Future Grid: The Environment

Future Grid Initiative White Paper

Power Systems Engineering Research Center

Empowering Minds to Engineer
the Future Electric Energy System

Future Grid: The Environment

The Future Grid to Enable Sustainable Energy Systems
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Executive Summary

Three critical environmental issues face the electric energy industry: mitigation of greenhouse gas emissions, adapting the industry to changing global and regional climates, and the availability of water for electric generation. The issues are complex, with significant interactions among costs to the industry and its customers; benefits to the industry, its customers, and society; and reliability of the electric supply. Electricity is critical to the national and world economies, so anything that affects the electric supply industry also has significant economic effects. Many of the environmental concerns, such as adapting to the effects of climate change, also have very high potential costs if not addressed, and are thus also important to the world's economy.

The issues will be addressed through significant new environmental regulations at the federal and state levels. Some of the regulations will require large investments by the industry in new technologies, some of which are not yet commercially available. The issues of limiting pollutant emissions and shared societal use of water are market externalities that are appropriately addressed through government regulations since they are not intrinsic to markets.

Regulations must be effective, actually addressing the issues. The electric energy supply and delivery system is extremely large and complex and regulations can have unintended or counterproductive consequences. Multiple regulations interact and can also produce unintended results. Careful research and consideration of the environmental needs and the goals of regulations is needed before they are put into place.

A wide range of technologies are available, and others are in development, that will help address the environmental issues presented in this paper. Technologies include:

- Fuel switching from coal to natural gas
- Carbon capture and storage
- Nuclear fission generation
- Renewable technologies
- Energy storage
- Energy efficiency improvements
- Designs that reduce water use by thermal generating stations
- Seawalls
- Asset relocation
- Designs that reduce vulnerability of assets to storms

Some technologies will address multiple issues, while some will address one issue but make others worse. The implications for multiple issues must be considered for each technology, and for combinations of technologies. The costs and reliability implications must also be considered.

Environmental costs and benefits from actions today will occur over a period of decades, so analyses should use appropriate time horizons. Electricity planning should consider life cycle costs and benefits, and must optimize the long-term environmental benefits, electric system reliability, and costs of implementation.

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1 Introduction

The objective of this paper is to present the significant near- and long-term unresolved environmental issues relevant to the electric energy industry, and to summarize the technologies that will help resolve them. The issues are those that the industry will be addressing in the coming years. The issues are complex, with significant interactions among costs to the industry and its customers; benefits to the industry, its customers, and society; and reliability of the electric supply. Electricity is critical to the national and world economies, so anything that affects the electric supply industry also has significant economic effects. Many of the environmental concerns, such as adapting to the effects of climate change, also have very high potential costs if not addressed, and are thus also important to the world's economy.

All the issues presented will have to be addressed by the industry. Some of the issues presented are being addressed in the U.S., some need additional work, and others are not being adequately addressed. Progress has been made on some in other countries. The questions presented are those that must be addressed over the next 5-90 years by the electric energy industry, policymakers, regulators, and researchers.

The industry will face regulations on most of these issues and it is important that those regulations be effective, actually addressing the environmental issues they were intended to. The electric energy supply and delivery system is extremely large and complex and regulations can have unintended or counterproductive consequences. Multiple regulations interact and can also produce unintended results. Careful research and consideration of the environmental needs and the goals of regulations is needed before they are put into place.

2 Environmental Regulation of the U.S. Electric Industry

2.1 History

In understanding possible future environmental regulations it is important to understand existing U.S. regulations, and why those regulations exist. The 18th and 19th century industrial revolution saw an exponential increase in the use of fossil fuels, and produced a corresponding improvement over previous centuries in the living and working conditions and health of a vast number of people.

By the 20th century the concentrations in air and water of the byproducts of burning fossil fuels sometimes reached levels that produced particularly severe health effects in exposed populations. One of the best known examples of this is an October 1948 event in Donora, Pennsylvania. Zinc smelting was the primary industry in Donora at that time. Sulfur dioxide and other pollutants from smelting were concentrated in the city's air for several days by a weather inversion, leaving 20 dead and 6,000 ill. A similar event in December 1952 held high levels of particulate matter from industrial and residential burning of coal over London, resulting in 4,000 deaths.

World economies were prosperous enough that policymakers, responding to these and other events, felt that regulations were needed to reduce the effects of air and water emissions. While the electric energy industry was not involved in either of the previously-mentioned events, the emissions from power generating stations were highly visible to the population, and were also significant portions of total emissions. The industry was thus included in the regulations.

U.S. regulation of emissions by the electric energy industry began in 1948 with the Federal Water Pollution Control Act, commonly known as the Clean Water Act. This act limited discharge of waste into water from most sources, including electric generators. The act was significantly strengthened in 1972.

In the U.S., the Air Pollution Control Act of 1955 began the regulation of airborne emissions from the electric energy industry. The federal act provided $5 million annually for five years for research by the Public Health Service into the effects of emissions and possible ways to limit those effects. The act was renewed in 1960 and 1962, and the first federal Clean Air Act was passed in 1963. The act provided $95 million over a three-year period to state and local governments and air pollution control agencies to conduct research and create control programs for airborne emissions.

The 1967 Air Quality Act established the first national emissions standards for stationary sources. Standards were significantly expanded by the passage of the 1970 Clean Air Act, which established the U.S. Environmental Protection Agency with the charge to establish National Ambient Air Quality Standards for pollutants considered harmful to public health and the environment. These pollutants are:

- Carbon Monoxide (CO)
- Lead (Pb)
- Nitrogen Dioxide (NO_2)

- Ozone (O_3)
- Particulate Matter
- Sulfur Dioxide (SO_2)

New Source Performance Standards strictly regulated emissions of these pollutants by new sources. Standards were also set for hazardous emissions.

The last significant amendment to the Clean Air Act was in 1990, establishing the acid rain program. The program encouraged the use of low-sulfur and alternative fuels as a means of reducing SO_2, one of the main components of acid precipitation.

In 1969, the National Environmental Protection Act (NEPA) was passed directing the executive branch of the federal government to assure the environmental issues were considered in all federal projects. The Act established the Council on Environmental Quality to coordinate the Act's implementation. NEPA applies to all projects that involve federal land and facilities.

2.2 Existing Regulations

Today the Clean Water Act and other federal and state regulations affect almost all water use by electric utilities. Cooling water must be withdrawn and returned to its source in a way that protects fish, other aquatic species, and local watersheds. The discharge into water of a variety of pollutants is limited. In addition, storm water runoff from construction and other activities is regulated in a number of ways.

NEPA requires that any project involving federal land conduct varying levels of environmental assessments depending on the environmental sensitivity of the land involved. Some states have extended the NEPA requirements to include routing of transmission lines, siting of generating stations, and other activities within the states.

The Clean Air Act and amendments today impose limits on nitrogen oxides (NOx), sulfur dioxide (SO_2), and particulate matter, including fly ash. NOx, a byproduct of coal combustion, is classified as a primary pollutant. NOx causes ozone, another primary pollutant. NOx creates airborne particulate matter and with SO_2 causes acid rain. Scrubbers are used to remove NOx emissions from the exhaust streams of coal-fired generating stations. From 2003 to 2008 a federal NOx market-based cap and trade program, the Budget Trading Program, was created to reduce limit NOx emissions from generating stations. That program was replaced in 2009 by the Clean Air Interstate Rule (CAIR) NOx ozone season program.

SO_2 is another byproduct of coal combustion that is classified as a primary pollutant. With NOx, SO_2 causes acid rain, and also creates particulate matter. Flue gas desulfurization removes SO_2 from the exhaust stream of coal-fired generating stations. There is a national cap-and-trade market for SO_2, with a permanent annual cap on SO_2 emissions and annual allowances that are issued and may be bought and sold.

Emissions of particulate matter, which for the electric energy industry includes fly ash and the particulates produced by other primary pollutants, are strictly limited. Precipitators and filters remove particulates from coal combustion exhaust. Before the

1990 acid rain provisions of the Clean Air Act, fly ash could be used in place of Portland cement in concrete. But the high carbon content in fly ash after NOx and SO_2 reductions now requires carbon removal before its use as cement, significantly reducing its economic value.

Electric generators that are included in the acid rain regulations of the 1990 Clean Air Act are required to monitor and report CO_2 emissions to the EPA. State and regional emission caps for CO_2 and other greenhouse gases (GHGs) are in place for electric utilities in 16 U.S. states [1]. In addition, eight more states have GHG emissions targets for which regulations have not yet been developed [2]. Thirty-six states have climate action plans, and two more are in development, outlining the steps the states should take to reduce their contributions to climate change [3]. Sixteen states also provide some kind of financial incentives for carbon capture and storage projects. [4].

Changing climate has many possible effects on the electric energy industry. Examples are raising sea levels flooding coastal generation facilities, more extreme weather damaging transmission infrastructure, and changing rainfall patterns reducing the capability of hydroelectric generation. To address issues like these, eleven states have implemented climate adaptation plans, and twelve more are developing plans, or plan development is recommended in the state's climate action plan [5].

Renewable generation and efficiency improvements are encouraged for a number of reasons, including economic, energy independence, and environmental. Numerous state programs exist for encouraging the development of renewables and energy conservation and efficiency improvements, including public benefit funds, renewable and alternative energy portfolio standards, net metering, green pricing, decoupling policies, renewable energy credit tracking, and energy efficiency resource standards. All but five states have one or more of these in place [6].

2.3 Forthcoming Regulations

There are four new regulations significant to the U.S. electric energy industry that are likely to take effect soon. These regulations address further reductions of SO_2 and NO_x in eastern states limits on heavy metals and acid gases in generator exhaust gases, storage and disposal of byproducts of coal combustion, and restriction of open-cycle cooling systems on generators.

The Cross-State Air Pollution Rule [7] was proposed by the EPA on July 6, 2010 and finalized July 6, 2011. The proposed rule requires further reductions in NOx and SO_2 emissions by electric generators in 26 eastern states. The purpose of this new rule is to reduce ozone and fine particle pollution in other states. On December 30, 2011**, t**he United States Court of Appeals for the D.C. Circuit issued a stay of the rule pending judicial review. EPA enforcement is transitioning back to the Clean Air Interstate Rule while the review proceeds.

On December 21, 2011, the EPA finalized the Mercury and Air Toxics Standards [8], which limits emissions of toxic air pollutants from new and existing coal- and gas-fired electric generators. The pollutants addressed are heavy metals, including mercury, arsenic, chromium, and nickel, and acid gases, which include hydrogen chloride and hydrogen fluoride.

Another new EPA rule [9], proposed June 21, 2010, would for the first time regulate the storage and disposal of coal combustion residuals, the byproducts of coal combustion. Materials regulated include fly ash, bottom ash, boiler slag, and flue gas materials. Public comment ended November 19, 2010, but a final rule has not yet been issued.

A new rule under the Clean Water Act, section 316(b), was issued by the EPA on April 20, 2011 [10]. The purpose of the rule is to protect fish and other aquatic life from hazards associated with being drawn into open-cycle electric generator cooling systems. The proposed rule limits open-cycle cooling on existing generators and requires closed-cycle cooling on new generators. Public comment ended on August 18, 2011, and a final rule is being awaited.

3 Unresolved Environmental Issues Facing the U.S. Electric Energy Industry

Three critical environmental issues face the electric energy industry in the years ahead: mitigation of greenhouse gas emissions, adapting the industry to changing global and regional climates, and the availability of water for electric generation. There are technologies in development, such as carbon capture and storage that directly address some of these issues. There are other technologies, some of which are commercial and some that are not, such as increasing the use of nuclear generation and improved energy efficiency, that are being considered to help address these issues. Some technologies address all three issues, but others may address one or two but be detrimental to others.

These three issues will eventually be addressed through significant new environmental regulations at the federal and state levels. Some of the regulations will require large investments by the industry in new technologies, some of which are not yet commercially available. The issues of limiting pollutant emissions and shared societal use of water are appropriately addressed through government regulations since they are not intrinsic to markets; these issues are referred to as externalities since they are external to market theory.

A variety of state and regional regulations now address these issues. Regulating them on state and regional levels pose problems to the many utilities that operate in more than one state. Differing and conflicting regulations from one state to another require significant resources to track and comply with each state's regulations. For this reason, federal regulations are preferable to state or regional regulations. Many state and regional regulations that exist now are in response to perceived lack of needed action at the federal level.

3.1 Greenhouse Gas Mitigation

In 2009, the electric power sector produced 39.8% of total CO_2 emissions in the U.S. [11]. The industry also uses SF_6, another greenhouse gas, as an insulator in high voltage equipment. While the volume of SF_6 is miniscule compared to CO_2, it has 16,000-22,000 times the global warming effect of CO_2, depending on the time frame considered [12]. Regulations on the use and release of SF_6 will continue to tighten in the future. But because of the volume of CO_2 involved (the U.S. sector emitted 2,160 million metric tons in 2009) and the expense of removing carbon from fuel or exhaust streams or replacing fossil-fired with carbon neutral generators, CO_2 mitigation will be the most costly.

A 2007 PSERC report [13] provided a detailed analysis of how the need to mitigate GHG emissions in response to global climate change will affect the electric energy industry. No federal action has been taken since that report was published. The climate science community, however, is observing that climate change is happening faster than was predicted at the time of that report [14]. The 4th IPCC report [15] used a conservative model for the melting of polar ice because of questions about the ice models available at the time. Recent changes in polar ice have occurred at a much faster rate than the report predicted. In the absence of federal regulations, state and local governments have taken actions outlined in the previous section on existing regulations. Widely differing state, local, and regional regulations, and uncertainty about the form and timing of federal regulations, make it difficult for the industry to know how to plan long-term for GHG mitigation.

Numerous technologies are being considered for reduction of electric industry GHG emissions, and these are discussed in the next section of this paper. Other industries besides electric energy, most notably transportation, will also be required to reduce their CO_2 emissions. In 2009 transportation was responsible for 34.1% of CO_2 emissions in the U.S. [11], just behind the electric energy sector. A growing part of the transportation industry's response is to switch to electric vehicles. While this provides load growth for the electric industry, it also shifts a greater part of the burden of decreasing CO_2 to the industry.

The climate science community is nearly unanimous in its support for federal regulations on all U.S. industries to reduce GHG emissions in the coming years. Actually reducing the emissions of CO_2 from electric generation is a highly complex undertaking because of the size and complexity of the interconnected electric production and delivery system. Technologies and policies that would seemingly produce obvious reductions in emissions may not produce the reductions expected. A substantial amount of research is yet to be done to understand and implement significant CO_2 reductions in the electric energy industry.

3.2 Climate Change Adaptation

The 2007 PSERC report stated well the issue underlying the industry's need to adapt to climate change: "*Electricity assets have been designed on the basis of historic climate data and a period of relatively stable weather"* [13]. Climate change affects these assets in many ways. Some of these effects are already being seen, and the industry needs to move quickly to begin adapting to changing climate, and to form a long-term plan for adaptation.

3.2.1 Higher Average Air and Water Temperatures

The most direct effect of climate change is higher average air and water temperatures. Average global temperature increases of 1-2° C are projected for 2050, and 1.5-5° C by 2100 [15].

Because so much electric load is temperature-dependent, this increase will have a direct effect on energy consumption and peak load patterns. The use of air conditioning for cooling is expected to increase significantly, producing higher summer peak loads and greater total electric energy consumption [16]. Higher overnight temperatures reduce cooling times for transformers and other assets and will produce higher failure rates.

Population migration is expected, especially in response to failures of agricultural areas. This may also prompt increased urbanization, creating additional capacity and reliability challenges for urban utilities, as well as a potential increase in the number of customers unable to pay for their electricity needs.

Ratings of transmission and distribution lines and thermal generating units are dependent on ambient air and cooling water temperatures. Higher temperatures will reduce the capacity to generate and deliver electricity at the same time as demand is increasing.

Snow and ice will melt as temperatures rise. This will initially increase runoff and hydroelectric production. But as long-term snow and ice levels are reduced because of warmer winter months, runoff will decrease and reduce hydro generation availability. The integrity of some structures built on permafrost will be compromised. Production of oil and natural gas in these areas may be reduced.

Research is needed to quantify the scope of increased loads and decreased generation and delivery, and possibly fuel production, capacities due to higher average temperatures. Planning models need to be developed that include these issues. With these models the industry can address the potential capacity and reliability issues involved.

3.2.2 Rising Sea Levels/Land Subsidence

As temperatures rise and existing snow and ice melts, sea levels will rise, and ocean salinity will change. Average sea level increases of between 25 and 50 cm are projected by 2050, and rises of 70-180 cm by 2100 [17]. Such increases place assets located near sea level at risk. Besides being directly affected by water level increase, land subsidence in some areas caused by increased erosion and oil and gas extraction is also becoming more of an issue. Parts of the Louisiana coast, for example, are expected to subside by 30 cm by 2050 [17]. Increased storm surge, resulting from rising sea levels and increased severity and frequency of extreme weather, discussed in the next section, further threatens assets near sea level. The industry needs to identify all potentially affected assets and plan for retirements or retrofits of these assets.

3.2.3 Severe Weather

Climate change is expected to result in more severe weather and extreme weather patterns. Increases are projected in the frequency, severity and duration of wind, including hurricanes, cyclones, and tornadoes, ice, hail, and thunderstorms. For the U.S. Gulf coast, for example, a one in 100 year severe weather event today is projected to become a one in 40 year event by 2100 [18]. These expected changes have many implications for the electric energy supply system.

Wind and ice are the major load components for transmission and distribution line designs. A British Columbia study forecasts that storms will exceed design standards for lines and hardware [19]. Existing designs need to be evaluated and upgraded for increased wind and ice loading, and new designs are needed. Increased lightning activity has direct implications for transmission reliability. An increase in forest fires due to lightning is also projected, threatening assets located in forests. The industry must identify threatened assets and schedule upgrades or replacements as part of long-term planning.

While average global temperature increases are expected to be in single digits, the high and low temperatures associated with the averages are expected to increase. This is a regional phenomenon, with summer high temperatures in some areas expected to increase and winter low temperatures to decrease. Periods of extreme heat or cold are expected to grow longer. Such changes in temperature affect the thermal ratings of generation and delivery assets, and can have reliability effects in the case of extended periods of high temperatures and higher nighttime summer temperatures.

Access to transmission lines for maintenance, especially by helicopter, will be hampered by increased fog and severe weather. Fog will also increase the likelihood of cloud icing and flashover. Severe weather may also affect the overall economy in some regions through reduced growth and reinvestment. Production of fossil fuels, especially by undersea oil and gas platforms and flooding of coal mines, may also be affected. An expected increase in flooding is discussed in the following section.

3.2.4 Changing Precipitation Patterns

Precipitation patterns are projected to change with increasing global temperatures. The changes will vary by region, so each area must be evaluated individually. In some areas higher total rain and snow are expected. Runoff is projected to increase, for example, by up to 40% by 2050 at higher latitudes [15]. This increase will result in more erosion, flooding and mudslides. Trees will fall because of weakened root systems. In some cases lakes will overfill and dam security may be threatened. Corrosion rates will increase on transmission towers, hardware, and conductors. Hydro turbines may be damaged by increased sediment flows.

In other areas, less precipitation is expected. Runoff is projected to decrease by as much as 30% at mid-latitudes by 2050 [15]. Many semi-arid areas, including parts of the western United States, will experience a decrease in water resources due to climate change. Droughts will increase in severity and frequency. In these areas there will be increasing competition for water resources, which will magnify the water issues discussed in the next section.

Climate changes will in some areas affect existing wind and sunlight patterns [20]. Resource availability for wind and solar generation may increase or decrease. Existing wind turbine and solar thermal and PV generator availability will change accordingly. Changes in wind speed, gusts, turbulence, and prevailing direction will increase structural failures of many assets, increase recovery time, and reduce overall reliability.

3.2.5 Changing Vegetation

Changes in climate patterns naturally affect the vegetation that is growing in an area, and can affect growth rates and other characteristics of existing vegetation. This can have a significant effect on crops, resulting in increases or decreases in irrigation loads and population migrations of agricultural personnel out of some areas and into others. Biomass crops will be among those affected, potentially making more or less such crops available, depending on the region.

Asset-related vegetation control will also need to be reassessed. Transmission line rights of way may require more, or less, work to maintain. Transmission and other asset owners will have to adapt to increased or decreased growth rates and new forms of vegetation.

3.2.6 Changes to Insect and Animal Populations

Like vegetation, insect and animal populations will also be affected by climate change. Existing species may proliferate, or be reduced, by climate change. New species will move into previously unpopulated areas and out of others, and their effects on the electric power system will go with them. For example, mountain pine beetles have moved into British Columbia in recent years. The resulting death of pine trees increases forest fire risk. The eventual loss of forested areas alters water flow and hydrologic profiles and can contribute to increased flooding, erosion, and mudslides. Wood supply for poles and other assets may be affected.

Likewise woodpeckers and the tree and pole damage they cause will proliferate in areas where they did not exist before. Changing and migrating populations of squirrels, raccoons, snakes, raptors, and other animals will affect transmission and distribution reliability. Burrowing animals will undermine structures.

3.2.7 Research Needs

Some of the effects described in this section are already occurring, but little information is available for electric industry planning. Research is needed to develop detailed forecasts of each potential affect. These forecasts must then be built into planning models so that the industry can begin the necessary adaptation measures. Financing and rate adjustments will be needed to allow changes to be made before assets are actually affected and reliability degraded.

3.3 **Availability of Water**

Most electric generating technologies use water from external sources in their operation. Water use is considered in two ways. The first is water withdrawal, water that is drawn from sources such as rivers and lakes but is then returned to the source after use. Cooling water for a thermoelectric generator using a once-through cooling system is an example of water withdrawal. The water must be available, usually in large quantities, but the net water removed from the source is much less than what is withdrawn. The water returned to the source is available for other uses or reuse. Figure 1 [21] shows typical water withdrawn from sources by various generation technologies.

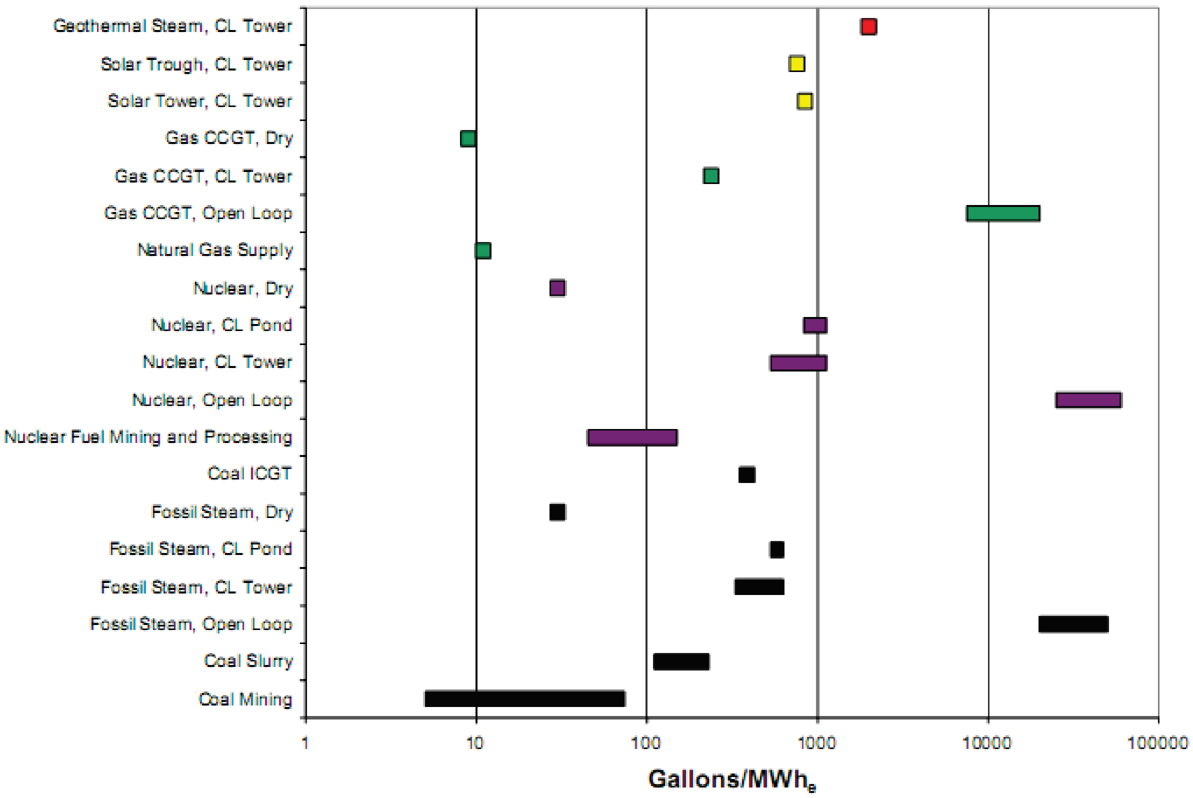


Figure 1: Water Withdrawal for Electricity by Generating Technology [21]

Water consumption is water withdrawn from sources, including groundwater, which evaporates or is otherwise used and is not returned to the source. In a once-through cooling system, the water that evaporates during its use is water consumed by the cooling system. This water is no longer available for any use until it returns as precipitation. Figure 2 [21] shows typical water consumed by various generation technologies.

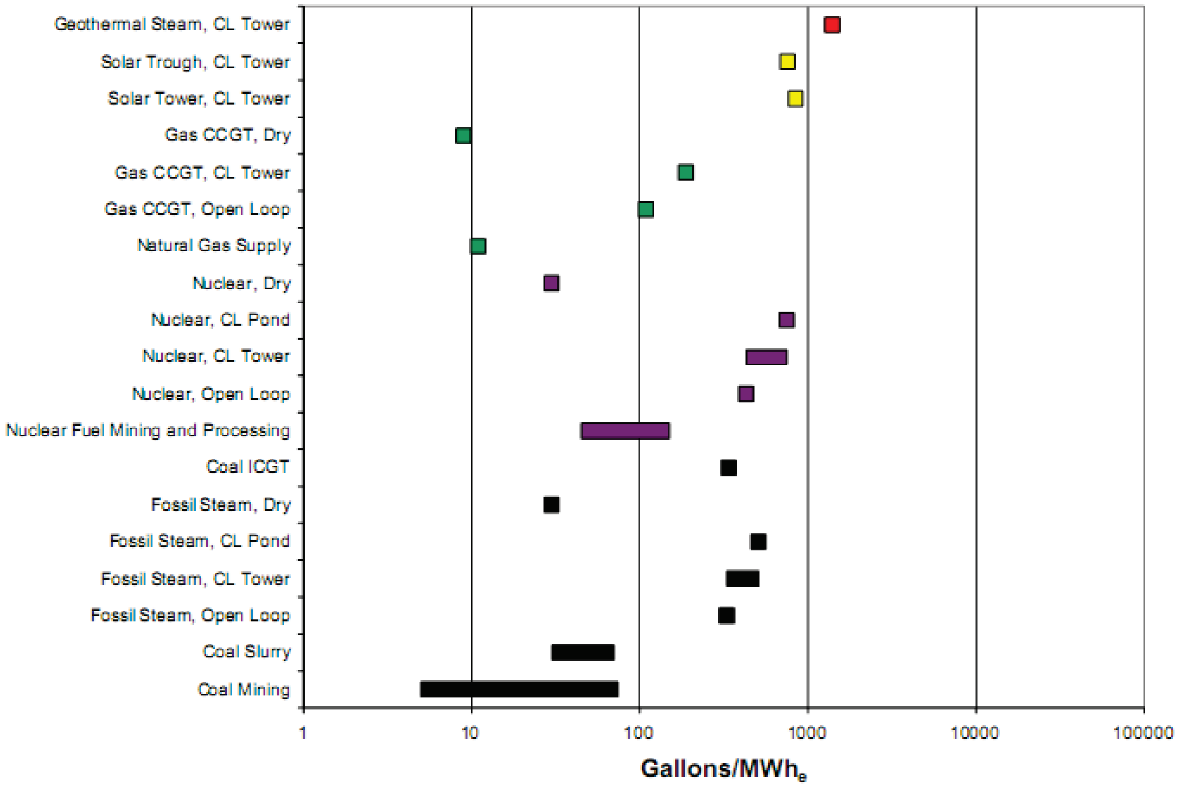
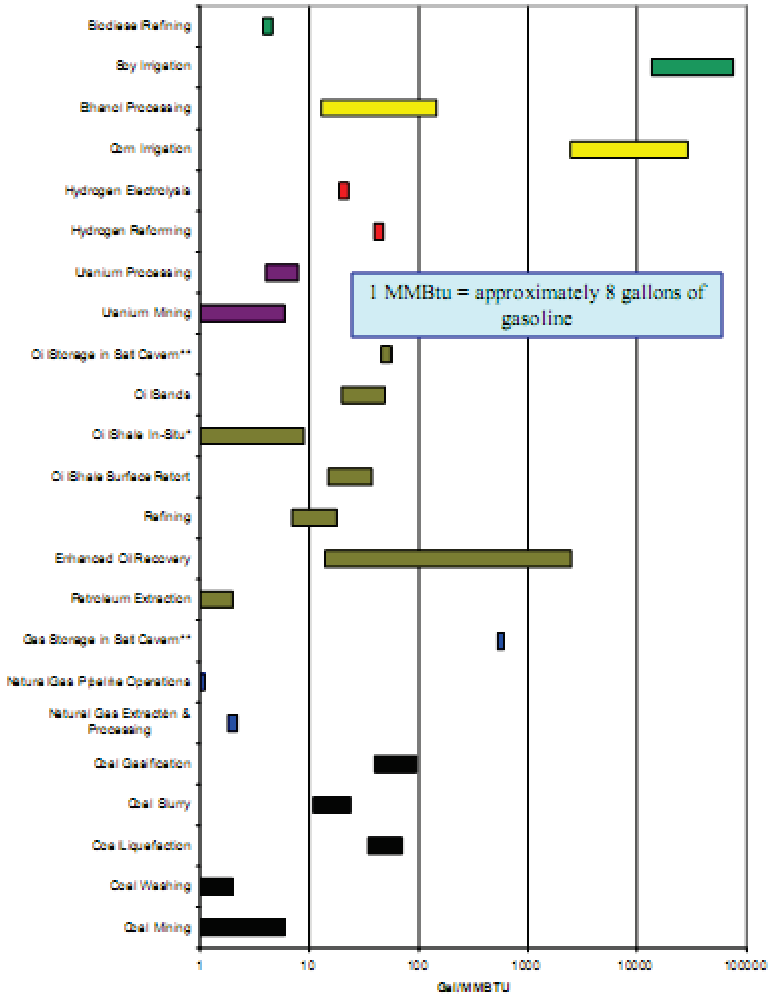


Figure 2: Water Consumption for Electricity by Generating Technology [21]

Note that thermal renewable technologies, solar thermal and geothermal, both withdraw and consume water during operation. Solar photovoltaic (PV) and wind turbines do not use any water when operating. Biomass or waste-fueled generator water withdrawal and consumption are similar to that of fossil-fired generators [21].

Water use in the extraction, production, and transportation of fuel for generation must also be considered. Such water use will often be in a different geographical location than the generator, which complicates the analysis. Figure 3 shows the water use for fuel production in the U.S. [21].



1 MMBtu = approximately 8 gallons of gasoline

Figure 3: Water Consumption for Fuel Extraction, Processing, Storage, and Transport [21]

Hydroelectric generation is directly affected by the availability of water. Climate change, as discussed previously, is expected to change the amount, intensity, and annual schedule of precipitation and snowmelt in many areas. These may affect the long-term availability of hydro capacity, increasing it in some areas, decreasing it in others, and changing the monthly availability in both. For example, hydro generators that rely on glacial melt will first experience an increase in water availability as glaciers melt. That availability will decrease, however, after the glaciers have reached a new, smaller, steady-state [22].

As climate changes, other purposes of the hydroelectric reservoirs, such as flood control, water supply, and recreation, will also be affected, and these needs may in turn affect water availability for electric generation. Evaporation from reservoirs will also increase as average global temperatures increase. Hydro is often very flexible generation and is thus relied on in some areas for peaking energy and ancillary services such as reserves. Its availability for these must also be considered in long-term electricity planning.

As world population increases, demands for water for human consumption, agriculture, and electricity production also increase, and future shortages are expected in some regions of the U.S.. Figure 4 [21] shows the year 2000 breakdown of water withdrawal by sector, and Figure 5 [21] shows water consumption by sector for the year 1995. Figure 6 [21] details for the U.S. by county how much the annual water used in 2005 exceeded the precipitation for the county. The map also shows regional population growth that is projected for 2025. Water deficits are expected to worsen with population growth.

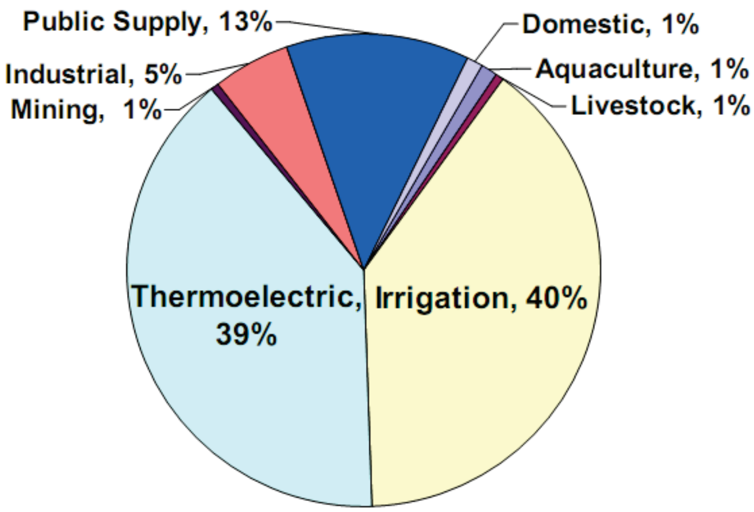


Figure 4: U.S. Freshwater Withdrawal by Sector, 2000 [21]

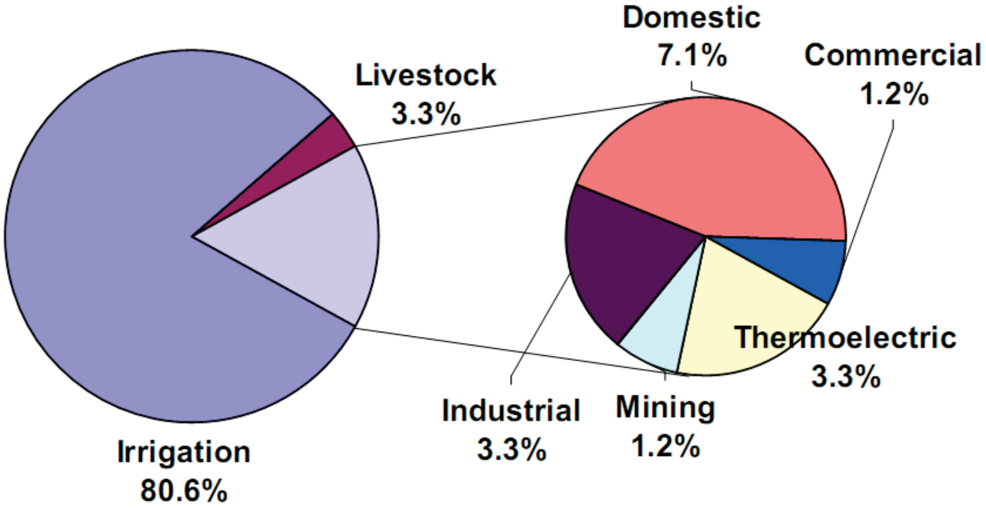


Figure 5: U.S. Freshwater Consumption by Sector, 1995 [21]

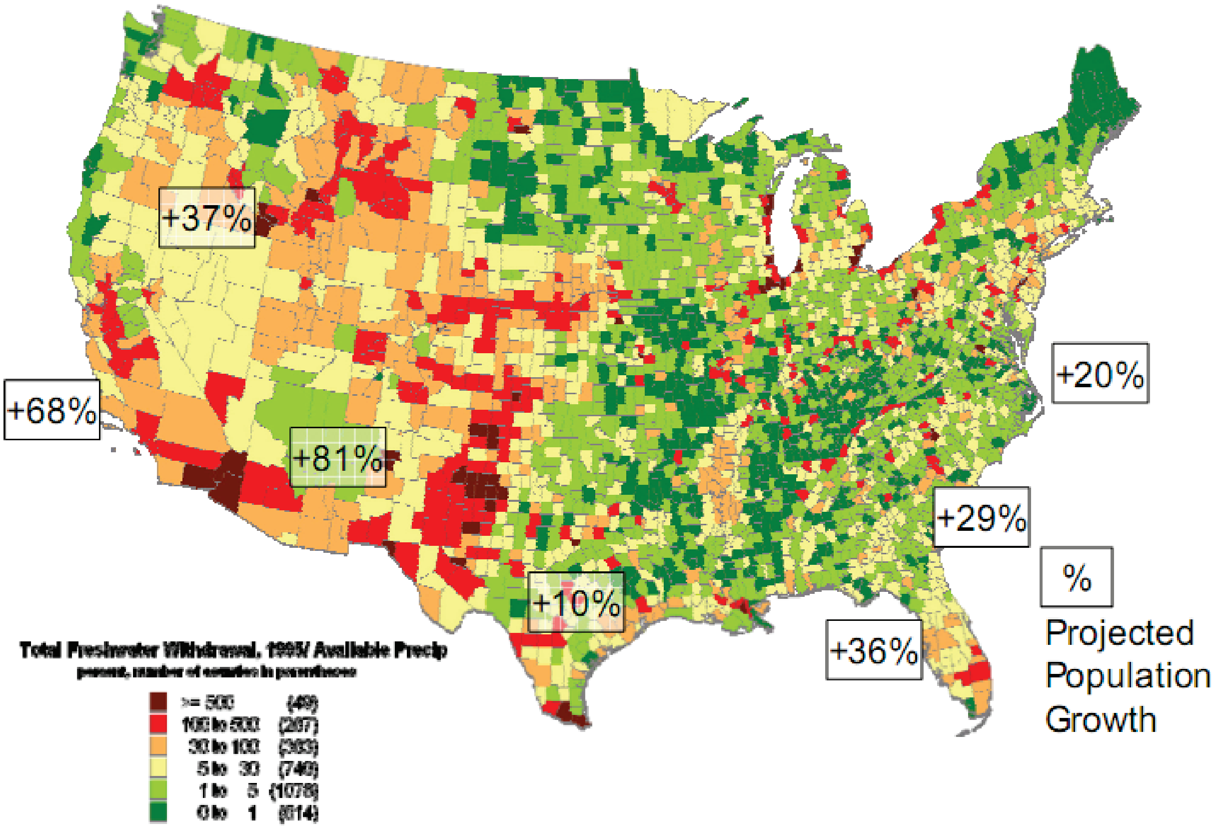


Figure 6: 2005 Water Use Vs. Precipitation and Projected Population Growth by 2025 [21]

The availability of water is regional, with large differences in availability sometimes occurring over relatively small distances. Water availability is also being affected by climate change, as discussed in the previous sections. As the demand for water and electricity increase, providers of electricity must consider how much water will be available for use in electric generation and in the production of fuel for those generators. Generation technologies and fuels that withdraw and consume less water will become more important, and technological improvements to reduce water use by generators and fuel production are needed. Significant research is needed very soon to guide the industry in planning of future generation supply.

4 Technologies to Resolve the Critical Issues

A wide range of technologies are available, and others are in development, that will help address the environmental issues presented in this paper. Some technologies will address multiple issues, while some will address one issue but make others worse. The implications for multiple issues must be considered for each technology, and for combinations of technologies. The costs and reliability implications must also be considered.

To reduce the CO_2 emissions of the electric industry using existing generation, natural gas fired plants can be more heavily loaded, allowing the output of coal fired units to be reduced. Minimum outputs, ramping, and other constraints will set the upper limits of this fuel switching technique, but it can provide some significant reductions in CO_2 emissions. Increased use of natural gas will result in price increases in the fuel, and the environmental effects, including water use, of hydraulic fracturing and other advanced recovery techniques now being used to increase U.S. production of natural gas must be considered.

Another option for CO_2 reduction is to capture, either in the fuel or exhaust streams, and store the carbon from low-cost coal-fired generation before it is released into the atmosphere. Carbon capture and storage (CCS) is being done and is feasible [23], but it will add significantly to the cost of coal-fired generation. The environmental effects of transportation of coal should also be considered in the assessment of future coal use.

Nuclear fission electric generation is an already-mature carbon-neutral technology, and increased use of nuclear generation would reduce CO_2 emissions. Public acceptance of new nuclear plants, however, especially after radiation leaks that resulted from the recent Japanese earthquake, is uncertain [24].

Natural gas, coal, and nuclear generation are all thermal technologies that have significant cooling water requirements. Cooling systems can be designed or modified to reduce water use, and this will be important in water-limited regions.

The use of renewable energy has increased rapidly over the past few years, driven partly by the desire to reduce GHG emissions. Non-thermal renewables offer much lower water requirements as well. Renewable technologies themselves are carbon-neutral, but they require backup generation, usually natural gas, or energy storage to maintain grid reliability, so they are not completely environmentally neutral. Energy storage has the potential to serve as backup for renewables, but storage costs are still high, adding at least $0.05/kWh to the cost of electricity [25]. Storage without renewables may also be useful in reducing emissions.

Improved energy efficiency reduces the amount of electric energy generated, and thus reduces GHG emissions and water use from generation. Efficiency improvements can be made in both the T&D systems and on the consumer side. Demand-side efforts to influence electricity use can also be useful in reducing emissions.

Many electric system assets are threatened by rising sea levels and increased severe weather in the coming decades. Rising sea levels can be addressed by seawalls or other water control technologies, or by relocating assets. Severe weather will in some cases require more robust asset design that can withstand more severe and more frequent storms.

4.1 Fuel Switching

The first reductions in CO_2 emissions will come from fuel switching, redispatching existing generation to increase loading of natural gas-fired generators while decreasing loading of coal-fired resources [26]. Natural gas produces approximately half the CO_2 per kWh produced as coal, so emissions reductions by fuel switching are limited. Depending on the cost of natural gas and coal, a high price on carbon is needed to produce significant reductions in CO_2 emissions. A CO_2 price range of $98-285/ton [27] was found for a simple breakeven price. The minimum cost was reduced to $70/ton using optimal power flow on a simple test system when losses and congestion were included [27].

Fuel switching in the longer-term will involve retirement of coal units, mostly older and less-efficient stations, or in some cases, actually changing the fuel used in an existing plant [28]. These will occur at significantly lower prices CO_2 than those required for redispatch from existing coal to gas. Retired coal units will be replaced with combined-cycle natural gas fired units. Australia, which has historically generated most of its electricity using coal, an abundant resource in the country, plans to rely heavily on fuel switching of this type to reduce its GHG production [29]. One study showed that Western Europe has a potential for 19% reduction in CO_2 emissions by fuel switching [30].

It is important to note that a recent study shows that the reduction in particulates emitted by switching from coal to gas, and methane leakage from natural gas production, may actually offset some of the mitigation produced by reduced CO_2 emissions [31]. Such particulates may also be limited by new regulations in the future because of other adverse environmental effects. More research is needed on this issue.

Increased burning of natural gas for generation may depend on increased use of enhanced recovery techniques. Some of those techniques have significant water requirements, which must be balanced against the availability of water and other potential uses for that water.

4.2 Coal-fired Generation: Carbon Capture and Storage

Because of the abundance and low cost of coal, there is significant interest in technologies that remove and sequester carbon from coal. Technologies being considered and under development include both pre-combustion and post-combustion capture of carbon. In pre-combustion capture, coal is converted to a gas, from which the CO_2 is then removed. The remaining gas, mostly hydrogen, is burned in a combined-cycle generating unit. In post-combustion capture the CO_2 is removed from the exhaust stream of a coal-fired generator. Burning coal in a pure oxygen environment produces an exhaust stream of almost pure CO_2, which is then completely captured.

The captured CO_2 from all processes is then placed into long-term storage. In the U.S. the largest potential for storage is in deep saline formations, in which there is sufficient storage for centuries of CO_2 production [32]. CO_2 is also injected as a liquid into petroleum wells to enhance recovery of petroleum, and most of the CO_2 remains underground in the well.

The longest-running CO_2 sequestration project is the Weyburn-Midale Project in Canada, an enhanced oil recovery project that has been injecting and storing CO_2 underground since 2000 [23]. The project includes a monitoring system designed to assess the long-term ability to keep CO_2 underground [33]. The source of the CO_2 is the Great Plains Synfuels Plant [34] which includes a coal gasification facility. The CO_2 is transported to Weyburn-Midale through an underground pipeline. Inventories of U.S. [35] and international [36] CCS projects are maintained by the U.S. Department of Energy.

Cost estimates for CCS vary significantly. A 2007 report, for example, estimates incremental electricity cost for future commercial CCS to be \$10/MWh [37]. A 2008 report estimated 60 to 90 euros per tonne (\$70 to \$110 per ton) for early demonstration projects, reducing to 30 to 45 euros per tonne (\$35 to \$55 per ton) by 2030 [38]. These translate to incremental costs of approximately \$70 to \$110 /MWh for early projects and \$35 to \$55/MWh by 2030. A 2009 report [39] projects that costs will drop to \$20-50/MWh as CCS use increases. The latest DOE estimate [40] is \$150/ton (about \$150/MWh) now.

4.3 Nuclear Fission Generation

Generating electricity from conventional nuclear fission reactors is a carbon-neutral technology that has been commercial for decades, since the Calder Hall nuclear power station in the UK first began supplying energy in 1956. While no new nuclear generating stations have come online in the U.S. since the 1980s, interest in new reactors has risen recently because of concern about CO_2 emissions from other technologies. But following the 2011 failure and radiation leaks at the Fukushima Daiichi station in Japan, support among the U.S. public for new plants was down to 43% [24].

While many consider the remaining issues of cost, safety, waste management, and proliferation risk to be outweighed by concerns about climate change [41,42], lack of public support for nuclear power remains a source of significant uncertainty in the future of nuclear power [43,44]. Such lack of support often becomes active opposition when a new plant is proposed. The public support issue must be addressed if nuclear is to have any increased role in electric generation in the future of the U.S. energy mix, but the nuclear industry has had almost no success over the years in doing so.

4.4 Renewable Technologies

Most of the policies and regulations regarding sustainability and carbon reduction in the electric energy sector focus on renewable technologies. Among renewable, geothermal and hydroelectric generation are dispatchable and can thus be considered carbon neutral. Both, however, have significant water requirements. Biomass or biofuel generation also use significant water but are dispatchable. Production of the fuels often relies on fossil fuels, so the carbon analysis for such generation is complex [45,46]. Renewable generation that relies on variable resources, including wind, solar, tidal, and wave power, is not fully dispatchable. These technologies can be curtailed while operating, but if the renewable resource is not available, other generation, or storage, must provide the energy needed.

The system effects of high penetrations of renewable generating technologies are the subject of the entire DOE/PSERC Future Grid Initiative [47], of which this paper is one part, and many other studies. The primary unanswered environmental question for renewables is their actual carbon footprint. While the carbon footprint of operating wind and solar generators is very low, it is not completely neutral, because it must be backed up by conventional, usually natural-gas-fired, generators. An example of this is shown in Figure 7 [48]. For a simple test system, dispatched using optimal power flow, the first 100 MW increment of wind capacity results in a reduction in CO_2 emissions of 9.4 tons/MW of installed wind generation. Subsequent addition of wind, because of needed natural gas backup generation, and because of system losses and congestion, result in lower decreases in CO_2 emissions. The actual CO_2 reductions obtained from variable renewable resources are system-dependent, so they vary from one system and one renewable technology to another.

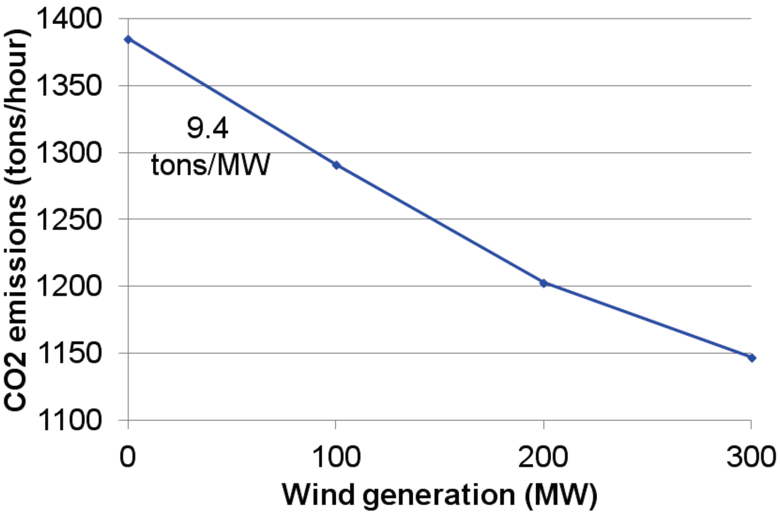


Figure 7: Reductions in Carbon Emissions with Increasing Wind Penetration [48]

The life cycle carbon emissions from various generation technologies are discussed in the life cycle analysis section of this report. But even when total lifecycle values of GHG emissions are considered, renewable resources have very low GHG emissions when compared to fossil fuel technologies.

4.5 Storage

One of the most significant uncertainties faced by planners has been the extent to which the ability to utilize renewable energy resources to their full potential is limited by their variability and uncertainty. Energy storage can counteract these disadvantages, though the optimal way to implement this, or even when it will be necessary, is still open to question.

The conventional use of energy storage to minimize operating costs often shifts load from gas-fired peaking units during the day to base load coal-fired units at night. This produces cost and capacity advantages but also increases CO_2 emissions. Storage optimizations must be revised to include emissions, water use, and other issues. Other questions to be answered relating to the use of energy storage include: what are the most effective storage technologies, should storage be co-located with renewable sources or loads, what is the scale of storage installations (utility or distributed), and finally, what is the optimal policy for maximizing the value of the storage and renewable resources as a system?

4.5.1 Storage Technologies

Energy storage is divided into three categories based on the length of charge/discharge cycles. In the first category, the storage devices are applied for seconds, usually to deal with power quality issues [50]. Storage in the second category is applied for minutes, mostly as bridge power when switching from one source of energy generation to another [50]. The third category of energy storage devices operate on the scale of hours and can be used to supply power for up to 24 hours or longer. Devices in the first and second category are used in power management, while those in the third category are used in energy management. Energy management applications use stored energy to decouple the timing of generation and consumption of electric energy. Power management applications use stored energy to ensure continuity, quality, and proper frequency of delivered power in real time [50]. The selection of the best storage technology depends on the application and is a balance of expense and efficiency. The decision on the type of storage technology will also provide guidance in the determination of the location and scale of the storage.

In balancing renewable energy sources, the consistency of the power source can be maintained by co-locating storage resources with the renewable generators. Conversely, location of storage resources near load centers will reduce potential transmission constraints and more efficiently serve load in the high load region, extracting value not only from balancing wind resources. However, it is important to ensure that storage is dispatched in order to minimize emissions (or maximize renewable use) and not merely as an arbitrage device.

There is significant interest in the question of optimal operation of storage with intermittent resources [51-53], though the optimal dispatch of a storage facility cannot be decoupled from the decision of scale and location. Each of these studies considers different aspects of the same problem, but essentially seeks an optimal strategy for use of a storage facility to maximize value, or minimize deviations from contracted generation of renewables sources. However, many of these studies consider the use of storage to smooth production from a specific wind generation site. Findings of major wind integration studies [54-55] indicate that maximum economic value is extracted from storage facilities when used to provide ancillary services to the grid as a whole. Presumably, the environmental benefits of storage will also be yielded through this application, though this is not specifically considered in the wind integration studies to data.

In preparation for significant wind generation resources entering power systems in the future, more than a dozen wind integration studies have been completed by ISOs across North America The general finding is that storage is not needed at low penetrations, but as penetrations reach and exceed 20%, some combination of additional resources, new generation, transmission, storage, and responsive demand, will be essential to maintaining grid stability. In [50], conclusions indicate that the use of storage with existing levels of reserves provides superior results at 33% penetration, as compared to increasing available reserves. There is currently much interest in the application of storage technologies to assist in the reduction of environmental impacts of electricity generation, but there has not yet been a decisive or widely applicable finding.

4.6 Energy Efficiency Improvements

Improvements in the efficiency of the delivery and use of electricity are another resource for GHG and water use reductions for the electric industry. Energy conservation is environmentally neutral; a kWh not generated because of conservation or improved efficiency produces a corresponding direct reduction in GHG emissions and water use.

A recent report [56] cited sources that estimate losses in the U.S. electric transmission and distribution systems to be somewhere between 7% and 15%. Another source indicates those losses to have remained fairly constant at around 7% from 1996-2009 [57]. Another way to interpret these numbers is that 7-15% of the GHG emissions and water use from the electric industry in the U.S. goes to losses. Any improvement to T&D efficiency produces a corresponding reduction in environmental effects.

Even more significant reductions in energy use are available on the customer side of the electric energy system. Estimates are that reductions of 30% and more are possible on the customer side [58]. But incentives for the electric industry to promote customer conservation vary. At times the industry would like to reduce customer load, but usually a time shift is used instead of a true reduction. When generation or purchased energy costs are higher than the selling price, utilities prefer to shift load to times of lower-cost generation. This tends to shift generation from natural gas to coal, increasing GHG emissions. True conservation, actually reducing the energy generated, also reduces generator revenues, and thus is less economically favorable to a for-profit company. Public utilities (cooperatives, municipals, federal Power Marketing Administrations) do not have the profit motive so they can consider efficiency/conservation directly with generation options. Government incentives must provide the business case to for-profit utilities considering conservation.

The cost of reduced energy use through conservation can be directly compared with new generation. Supply curves have been developed [58] that estimate actual and marginal costs for conservation. For example, electricity use reductions of 1-3% are available for an average cost of \$25-35/MWh. The marginal cost at this point is \$50/MWh. As expected the cost increases for each additional increment of energy conserved. These curves allow the comparison of customer-side conservation with the cost of additional generation in planning studies. Policymakers and regulators should consider this comparison when formulating environmental policies.

4.7 Demand Response

Historically the power system has been designed and operated assuming load to be independent, with generation and other equipment being controlled to serve this load. Numerous recent changes, including advances in communications and control technologies, the desire to reduce the environment impact of energy use, and difficulty in siting and financing new centralized facilities are resulting in moderate interest by customers and regulatory bodies in making electricity demand responsive to system and market operating conditions. Demand response, when available, could be used to shift load from generation with higher environmental impacts to lower-impact generators. This section discusses some industry initiatives in demand response, current research directions, and identifies questions for further advancing demand response.

Widespread use of demand response has yet to be achieved. However, three general categories of responsive load are well established in the electric power industry. One category is interruptible load in which, for example, system operators have standing agreements and contracts with large industrial customers who agree to curtail energy consumption a limited number of times during a year for a specified MW amount and duration when called upon to do so by system operators. A second category is that of public appeals made by a system operator via radio, television or the internet, requesting customers to cut back on electricity use, for example during heat waves in the summer. A third category is simply that of the natural system response to an imbalance in the supply and demand of electricity for which various appliances and equipment draw less power as frequency or voltage decrease. Another distinct category, relying on more ubiquitous and automated demand response, is the objective of current research, market design and policy efforts, and is the focus of this discussion.

A variety of pilot demand response projects throughout the country have demonstrated that demand response can both be effective and be readily accepted by customers. A project with Baltimore Gas and Electric tested a variety of pricing structures for residential customers with and without enabling technologies in the summer of 2008 [59]. Pricing mechanisms that were tested included dynamic pricing or various forms of rebates, all implemented for peak demand times. During low demand periods, customers remained under the standard BGE pricing. The technologies tested were a switch for air conditioning units and the “energy orb,” a wireless device able to display colors in order to indicate changing prices. Results of this study indicate the customers’ behavior was similar across the different pricing schemes, and in all cases did show a reduction in energy use. The technologies were found to have moderate impact on customer behavior.

In the category of demand response for reliability concerns, the Pacific Northwest National Lab within the U.S. Department of Energy has created the GridWise project [60]. For this project, researchers developed circuit boards to be retrofitted into existing home appliances, enabling these appliances to respond automatically to signals from the system operator, for example to help stabilize frequency. Tests have demonstrated expected behavior from the appliances, as well as customer acceptance with respect to participation in pilot projects.

In order to manage interactions with the system operator and participation in electricity markets, load aggregators have the ability to act as an intermediary between the operators and individual customers. Two such companies in this area are Comverge [61] and EnerNoc [62], with mixed experience in promoting the expanded use of demand response throughout ISO and electric utility service territories.

Basic technologies must be installed to enable customers to respond to utility signals and information. A first priority would be universal implementation of advanced metering infrastructure, AMI, which would facilitate the gathering and communication of information required both by power system operators and their customers. A significant oversight in the current AMI technologies unfortunately is the lack of privacy and security protections. Beyond the installation and use of smart meters, technologies that allow remote and probably wireless communication with and control of equipment and appliances at industrial, commercial and residential locations will be required before demand response is widely implemented.

A necessary element for promoting the use of these technologies and the acceptance of demand response programs will be federal and state regulations and regional market structures. Recent activity at the federal level has resulted in FERC Order 719 [63] and Order 745 [64]. A significant issue addressed by the federal government is that of pricing demand response and paying customers essentially for *not* consuming energy.

An idealized market which would avoid this confusion is one in which all consumers would pay a form of dynamic pricing, and decisions to not consume would thus not need to be compensated by the electricity suppliers as consumers would be simply be acting rationally and not buying an expensive product. Until such time as all consumers pay dynamic prices though, there does need to be a mechanism by which those who respond to signals for decreasing demand are in fact rewarded. To this end FERC has proposed a framework in which all demand response is paid the locational marginal price (LMP). Though elegant in its simplicity, this method requires market operators to determine the amount of energy *not consumed*. Additionally, as discussed in [65], such a framework risks paying some customers, such as those operating distributed generation, double. Alternatives to the FERC pricing scheme have been proposed, with one such example from PJM [66] proposing a payment scheme of LMP minus the retail price of energy not consumed (LMP-G; see [66] for further discussion).

Technologies that are required to facilitate responsive demand, such as interval meters, telecommunications, and circuitry for equipment and appliances to respond to price and reliability signals, do exist. These technologies remain in initial development stages though with respect to their ability (or lack thereof) to safeguard the privacy and security of the data that would be gathered and transmitted to operators, load aggregators and utility companies. One immediate research need is thus the development of methods to ensure the privacy and security of customer data. A second area for research is the development of algorithms and tools to compensate both customers and suppliers for the energy actually bought and sold, without relying on paying customers for energy *not consumed*. Research spanning the engineering and social science disciplines is required in order to achieve broad acceptance of the need for demand response, and so achieve widespread participation in these programs. Finally, as an integral part of the evolving smart grid with respect to communications technologies and automating equipment and appliances, demand response initiatives must be integrated into the larger smart grid research programs and development.

The environmental benefits of demand response depend on whether energy consumption is actually reduced, or delayed to a later time. The first is energy conservation, whose environmental benefits are straightforward to analyze. The second, delayed consumption, often shifts the load to different generation using different fuels and water requirements, complicating the analysis.

5 Other Issues

5.1 Electric Vehicles

New environmental policies will affect other industries besides electric generation. Because of transportation's reliance on petroleum fuels, the transportation industry is second after electric energy in production of GHGs in the U.S. [11]. Options for reducing those emissions include switching to electricity as the energy source for transportation. The GHG production is then shifted from transportation to electricity. With the current electric generation mix and transportation fuel efficiency, EVs offer some benefits in GHG reduction. As the GHG output of the electric system is reduced, that benefit can increase significantly. Electric vehicles (EVs) also offer benefits to consumers of lower energy prices and decreased price volatility [67]. Water use comparisons should take a life cycle approach that includes the geographic issues in water availability.

High penetrations of EVs offer a significant new load and also significant challenges to the electric industry. If new generation is to be avoided, most of the vehicle charging will need to be at night, and new smart grid systems to schedule charging will be needed. Increased night loading will have system reliability effects, as reduced overnight loading, which allows component cooling, is part of the conventional electric system design. These and many other issues must be considered as the use of EVs increases.

5.2 Life cycle Planning for Future Environmental Regulations

Long-term planning for the electric energy industry has always been a complex activity. With these significant new environmental issues to be considered, it becomes even more so. Designing the system to optimally address the issues of GHGs, adaptation, and water in the years ahead requires complete understanding of the issues, their interactions, and how industry technologies and techniques actually affect each. Life cycle analysis assesses the environmental impacts and costs of each technology in a complete way, from raw materials needed in construction, through fuel production, delivery, and use, through waste disposal during and at the end of life. Such analysis can help assess the optimal strategies in addressing the complex and often conflicting environmental issues. Long term electric industry planning requires substantial information to achieve further improvements. Life cycle analysis can find opportunities for improvement and potential areas of sustainability impact for the power generation sector.

In general terms, a life cycle analysis consist first of a detailed set of energy and mass balances (the life cycle inventory, LCI) on each specific part of a power generation technology, such as coal mining, transport, preparation, combustion, steam utilization, thermal energy integration, and management of emissions (each referred to as a gate-to-gates, GTG). This produces a cradle (fuel in the ground)-to-electricity profile of each type of technology for a power plant. These GTG LCI may also include the analysis of manufacturing the capital structures of these plants. A similar concept is applied to renewable power plants except that no direct fuel is needed in the LCI. The LCI can then be converted to a life cycle impact assessment, where the same power plant LCI data are converted to categories such as greenhouse gases, stream eutrophication, ecological toxicity, and human health.

The environmental results generated from a life cycle analysis of electrical power generation systems are generally available [68-70] but provide a low granularity comparison of electricity generation from renewable and nonrenewable fuels. However, the field of life cycle analysis has advanced substantially in terms of transparency, analysis of actual components within the power generation plants, and the use of representative LCI to reflect each type of plant with engineering input. In essence, the life cycle analysis helps U.S. understand how the complex system of facilities and technologies necessary to produce electricity for consumers is interconnected. These large scale systems for electric power can then be evaluated for potential improvements (both large and small) that can reduce the cost and impact of the power generation sector.

With the development of new, transparent, and in-depth LCI, a broader variety of areas can be analyzed and used with the industry for electricity generation. Having a complete cradle-to-gate LCI allows the evaluation of the net effect for specific improvements. For example, the substitution of new nano-based epoxies in wind turbines can be understood not just for the blades, but for the whole supply chain, 20 years of maintenance, and alternatives for end-of-life of these materials, all from the LCI information. This expands the ability to see hidden benefits that may occur in different supply chain geographic locations and over long periods of time. Comparison of various improvements to any of the power generation technologies can thus include more complete or net effects.

Another use of life cycle information is to examine investments in energy conservation or demand response at user facilities. While the reduction in energy use (kWh) is direct, the life cycle effects may be different for the same kWh reduction. For example, if energy reduction shifts the time of day, period of year, or trajectory of energy consumption over years, the life cycle can compare these on a scientifically uniform basis of environmental impact. Another significant opportunity in energy use is when the electric energy use make processes more mass efficient, such as use in compressors to allow more selective membrane separation and hence higher chemical product yield. The improved mass yield then reduces the whole supply chain in the life cycle analysis (to get a unit amount of final product) and all the resulting energy (electrical and thermal) is thus reduced. Or using electricity to recycle metals can be evaluated with life cycle to establish the environmental benefits of not manufacturing virgin metals. Thus life cycle puts chemical or material improvement into energy terms for use with power generation life cycle energy as a means to seek larger net improvements.

The electricity profile of electric consumers is being analyzed by utilities to understand loads and identify improvements. New types of sensors are used in this field. These profiles contain important life cycle information that should now be used in the environmental analysis of electric generation. For example, new load profile data can be used to better estimate the overhead or nonprocess energy occurring in different categories of manufacturing facilities. Thus the transparent life cycle effects can be useful in process, material, and overhead reductions in industry (such as manufacturing, services, healthcare, etc.).

Life cycle analysis is also growing to provide the same system-wide connectedness and impact concepts found with environmental data, but in economic [71, 72] and social [73, 74] life cycle technologies. These techniques share with environmental life cycles the principles of evaluating systems using cradle-to-end-of-life boundaries and the evaluation of improvements over the wider boundaries of such life cycles. Power generation sector life cycle analysis can thus also be expanded to include economic and social life cycle information.

Another important attribute of life cycle for electric generators is the link to sustainability programs by these industries. Corporate sustainability is a growing concept in industry with a unique focus on the four pillars: business excellence, innovation, human contribution, and environment [75]. Life cycle is the principal tool for quantifying sustainability improvements in industry. Thus utilities should develop improved life cycle information, but make these consistent with the information needs of sustainability programs of their own or their customers.

Life cycle is also useful in the evaluation of current and future environmental or energy regulations. Such regulations are often focused on parts of the overall system, such as water use in power plants or GHG production. Life cycle analysis provides the understanding of the whole systems effect of such regulations. For example, there is a tradeoff between reduced air emissions and wastes for landfills from such air emission control at a coal-fired power plant, Figure 9 [76]. The life cycle analysis shows nearly a 10 to 20-fold greater net waste mass going to the landfill from air emission control than is actually removed from the air streams. Also the life cycle shows that the next incremental step to lower emissions through control (see maximum mass removal line) has a nearly exponential effect of increasing net waste to landfill. Life cycle analysis captures these broader effects of specific regulations. Grid policies, environmental regulation, and programs for utility growth can all be evaluated in a net effect paradigm with life cycle tools.

Research opportunities in the life cycle field related to electric generation are numerous as technology advances. One area is to couple the net or system opportunities for improvement to new utility real-time data that may be collected at the machine, appliance, or process level. This expands the information beyond each machine to the larger systems life cycle effect. Examples of this would include a manufacturing company or an imaging department of hospital that uses equipment level energy information for making operational changes in order to conserve system energy [77, 78]. Another research area is to project or anticipate the environmental life cycle results of new or growing technologies, such as data centers, not just as black boxes, but in relation to the actual machine level computations [79]. A third research area is in providing quality, transparent LCI and LCI assessment data to utility users. The investment in clear, concise energy life cycle data for electricity and other energy sources (natural gas for steam, fuel for heating, etc.) establishes a scientific source of energy-related LCI information.

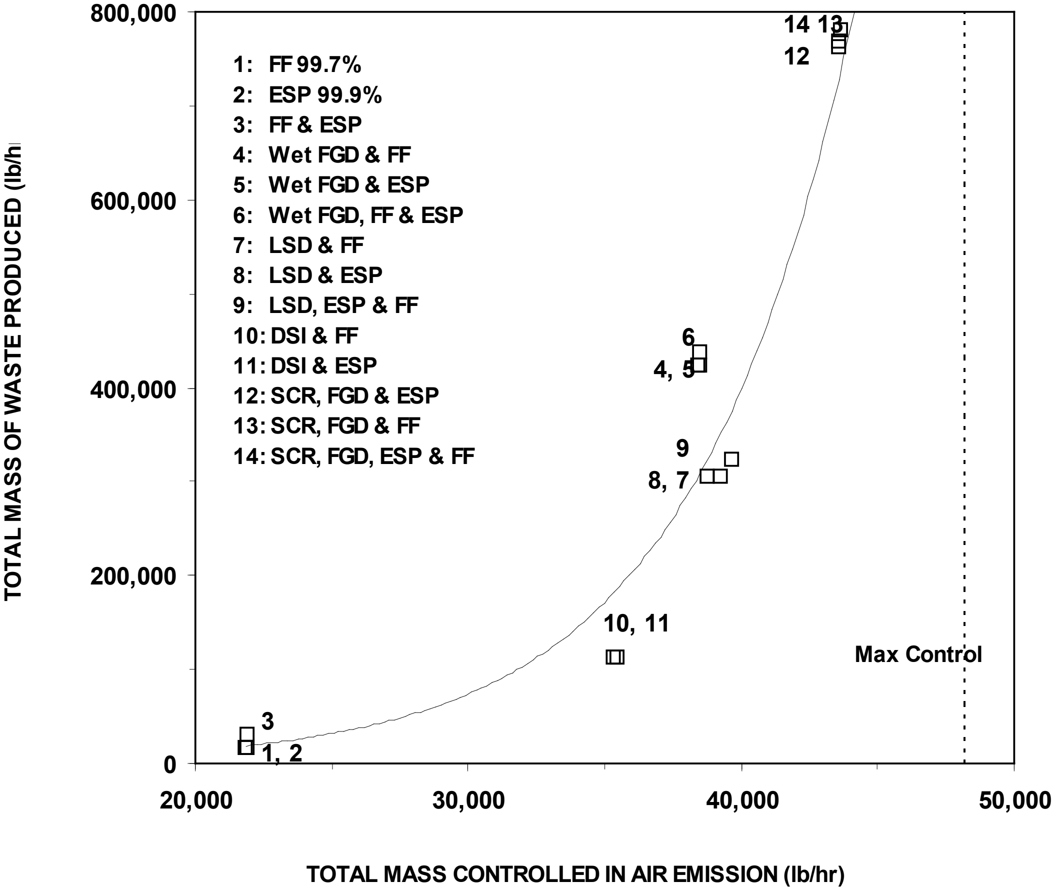


Figure 8: Life Cycle Analysis of Total Multi Media Waste Produced as Environmental Regulations on Air Emission are Adopted at Coal-Fired Power Plant [76]

5.3 Interactions Among and Secondary Effects of Regulations

As discussed in the previous section, the environmental issues and regulations intended to address them have numerous interactions and are dependent on many factors including geography and time. The issues often conflict. A recent PSERC report [80], for example, found that a cap and trade system for CO_2 emissions will significantly affect other emissions, such as SO2 and NOx, and the demand for and price of permits for those emissions. Cap and trade for multiple pollutants can result in extreme price volatility and uncertainty for those markets. Permit prices can also be strongly dependent on weather and other external factors, with high prices and limited permit availability during periods of high demand, or a drought that limits the availability of hydroelectric generation.

Those creating environmental policies and regulations must insure that they are effective in addressing the intended issues, and must understand their effects on other issues. The potential interactions among all the environmental issues are significant and must be considered when designing programs to mitigate them. New regulations and policies must be thoroughly tested before implementation.

6 Conclusions

The electric energy industry in the U.S. has been addressing environmental issues associated with the production and delivery of electricity since the 1940s. Three significant new concerns now face the industry: reductions in the production of greenhouse gases, particularly CO_2; adapting to the changing climate; and the availability of water. Technologies exist to address these issues, and new technologies are being developed. The issues are appropriately addressed through government regulations since they are not intrinsic to markets, and new policies and regulations will be created to address them. At the same time, the use of electric vehicles will increase as the transportation industry also addresses these same environmental issues. High penetrations of electric vehicles present new challenges to the electricity industry that also must be addressed.

The environmental issues, technologies, and regulations all interact and at times conflict; none may be addressed without considering the effects on the others. All will affect the cost of producing and delivering electricity. Electricity and its cost are critical to the U.S. and world economies, so potential costs must be balanced against the benefits of improving, or the costs of not improving, the environment. Environmental costs and benefits from actions today are forecast to occur over a period of decades, so analyses should use appropriate time horizons. Electricity planning should consider life cycle costs and benefits, and must optimize the long-term environmental benefits, electric system reliability, and costs of implementation.

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