions Act of 2006, California Air Resources Board, 2006, Available [online] http://www.arb.ca.gov/cc/factsheets/ab32factsheet.pdf

[BigSky] Big Sky Carbon Sequestration Partnership, January 10 2007, Big Sky Carbon and Sequestration Partnership, Montana State University, February 24 2007 website: http://www.bigskyco2.org/

[Carcieri] Donald L. Carcieri, Rhode Island State of the State Address, January 30, 2007, Available [online]: http://www.governor.ri.gov/other/statemessage07.php

[Eilperin] Eilperin, Juliet. "California Tightens Rules on Emissions." The Washington Post September 1 2006; Page A01. Available [online]: http://www.washingtonpost.com/wp-dyn/content/article/2006/08/31/AR2006083100146.html

[EIA, 2005] US Department of Energy, Energy Information Administration, Voluntary Reporting of Greenhouse Gases Program, website: http://www.eia.doe.gov/oiaf/1605/frntvrgg.html

[Executive Order S-17-06], Office of the Governor of California, October 16, 2006, Available [online]: http://www.pewclimate.org/docUploads/CAExecOrderS%2017%2006%2Epdf

[Fletcher] Susan R. Fletcher, Global Climate Change: The Kyoto Protocol, Congressional Research Service, RL30692, July 21, 2005, Available [online]: http://fpc.state.gov/documents/organization/50815.pdf

[Foster] Foster Electric Report, "EEI, EPSA outline climate change policies," Report 494, pg 9, February 14, 2007.

[Initiative 202] Initiative 202, Climate Action Plan Tax, Boulder, Colorado, November 2006, Available [online]: http://www.ci.boulder.co.us/index.php?option=com_content&task=view&id=6136&Itemid=169

[Morgan] Morgan, G., L. Lave, and J. Apt, "The US Electric Power Sector and Climate Change Mitigation," Pew Center on Global Climate Change, June 2005, Available [online]: http://www.pewclimate.org/docUploads/Electricity%5FFinal%2Epdf

[NAS] National Academy of Sciences, Committee on Science, Engineering, and Public Policy, Policy Implications of Greenhouse Warming, National Academies Press, 1991, Available [online]: http://books.nap.edu/openbook.php?isbn=0309044405

[NETL] National Energy Technology Laboratory website: http://www.netl.doe.gov/technologies/carbon_seq/index.html

[Parker] Larry Parker, Climate Change: Greenhouse Gas Reduction Bills in the 110th Congress, Congressional Research Service, January 31, 2007, Available [online]: http://fpc.state.gov/documents/organization/80247.pdf

[Pew] Pew Center on Global Climate Change, "Legislation in the 109th Congress Related to Global Climate Change," Available [online]: http://www.pewclimate.org/what_s_being_done/in_the_congress/109th.cfm

[Pew 2006] Pew Center on Global Climate Change, Agenda for Climate Change, February 2006. Available [online]: http://www.pewclimate.org/global-warming-in-depth/all_reports/agenda_for_climate_action/index.cfm

[RGGI] Regional Greenhouse Gas Initiative, website: http://www.rggi.org

[Stern] Sir Nicholas Stern, "Stern Review on the Economics of Climate Change," Available [online]: http://www.hm-treasury.gov.uk/independent_reviews/stern_review_economics_climate_change/stern_review_report.cfm

[Sullivan] Kyle Sullivan, Press Release, Governor Patrick Signs Regional Pact to Reduce Greenhouse Gas Emissions, January 18, 2007, Available [online]: www.mass.gov/?pageID=pressreleases&agId=Agov3&prModName=gov3pressrelease&prFile=reduce_greenhouse_gases011807.xml

[WRCAI] Western Regional Climate Action Initiative, Available [online]: http://www.governor.wa.gov/news/2007-02-26_WesternClimateAgreementFinal.pdf

[UN, 2007] United Nations Foundation, "Confronting Climate Change," February, 2007, Available [online]: http://www.unfoundation.org/SEG/

[Yacobucci] Brent D. Yacobucci and Larry Parker, Climate Change: Federal Laws and Policies Related to Greenhouse Gas Reductions, Congressional Research Service, February 22, 2006, Available [online]: http://www.ncseonline.org/NLE/CRSreports/06Mar/RL31931.pdf

TASK 5: Industry Planning

[American Chemical Society, 2006] American Chemical Society, *"Environmental Science & Technology,"* February 1, 2006.

[Aviva, 2006] "Aviva to be the first insurer to carbon neutralize [sic.] its operations worldwide" Aviva CSR [Corporate Social Responsibility] website. December 28, 2006, Available [online]: http://www.aviva.com/index.asp?PageID=104&year=&newsid=2954&filter=csr

[CAISO, 2007] "California ISO Asks Federal Government to Back New Plan for 'Greening the Grid'". News Release, January 25, 2007.

[Ceres, 2006] "Leading Investors Worldwide Release Global Framework for Climate Risk Disclosure", *Investor Network on Climate Risk*. October 11, 2006. Available [online]: http://www.incr.com/index.php?page=ia&nid=236

[Denning et al, 2003] R.M. Denning, J.E. Allen, F.W. Armstrong, The Broad Delta Airliner, *"Royal Aeronautical Society"*, Volume 107 pp 547-558.

[DHL, 2007] "DHL's GoGreen service helps World Economic Forum meet its carbon neutral promise for Davos," *DHL Press Release*. Jan 18, 2007 Available [online]: http://www.dhl.com/publish/g0/en/press/release/2007/180107.high.html

[DOE, 2007] “Fossil Energy: West Coast Regional Carbon Sequestration Partnership,” Available [online]: http://www.fossil.energy.gov/programs/sequestration/partnerships/2003sel_westcoast.html; *and* [WESTCARB] website: http://www.westcarb.org/

[DuPont, 2007] “DuPont™ Energain™” DuPont Corporate Website Available [online]: http://www2.dupont.com/Energain/en_GB/index.html

[EBRD, 2000] “EBRD and Dexia sponsor an innovative equity fund for energy efficiency and emissions reductions investments” Press Release. *European Bank for Reconstruction and Development*. February 15, 2000. Available [online]: http://www.ebrd.com/new/pressrel/2000/17feb15x.htm

[Energy Central, 2007a] “Total Launches CO2 Capture Project”, Available [online]: http://www.energycentral.com/centers/news/daily/article_share.cfm?aid=4712877

[Energy Central, 2007b] “Rogers: Global warming reversible: Duke CEO says keys are an emissions cap, carbon dioxide program.” Available [online]: http://www.energycentral.com/centers/news/daily/article_share.cfm?aid=5284577

[Energy Central, 2007c] “Hawaii Joins EPA in Boosting Clean, Effective Energy Use – State Aims to Reduce Greenhouse Gas Emissions.” Available [online]: http://www.energycentral.com/centers/news/daily/article_share.cfm?aid=8223387

[Energy Central, 2007d] “PSE Joins Chicago Climate Exchange”, Available [online]: http://www.energycentral.com/centers/news/daily/article_share.cfm?aid=6487887

[Energy Central, 2007e] “Record TXU Buyout Includes Unprecedented Global Warming, Emissions Plan,” Available [online]: http://www.nrdc.org/media/2007/070226.asp

[GE, 2007] “GE, AES Plan Partnership To Lead US Market In Offsetting Greenhouse Gas Emissions” *Joint Press Release, GE Energy Financial Services & AES Corporation*. January 16, 2007. Available [online]: http://www.geenergyfinancialservices.com/press_room/press_releases/AES-GE%20PressRelease11507_FINAL_ForDistribution.pdf

[Ford Motor Company, 2006] Ford Motor Co., Quarterly Report, November 14, 1006.

[France-Presse, 2006] “Honda To Invest In Eco-Friendly Cars After Record Year”, *Industry Week*. December 27, 2006. Available [online]: http://www.industryweek.com/ReadArticle.aspx?ArticleID=13310

[Hansen, 1996] Sven M. Hansen, “A Banker’s Perspective I,” *Climate Change and the Financial Sector*. 1996.

[Hoffman, 2006] Ian Hoffman, “California Carbon Dioxide Sequestration Test to Get Underway”, Oakland Tribune, 01 October 2006.

[Howe, 2007] Peter Howe, ‘Undersea power cable from Maine to Boston proposed.” *Boston Globe*. February 14, 2007.

[HSBC, 2004] “HSBC world’s first major bank to go carbon neutral” HSBC Press Release Dec. 6, 2004, Available [online]: http://www.hsbc.com/hsbc/news_room/news/news-archive-2004?cp=/public/groupsite/news_room/2004_archive/hsbc_will_be_the_worlds_first_major_bank_to_go_carbon_neutral.jhtml&isPc=true

[McQueen, 2006] M.P. McQueen “Home Insurance Premiums Increase Across the U.S.” *The Wall Street Journal Online*. March 24, 2006. Available [online]: <http://www.realestatejournal.com/buysell/taxesandinsurance/20060324-mcqueen.html>

[Morgan Stanley, 2006] "Morgan Stanley to Invest in $3bn of Emissions Reduction Credits and Other Related Initiatives". *Morgan Stanley Press Release*. October 26, 2006. Available [online]: http://www.morganstanley.com/about/press/articles/3818.html

[Piller, 2007] Dan Piller, "Energy secretary backs 'clean coal,' nuclear power." *"Star-Telegram"*, February 14th, 2007.

[Riley et al, 2006] C. Riley, C. Mollenkamp. "Moving the Market: HSBC Tops Citigroup to Become Top Bank as Measured by Assets" Wall Street Journal. Aug 2, 2006 Pp C3.

[Selko, 2007a] A. Selko. "GE & AES Corp. Partner To Reduce Emissions", *Industry Week*. January 19, 2007. Available [online]: <ttp://www.industryweek.com/ReadArticle.aspx?ArticleID=13429

[Selko, 2007b] A. Selko. "Green Fuel Production", *Industry Week*. January 22, 2007. Available [online]: http://www.industryweek.com/ReadArticle.aspx?ArticleID=13445

[Sissel, 2007] K. Sissel. "Major Corporations Form Advocacy Group to Curb Climate Change" *Chemical Week*. January 31, 2007. Pp 12.

[Silverstein, 2007] K. Silverstein. "Industry Getting Heat on Climate Positions" *EnergyBiz Insider*. February 23, 2007. Available [online]: http://www.energycentral.com/centers/energybiz/ebi_detail.cfm?id=284

[Sovacool, 2007] Benjamin Sovacool, "Think Again: Nuclear Energy." *Foreign Policy*

[USCAP, 2007] "A Call for Change" *United States Climate Action Partnership*. January 28, 2007. Available [online]: http://www.us-cap.org/ClimateReport.pdf

[WEF, 2007] World Economic Forum, "Global Risk 2007", *Global Risk Network Report*. January, 2007. Available [online]: http://www.weforum.org/pdf/CSI/Global_Risks_2007.pdf

[Woolsey, 2006] R. James Woolsey, "Gentlemen, Start Your Plug-Ins", *Wall Street Journal*. December 30, 2006 p A10.

[Wulff et al, 1997] A. Wulff, J. Hourmouziadis. Technology Review of Aeroengine Pollutant Emissions, *"Aerospace Science and Technology"*, Volume 1, Issue 8, December 1997. Pp 557 – 572.

8. Appendix: Previous PSERC Research

(*Judith Cardell, December 2006*)

The interest of PSERC members in pursuing research related to electric power-climate change interactions was raised at the 2006 Summer Workshop in Ashland, Wisconsin. From these initial group discussions on the importance of climate change related issues, it became clear that there is a significant range in both interest and understanding of environmental change and its relevance to PSERC members. As a first step in continuing these discussions, this appendix identifies themes of PSERC projects, proposals, and publications from 1996 through the present round of proposals. The purpose of presenting these themes is to identify PSERC research capabilities, or core competencies, that could be readily applied to research on climate change-power industry interactions. Note that the categories discussed below are not intended to encompass every project pursued by PSERC members, nor are the categories mutually exclusive. Rather, the discussion is intended to demonstrate that previous PSERC projects demonstrate the core competencies necessary to pursue research on many of the issues raised by the interactions of the power industry and climate change.

8.1 Adapting Existing Tools

The first theme that is apparent in past and current PSERC projects is that of adapting traditional power system tools to address changes brought about by industry restructuring. This category includes projects that analyze system planning and expansion tools, unit commitment, and optimal power flow tools. One project addressed the effects of competition and decentralized ownership on resource scheduling. PSERC researchers could similarly analyze the effect of emissions constraints upon resource location and scheduling. PSERC studies on optimal locations for resources that have accounted for reliability, adequacy, and stability issues could be extended to include regional emissions limits in determining optimal resource locations.

Deregulation and competition introduced the need for an OPF to maximize profit and/or social welfare, and PSERC projects have focused on developing these OPF tools. As the industry continues to evolve, environmental constraints suggest that the OPF objective function may need to include minimizing emissions. Alternately, emissions limits could be included as part of the constraints, with the added complexity that emissions limits may differ over time (diurnal and seasonal) and over space. Similarly, unit commitment algorithms may need to account for emissions constraints. PSERC researchers are well qualified to continue adapting system tools as required by the industry.

Finally, PSERC projects have analyzed methods to adapt system operations and control to the competitive market-based decision-making environment imposed by industry restructuring. PSERC researchers could investigate further changes required for system operations and control that may be imposed by environmental regulations in the form of constraints on generation location, operation and type (fuel source).

8.2 Developing New Tools

A second and related category of projects is that of developing new tools and methods for system control, operation, and analysis. Generally, members have proposed developing tools to improve understanding and operations in a deregulated environment; tools to analyze and evaluate the effects of alternative restructuring paradigms on electric power system operation. Similar tool development will be necessary to improve understanding for operating an environmentally constrained system and one that is likely to be confronted by a variety of federal and state emissions regulations. One project in the category of new tools and methods researched new system control methodologies in response to industry restructuring and the subsequent influences on system control of independent, competitive, and small-scale generators. Environmental regulations are also likely to require new generator and system-level control schemes that account for environmental restrictions; PSERC members will be well-equipped to develop these strategies. New tool development has also led to the widely used visualization tool PowerWorld. Visualization of emissions levels may come to be as important to system operators as the current need for visualization of the voltage profile, for example.

Other new tools have drawn upon research into multiagent systems. One example is Powerweb that incorporates software and human intelligent agents to test various electricity market designs and reveal behavior. This tool could potentially be expanded to include market rules and system constraints related to environmental issues. PSERC projects also investigate developing new tools that exploit data from wide-area measurement systems and real-time, or online, dynamic analysis capability. Methods for determining transfer limits dynamically rather than through pre-determined, conservative operating assumptions have been proposed. The ability to determine generator parameters from operating data also exploits the use of new technology and access to more and better data. These same core competencies will be required in new research projects as entirely new sets of data and parameters relating to emissions and environmental control technologies become important decision variables and constraints in system operations.

8.3 Assessing Risk and Uncertainty

A third category of PSERC projects are those that address risk and uncertainty. One such project focused on risk-based maintenance allocation and scheduling, including an assessment of network reliability. Methods of monitoring and assessing the overall risk of cascading failure blackouts under development in PSerc projects will be useful in translating the effect of increased stresses on the power system due to climate change into the frequencies and risks of blackouts of various sizes. There has also been considerable attention paid to the impacts of uncertain power flows on system operation and control that have resulted from competition and restructuring. The general capability to analyze and model risk and uncertainty will be important for topics addressing power system-climate change interactions, and in interacting with other researchers who work primarily in the area of climate change.

8.4 Interregional Coordination

A fourth theme of PSERC projects is interregional coordination. Projects in this area include the accurate calculation of ATC and TTC along with interregional coordination of transfer ratings, the simulation of OASIS, and reliability assessment for interconnected grids. Environmental constraints on generator dispatch are also likely to require regional coordination. A new type of 'seams' issues will arise from the fact that air quality regions, global emissions transport, and control areas/RTOs are unlikely to have the same boundaries, resulting in potentially overlapping and possibly conflicting regions for emissions and environmental analyses. There is ongoing interest in PSERC for designing optimal electricity markets to minimize the inefficiencies introduced by seams and to encourage investment on a wide-area basis. Climate change issues and environmental restrictions are likely to add more complexity to optimal market design and will require continuing research in this area.

Interregional issues also are relevant for projects relying upon wide-area data. For example, one PSERC project recognized that an advanced state estimator would necessarily rely upon access to measurements and data that belong to more than one company. For environmental issues, the power industry will also be confronted with the need to assimilate data from more than one company.

8.5 Changing Weather Patterns

Industry response to extreme and changing weather patterns is a fifth theme. Projects in this area have addressed weather-related stress on system components, and analyses of flashover, corona discharge, and line sages. There has also been work on developing online tools to assess the health of substation equipment and predict cascading outages. This area of research may become more important as a result of increased stress on the system induced by climate change.

8.6 Market Rules and Behavior

A sixth category of projects focuses on electricity markets. Projects have focused on the high-level design of market mechanisms for competitive electricity markets, including competitive bidding, strategic behavior, financial instruments, rate structures, and new planning and risk management tools. Projects have addressed long-term issues such as designing investment signals to ensure transmission adequacy, including optimal prices for transmission rights and allowing credits for participants that improve reliability and minimize risk over the long run. A number of projects have examined optimal bidding strategies, looking at multiperiod electricity markets with uncertainty, and developing a comprehensive framework for the analysis and formulation of bids. With respect to climate change issues, emissions restrictions from generators will introduce an additional set of constraints into bidding strategies and may affect the ability of different players to exercise market power. There may be a need to integrate pollutant-emissions permits into market structures and trading regimes, as well as to analyze and minimize the effect of the subsequent generator restrictions on system operations.

A recent project addressed public versus private goods with respect to reliability and electric power. The thesis that traditional power system optimization tools fail to adequately define the economic objective with respect to public good of reliability is applicable to the public good that is represented by the environment. Demand response, an element typically missing from electricity markets, has also been addressed in PSERC projects and could be a significant element of an industry strategy to reduce pollutant emissions. Overall, PSERC researchers are well qualified to design and analyze market structures and rules that will evolve in response to changing emissions regulations.

8.7 Integrating New Technologies

The final category of PSERC projects discussed in this paper is that of integrating new technologies into the power system. These projects have included new control technologies and advances in sensors, measurement technology, and automation. Environmental constraints and regulations are likely to introduce additional controls, sensors, and measurement devices whose effects on system operation and control will need to be understood. PSERC has pursued projects that analyze the system integration of distributed generation including fuel cells, wind power, and distributed storage. PSERC has also supported projects in the analysis of control and protection of microgrids, and in direct load control and load management. Projects such as these could be readily expanded to include an analysis of the environmental benefits and costs of these technologies.

8.8 Summary

Since its inception, PSERC has focused significant research effort on changes and impacts brought about by deregulation and industry restructuring, as well as challenges from technological advances. The industry is now confronted by similar widespread impacts brought about by climate change and environmental regulations. This appendix highlights the core competencies of PSERC members and how these abilities could be applied to address the current industry challenge of climate change-power industry interactions.