Key Technical Challenges for the Electric Power Industry and Climate Change

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***Abstract*—This paper, prepared by the Climate Change Technology Subcommittee, a subcommittee of the Power and Energy Society Energy Development and Power Generation Committee, identifies key technical issues facing the electric power industry, related to global climate change. The technical challenges arise from: 1) impacts on system operating strategies, configuration, and expansion plans of emission-reducing technologies; 2) power infrastructure response to extreme weather events; 3) effects of government policies including an expanded use of renewable and alternative energy technologies; and 4) impacts of market rules on power system operation. Possible lessons from other industries' responses to climate change are explored.**

***Index Terms*—Alternative technologies, electric power research, extreme weather, global climate change, government policy.**

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I. INTRODUCTION

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 (GHGs) 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% of the overall U.S. contribution, and 38% of this amount is derived from the electric power sector [1].

Though the ultimate extent of changes brought by climate change is uncertain, there is scientific consensus that GHGs will cause climate change through this century. This paper identifies key technical challenges to be met as the power industry confronts and is confronted by events caused by climate change. The main sections of this paper frame the scope of these technical challenges and offer a common understanding from which subsequent technical and policy discussions can proceed.

A. Organization of the Paper

Each section of this paper draws upon current literature and presents key technical issues facing the power industry and to be resolved, as identified by the IEEE Power and Energy Society Climate Change Technology Subcommittee in collaboration with the Power Systems Engineering Research Center (PSERC) [2]. Section II discusses the interaction between the production of GHGs and the production, consumption, and delivery of electricity. Section III discusses extreme weather statistics and events, and the potential impact on power system blackouts and component failures. Issues around U.S. federal and state policies on climate change, to the extent that they affect the electric power industry, are identified in Section IV, and Section V continues this topic with electricity market issues that relate to climate change. Section VI compares long-range planning in electric power and other industries with respect to climate change. Section VII concludes.

II. EMISSIONS REDUCING TECHNOLOGIES AND TRANSMISSION SYSTEM EXPANSION

This section defines the interaction between the production of GHGs and the production of electricity, including discussions on emission-reducing technologies and likely impacts on the transmission grid of their expanded use.

TABLE I
U.S. CO_2 EMISSIONS FROM THE ELECTRIC POWER SECTOR [3]

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**

A. U.S.' CO_2 Emissions

Table I summarizes U.S. CO_2 emissions from the electric power sector in the year 2005, demonstrating that coal generation is responsible for approximately 82% of electricity-related CO_2 emissions. The production of 1 megawatt hour (MWh) of electric energy with coal results in the release of approximately 0.97 metric tons of CO_2 (almost a 1 MWh to one metric ton ratio).

The most important conclusion from this table is that coal is responsible for the majority of GHGs, most importantly CO_2, generated by the U.S. electric power sector.

B. Technologies to Reduce GHG Emissions in the U.S.

1) Carbon Capture and Sequestration: The Department of Energy (DOE), through its Carbon Sequestration Program, is pursuing the goal of producing new coal-fired power plants with almost 90% lower CO_2 emissions. Through a process called carbon capture and sequestration (CCS), carbon is captured from these plants and stored in permanent repositories.

There are three technological options to capture CO_2, referred to as postcombustion, precombustion, and oxygen combustion (oxycombustion) [4]–[7]. After the CO_2 is captured, it must be transported from the source to the sequestration location. One approach is to build a direct pipeline. Alternatively, new power plants could be constructed near the carbon sink site along with required investment in the transmission infrastructure to deliver the power to the grid.

A final issue is that the carbon must remain sequestered 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 [4] and [8].

In response to the widespread reliance upon coal, there is broad interest in CCS among policy makers and industry. Nationally, there are six CCS regional partnerships: West Coast Regional Carbon Sequestration Partnership, Southwest Regional Partnership on Carbon Sequestration, Big Sky Partnership on Carbon Sequestration, The Plains CO_2 Reduction Partnership, Midwest Geological Sequestration Partnership, and Southeast Regional Carbon Sequestration Partnership. Overviews can be found at [9].

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%–100% to the cost of electricity [9]. In February 2008, the U.S. Department of Energy canceled plans to build the first clean coal generating plant due to the excessive cost of this demonstration project. Focusing on the need to reduce GHG emissions, the Obama administration appears likely to support CCS as one element of a national energy policy [10], [11].

2) Technologies for Reducing SO_x and NO_x: For the reduction of SO_x and NO_x, one alternative is simply to reduce the number of high emissions and increase the number of low-SO_x/NO_x plants, including natural-gas-fired plants that have no SO_2 and low-NO_x emissions. Alternatively, for NO_x reductions, modifications could consist of installing low-NO_x burners or adding postcombustion technology such as selective catalytic, or noncatalytic, reduction equipment [12]. For sulfur dioxide (SO_2), alternatives include switching to low-sulfur fuel and adding flue gas desulphurization to the plants.

3) Dispatchable Generation (Hydropower and 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 U.S. hydroresources that could be economically developed have already been developed, with little, if any, growth in net electric energy production from hydropower for decades.

Nuclear energy is the other major dispatchable energy source that is increasingly presented as climate friendly, although mining of uranium does result in CO_2 emissions [13], and there is limited flexibility in dispatching nuclear plants.

4) Wind Energy: While the potential for wind energy is promising, there are several significant issues that need to be considered. One issue is that the wind resource is variable, resulting in the capacity credit for wind typically ranging between 25% and 40%. Improvements in wind speed forecasts will provide better estimates of the hourly availability of wind power [14]–[17]. Energy storage, demand response, and/or backup generation paired with wind are other options for mitigating wind variability [18], [19].

Another significant issue associated with wind is that locations with the strongest wind resources tend to be remote. The transmission grid in the United States was not designed to deliver energy over large distances without reactive power compensation, indicating the need for upgrading the transmission system if it is to support significant wind power.

5) Other Alternative Technologies: Solar energy, though renewable and nonpolluting, is a time-varying resource, and therefore, raises concerns similar to wind power technologies. Another possible source of energy with low GHG emissions is geothermal energy, which harvests geothermal hot water or steam reservoirs deep in the earth. A third source of renewable energy is the energy of ocean waves used to drive linear generators or pumps connected to a generator.

6) Electric Vehicles: Plug-in hybrid and electric vehicles are a technology targeted as a solution to the transportation sector's need to reduce GHG emissions. Widespread use of electric vehicles would serve to transfer the production of these emissions from the transportation sector to the electric power sector. Key issues include identifying which generating technologies would be used in charging the vehicles, the likely need to reinforce the transmission and distribution systems 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.

7) 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 topic is discussed further in Section V.

C. Impact of GHG Reduction on the Transmission Grid

The technologies that help reduce GHGs often present additional challenges. One of the most noticeable is the direct impact on the transmission grid. Many of these technologies will be located in remote locations with the result that any expansion in the utilization of these technologies will require the construction of new transmission lines.

1) Microgrids: One alternative to expanding the high-voltage transmission grid is the implementation of microgrids. Microgrids are a cluster of power sources, storage systems, and loads that can be controlled independently of the transmission operator. The most notable of these proposed approaches is the Consortium for Electric Reliability Technology Solutions (CERTS) Microgrid Concept [20]. 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. Currently, this microgrid concept is under research and is in the process of validation on a test bed [21].

2) Regional Transmission Grids: For most of the past decades, transmission planning in the United States has been done to satisfy the local requirements of an area and in accordance with the North American Electric Reliability Corporation regulations. In recent years, with restructuring and deregulation efforts, the U.S. Federal Energy Regulatory Commission through Orders 2000 and 890 has placed the responsibility for transmission planning on regional transmission organizations (RTOs) [22]. This regionalizes transmission planning, with the requirement that any new transmission expansion needs the approval of the RTO for that region.

D. Key Technical Challenges

1) Researching the most cost-effective CCS technologies and develop policies and/or financial instruments to clarify who will bear the costs.
2) Analyzing the impact of an expansion of nuclear energy, in terms of impacts on the transmission system and power system operation, and in GHG reductions.
3) Analyzing system impacts and control needs of a significant penetration of large, remote wind farms.
4) Analyzing the effects on system load shape, transmission system expansion, system dispatch, and new control needs in response to an increased use of electric vehicles.
5) Clarifying and defining the objective of transmission planning in the new low-carbon regime.

III. Extreme Weather, Blackouts, and Component Failures

Electric power systems have been designed during periods of relatively stable weather and loading patterns. 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. This section evaluates 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 may be found in [23].

A. Extreme Weather

Over the next 20 years, the average global surface temperature is expected to rise about 0.2 °C per decade [24]. Over the next 100 years, the average global surface temperature is expected to rise between 0.2 and 0.4 °C per decade, depending on the human response to climate change [24]. This slow average temperature increase is likely to have a slight direct impact on power systems. The more important issue is the increase in the variability of temperature, precipitation, and other weather extremes.

The IPCC 2007 report [24] identifies the following trends and expects them to continue for the next 100 years, with the likelihood of these future trends exceeding 90%: 1) warmer and more frequent hot days and nights, and more frequent heat waves; 2) increased proportion or frequency of heavy precipitation; and 3) fewer cold days and nights. Also predicted with likelihood greater than 66% are changes in hurricane intensity, i.e., 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 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. If extreme weather changes occur on a timescale slower than decades, then the power system can adapt to the extreme weather changes by designing 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.

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.

Extremes of weather also make it more likely that generation sources are unavailable. For example, many types of generation, including wind generation, may be shut down when high winds are experienced or forecast. 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 vulnerable areas.

Changes in precipitation and water runoff would affect hydroenergy resources and scheduling. 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 on the volume of runoff [23].

Climate change is also 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 and subsequent wildfires directly dries other fuels, leaving forests of healthy, living trees that are more vulnerable to crown fires [25]. Increased fire activity could have significant repercussions for the transmission system infrastructure.

B. *Extreme Loading of the 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. These conditions may contribute to deterioration of dielectric materials, operating mechanisms, supporting structures, and cooling/insulating liquids. 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 United States will affect loading patterns significantly, particularly in the West and South. Two issues need to be considered: 1) population increases in the areas most affected by climate change put additional stress on the system and 2) population increases in areas with high risk for weather-related disasters bring a new dimension to planning for emergency electricity service restoration.

C. *Estimating the Effect on Blackouts*

Estimating overall blackout risk is an emerging topic, and it may become feasible to estimate the effects of climate change on overall reliability [26]. 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.

D. *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, incremental strategies for making improvements are more likely and 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 and more complex techniques for estimating the combined impacts of climate and load extremes.

E. *Key Technical Challenges*

1) Using predictions of regional climate change to estimate the rate of change of power system design parameters.
2) Investigating robust monitoring and control techniques for harsh weather and increased electrical demand.
3) Combining climate predictions of extreme weather with emerging blackout risk assessment.
4) Developing methods for improving system restoration in case of natural disasters.

IV. U.S. Federal and State Government Policies

A. *Federal Policies*

The first U.S. federal actions related to GHG emissions came in the 1990 Clean Air Act, and the Energy Policy Act of 1992 (Title XVI, Global Climate Change) [27], [28]. The December 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC) 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% 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 [29].

The presidential administrations following 1992 have relied on voluntary limits to CO_2 emissions, and no direct federal limits have been established. More than 20 bills that would impose mandatory limits on GHGs have been introduced in the 110th Congress, which convened on January 4, 2007. The Obama administration is currently promoting a cap-and-trade program, along with emphasis on renewables such as wind, solar, and cellulosic biomass, energy efficiency, and CCS for coal plants [10], [11].

B. State 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 are 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 CO_2 emissions" [30]. RGGI is a mandatory cap-and-trade program with emissions trading.

A second regional initiative was announced by the Governors of Arizona, California, New Mexico, Oregon, and Washington in February 2007 [31]. This initiative will set a regional goal for GHG emission reduction. It is designed with a regional emissions market and monitoring program to cover multiple sectors, with implementation in Summer 2008. Additional bills are continuously considered in various state legislatures, and the list of states with mandatory GHG reduction programs is likely to continue growing. At a local level, the U.S. Conference of Mayors Climate Protection Agreement highlights the support of close to 700 mayors in binding their cities to the Kyoto Protocol targets [10], [32].

1) California Assembly Bill 32 (AB32): The State of California is the largest contributor of GHGs in the nation, and the 12th largest in the world, with annual emissions comparable to those of Australia [33]. While RGGI addresses only electric power generators, the California Global Warming Solutions Act of 2006 (AB 32) caps GHG emissions from all sources. AB32 was approved by the Governor and filed with the Secretary of State in September 2006 [34]. 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% below 1990 levels. 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.

C. Key Technical Challenges

1) Analyzing the effect of system operations from changing dispatch patterns that result from production caps and changes in merit order as a result of emissions regulations.
2) Analyzing the impact on both existing generating plants and the power system from possible government regulations constraining the dispatch of specific types of generators.
3) Analyzing 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.
4) Analyzing the effect of bills such as California's AB32 on power system operations.

V. Market Mechanisms in Response to Climate Change

There is widespread consensus regarding the scientific understanding of climate change, with considerably less agreement concerning the appropriate responses. Market mechanisms such as a cap-and-trade policy, carbon taxation, renewables 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.

A. "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. The market created for trading permits allows the specified emissions reduction to be achieved, while ensuring that the reductions are made by those producers who can do so at least cost [35], [36].

A GHG emissions trading market design will be a complex endeavor balancing design elements affecting distribution, efficiency, and overall efficacy of the program. The growing number of GHG markets for auctioning and trading permits, each with significant variations, 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 [37].

B. Carbon Tax

A carbon tax is a tax on sources that emit CO_2 into the atmosphere. There is widespread support for a carbon tax from economists [38] and general support from CEOs of major American corporations for mandating ceilings on carbon emissions [39]. The U.S. Climate Action Partnership from the manufacturing and business communities supports capping GHG emissions at 60%–80% below 2007 levels by the year 2050 [10], [39].

An advantage cited is the transparency of the carbon tax compared with the complex permit allocation process [40]. In January 2007, a Carbon Tax Center was launched to educate and inform policy makers about the benefits of an equitable, rising, carbon tax [41].

C. Demand-Side Response

One way to reduce GHG emissions is to reduce consumption, which could be achieved via conservation and demand response. Examples can be found at: the New York Energy $mart Program [42]; several Electric Reliability Council of Texas (ERCOT) programs [43]; the California Demand Response Business Network [44]; the Community Energy Cooperative [45]; Toronto Hydro's Peaksaver ac program [46]; and critical peak pricing programs in California [47]. The stated energy efficiency targets of the Obama Administration would reduce electricity demand 10%–15% from the projected 2020 levels [10], [11].

D. *Renewables Portfolio Standards*

Renewables portfolio standards (RPS) that mandate a specified megawatt amount or percentage of electricity to originate from a renewable resource are increasingly being adopted by state governments. In a status report on RPS in the United States, Lawrence Berkeley National Laboratory reports that 25 states plus the District of Columbia have passed RPS, that together will include 46% of electrical load nationally [48].

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. 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.

Analyses have found that RPS, when compared to other policies, are likely to be the most effective at lowering GHG emissions [49]. A federal RPS has been considered but not adopted a few times in the U.S. Congress since 2002. This pattern may change as the Obama administration is likely to support a national RPS that requires electric utilities to provide 10% of demand from renewable energy sources by 2012, increasing to 25% by 2025 [11].

E. *Key Technical Challenges*

1) Responding to the risk introduced by uncertainty in climate change and the government policies designed to address climate change
   i) Develop new planning and risk management tools.
   ii) Develop optimal bidding strategies for multiperiod electricity markets with uncertainty in GHG policies and mandates.
2) Identifying potential conflicts and/or inconsistencies between regional cap-and-trade markets, as well as conflicts with renewable portfolio standards and RECs.
3) Analyzing the effect on merit order and short-term unit commitment from cap-and-trade and carbon tax policies.
4) Analyzing the effect on system planning and security of supply from changes in investment decisions due to cap-and-trade and carbon tax policies.
5) Analyzing advantages and disadvantages of possible trading of carbon emissions between sectors, such as could occur between transportation and electric power with widespread use of electric vehicles.
6) Analyzing the effect on system and market operations if demand response becomes more widespread and automated control systems are installed at customer locations.

VI. Long-Range Industry Planning

A. *Electric Power Industry's Long-Range Plans for Adapting to Global Climate Change*

The electric power industry is making long-range plans along several fronts to adapt to global climate change. As introduced previously in this paper, these measures include: 1) demand reduction and conservation; 2) electricity infrastructure efficiency improvements; 3) increased use of renewables (wind, solar, biomass, and biofuel) and distributed generation; 4) renewed interest in nuclear generation; and 5) CO_2 reduction, capture, and sequestration. These measures are generally consistent with the Policy Statement on Energy and the Environment approved by the PES Board of Governors on January 19, 2007.

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: 1) anticipated environmental regulations; 2) opportunity to increase market share or offer a new product; 3) prevention of financial losses; and 4) avoidance of litigation. Monitoring activities in other industries could lead to opportunities for the electric power industry to work with these industries, and also could suggest new actions to be undertaken by the electric power industry.

B. *Other Industries' Long-Range Plans for Adapting to Global Climate Change*

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 and hydrogen-fueled vehicles. This technology presents opportunities and challenges for the electric power industry, as discussed in Section II.

A group of corporations including BP, General Electric, and DuPont, has partnered with environmental organizations to form the U.S. Climate Action Partnership in an effort to create a carbon emissions cap and/or trading program in the United States [50].

2) 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" [51]. 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 [51].

3) Avoiding 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" [52].

C. Key Technical Challenges

1) Anticipating coordination with other industries, analyze the efficiencies of market structures where carbon trading is allowed within the electric power industry and between the electric power industry and other GHG-producing industries.
2) Learning from other industries' risk analysis, evaluate the consequences on system stability and loss of responsiveness caused by the reduction in hydrogeneration resulting from less rainfall.

VII. Conclusion

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 portion. International attention is focused on developing mechanisms to reduce GHG emissions from electric power generation. Parallel efforts must be pursued to ensure that the power system is modernized as necessary in order to ensure that system reliability is not compromised either by changes in weather or by the efforts to reduce emissions through introducing new technologies or new government policies.

The objective of this paper is to facilitate continued discussion of power system–climate change interactions. To this end, this paper identifies key issues relating to the interactions between the electric power industry and global climate change—issues that will not be resolved quickly, and that require sustained attention if they are to be resolved successfully.

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