

# More Extreme Weather and the U.S. Energy Infrastructure

NATIONAL WILDLIFE FEDERATION 2011



Bob McMillan/FEMA

**Climate change is bringing more extreme weather.** From more severe heat waves and droughts to more intense tropical storms and heavier rainfall events, this intensification will be the most apparent manifestation of climate change for many people in the United States. Weather-related disruptions cost the country \$17 billion a year on average from 1960-2005.<sup>1</sup>

**Power outages are becoming more common.** Major weather-related power outages have increased from 5 to 20 each year in the mid 1990s to 50 to 100 each year during the last five years. While changes in the electric transmission grid and maintenance practices might explain some of this increase, more frequent weather and climate extremes are also likely contributing.

**Oil and gas infrastructure in the Gulf region is at risk as hurricanes intensify.** Climate models project that hurricane wind speed will increase by 2 to 13 percent and rainfall totals by 10 to 31 percent over the next century. The approximately 4,000 offshore oil and natural gas rigs, 31,000 miles of pipeline, and more than 25 onshore oil refineries located in the Gulf region were built to meet the climate conditions of the past, not the future.

**Coal transport across the Midwest and Northeast will face more flooding disruptions.** Heavy rainfall events in these regions have increased by 31 to 67 percent since the 1950s, a trend that will continue this century. About 70 percent of coal is transported by rail lines that must navigate across or along rivers, providing another reason to reduce our reliance on coal.

**Electricity generation in the Southwest will be limited by water shortages.** About 89 percent of electricity in the United States is generated in thermoelectric power plants that require water for cooling. Water demand from the energy sector is projected to increase by 32 percent by 2030, while droughts are expected to become more frequent and severe.

**Future investments must transform the U.S. energy infrastructure to be resilient in the face of more extreme weather and climate.** We recommend that the nation undertake a detailed national climate vulnerability assessment for the energy industry and develop climate adaptation plans to address vulnerabilities. Furthermore, we must begin designing, strategically locating, and making investments in energy systems — such as appropriately sited offshore wind and distributed photovoltaic solar — that are more resilient to severe weather and climate disruptions.



CONFRONTING GLOBAL WARMING

# Report

# Climate Change is Bringing More Extreme Weather

The decade from 2000-2009 was the hottest on record<sup>2</sup> and 2010 tied for the hottest year on record.<sup>3</sup> These global temperature records are not surprising given the steady increase in the atmospheric greenhouse gas carbon dioxide, which hit 390 parts per million (ppm) by the end of 2010.<sup>4</sup> Yet, changes in extreme weather and climate events — such as heat waves, droughts, and heavy precipitation — are the most tangible experience of climate change for many people. Indeed, such extreme events are showing noticeable trends across the United States and promise to become more severe, especially if climate change continues unabated.

## HOTTER SUMMERS AND HEAT WAVES

The United States has warmed by about 2°F over the last 50 years, even more than the warming averaged for the whole planet.<sup>5</sup> Record hot days are more likely and record cold days less likely.<sup>6</sup> Night-time temperatures have shown a particularly striking upward trend, with an approximate doubling of the area in the United States experiencing unusually hot daily minimum temperatures during summer.<sup>7</sup>

With another 4 to 11°F warming projected for the United States over the next century, heat waves will continue to get worse in the coming decades, especially if steps are not taken to reduce greenhouse gas emissions.<sup>8</sup> In fact, the magnitude of emissions will have a significant impact on the number of days over 100°F we will have each year. For example, heat wave days in Chicago could quadruple by the end of the century.<sup>9</sup>

## HURRICANES GETTING STRONGER AS OCEANS WARM

The destructive potential of tropical storms in the North Atlantic has increased by about 50 percent since the 1970s.<sup>10</sup> This increase, which primarily reflects longer storm lifetimes and greater storm intensities, is correlated with an increase of 0.9 to 1.3°F in sea-surface temperatures in the main development area for tropical storms in the North Atlantic.<sup>11</sup> If carbon pollution continues unabated over the next century, tropical sea surface temperatures could increase another 3°F — three times the warming to date.<sup>12</sup> If this happens, tropical storms are likely to have wind speeds that are 2 to 13 percent greater — enough to bump a hurricane up to the next more severe category — and to have 10 to 31 percent more precipitation.<sup>13</sup>

Rising sea level will further compound the risk to coastal communities from hurricanes. If the world follows higher emissions

scenarios, sea level is expected to rise by 3 to 4 feet by 2100.<sup>14</sup> To put this in perspective, a two-foot rise in sea level would mean regular inundation for 2,200 miles of major roads and 900 miles of railroads in Maryland, Virginia, North Carolina and the District of Columbia.<sup>15</sup> When a tropical storm hits, higher sea-level translates into bigger storm surges that can cause flooding further inland. In addition, the heights of big waves — those higher than about 10 feet that are likely to be present during strong storms — have already increased by 20 percent along the eastern United States during hurricane season since the late 1970s,<sup>16</sup> a trend that is likely to continue and pose challenges for offshore infrastructure.

## MORE FLOODING AS HEAVY RAINFALL INCREASES AND SNOWMELT SHIFTS

Climate change is bringing more heavy rainfall events because warmer air can hold more water.<sup>17</sup> For every 1°F





NOAA

warming, atmospheric water vapor has increased by about 3 to 4 percent.<sup>18</sup> For the continental United States, the most intense events have seen an increase in total rainfall of about 20 percent over the last 100 years.<sup>19</sup> These increases are correlated with a corresponding increase in days with heavy streamflow in the medium and large river basins of the Eastern United States.<sup>20</sup> Long periods of heavy rainfall that contribute to major flooding are also becoming more common. The United States has seen a 20 percent increase in the incidence of 90-day intervals with precipitation totals in the top 5 percent of the historical average during the last century.<sup>21</sup> With more moisture in the air, the trend towards increasingly intense precipitation events will continue. In the Midwest and Northeast, big storms that historically would only be seen once every 20 years are projected to happen as much as every 4 to 6 years

by the end of the 21<sup>st</sup> century.<sup>22</sup>

Mountainous areas across western North America and in the Northeast have seen snow melt and peak streamflow happen earlier in the spring. For example, snow melt discharge occurs 5 to 20 days earlier than it did 50 years ago at many observing stations in the Pacific Northwest.<sup>23</sup> This river discharge could be an additional 30 to 40 days earlier by the end of the 21<sup>st</sup> century if carbon pollution is not curbed. Dates of high flow in the Northeast are already 1 to 2 weeks earlier today than in the 1970s.<sup>24</sup> These trends will likely mean water shortages in the summer and fall, and an increased risk of winter and early spring floods. At the same time, winter precipitation is beginning to shift toward more rain instead of snow. The fraction of wintertime precipitation falling as snow has declined by 9 percent since 1949 in the Western United States<sup>25</sup> and by 23 percent in the Northeast.<sup>26</sup> The

increase in winter rainfall will bring increased flooding risk during those months.

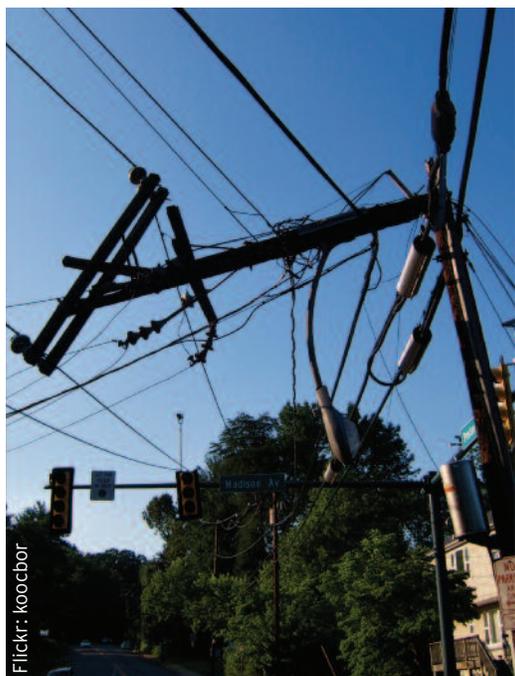
### **WATER SHORTAGES MORE COMMON AND MORE SEVERE**

Naturally arid locations, like the southwestern United States, are prone to drought because they rely on a few rainfall events each year to supply moisture.<sup>27</sup> Future temperature increases and the corresponding increases in evaporation mean that many land areas will become drier in the coming decades, especially if emissions follow a higher scenario.<sup>28</sup> Indeed, climate projections indicate that the Southwest may transition to a more arid climate on a permanent basis over the next century and beyond.<sup>29</sup>

Several climate trends point to an even drier Southwest in the coming decades:

- As global temperatures have increased over the last few decades, so has evaporation, increasing the fraction of land area considered dry from 15 percent to 25 percent of the globe.<sup>30</sup>
- Climate change is modifying the global circulation patterns of the atmosphere, resulting in a pole-ward expansion of dry belts.<sup>31</sup> This expansion is likely causing areas just adjacent to deserts, such as much of the Southwest, to become drier.
- Snow pack has been shrinking, as more precipitation falls as rain instead of snow.<sup>32</sup> At the same time, snow pack is melting earlier in the year.<sup>33</sup> Both of these trends can cause major water shortages in late summer and fall.

# Why So Many Weather-related Power Outages?



Power outages and disturbances are estimated to cost the U.S. economy between \$25 and \$180 billion annually<sup>34</sup> and severe weather is a factor in more than half of the outages in recent years.<sup>35</sup> Indeed, major power outages caused by weather have increased from about 5 to 20 each year in the mid 1990s to about 50 to 100 each year during the last five years, with significant year-to-year variability. These major weather-related outages are almost always caused by an interruption in electricity distribution, rather than in electricity generation. Changes in extreme weather, power transmission infrastructure and maintenance practices, and demographic trends may all be contributing to more frequent power outages.

Strong winds are a major contributor in around 80 percent of major weather-related power outages.<sup>36</sup> Since the early 1990s, insured damages from wind storms have increased by a factor of 4 to 5, today costing the United States an average of \$174 million a year.<sup>37</sup> There has not been a trend in

the annual number of catastrophic wind events over this time period, suggesting that either the wind events are becoming more severe or more property has been developed in places vulnerable to wind damage.

Some of the biggest outages are caused by hurricanes and other tropical storms, which are expected to have stronger winds and more rainfall because of climate change.<sup>38</sup> Millions of customers can lose power during major storms. For example, Hurricane Ike, which made landfall near Galveston, Texas, in September 2008, left 3.9 million customers in nine states without power, many for a week or longer.<sup>39</sup> Downed transmission lines are the prime cause of outages in Hurricane Ike and other major hurricanes, which can

destroy tens of thousands of utility poles.<sup>40</sup> In addition to the impacts on individual customers, lengthy power outages can delay the recovery of other parts of the energy infrastructure in the region, such as refineries, pipelines, and gas processors.<sup>41</sup>

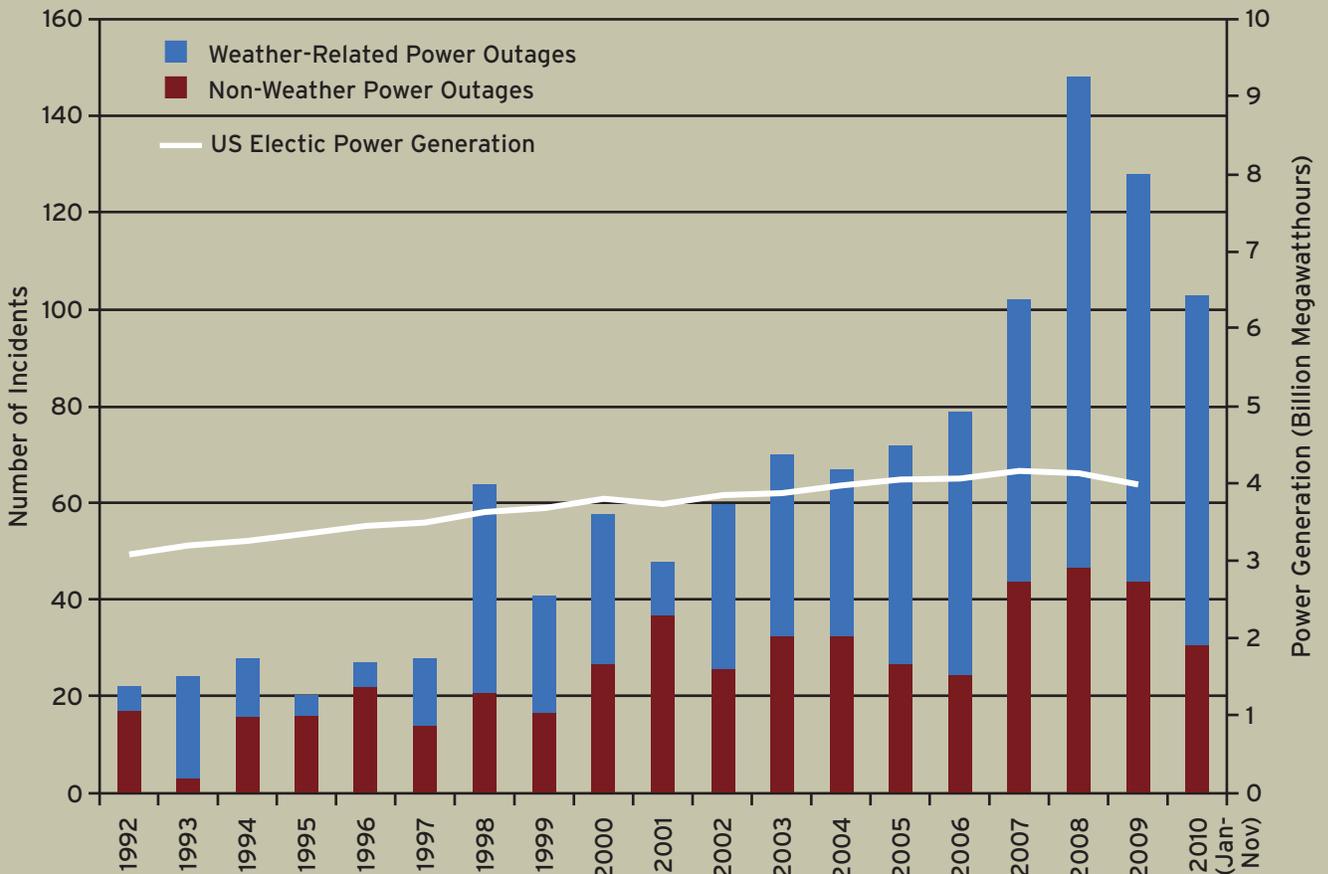
It is more difficult to sort out how climate change is affecting windiness and storms in areas outside the tropics. Existing measurements of wind speed are generally of insufficient spatial coverage and quality to determine a robust trend of extreme wind conditions, and there has been relatively little research in this area. Past measurements of windiness show conflicting trends depending on which data set is analyzed, although it appears that average wind speeds may

## NUCLEAR POWER PLANTS AND EXTREME WEATHER

**The March 2011 nuclear crisis in Japan has raised new concerns about the risks associated with nuclear power plants. This crisis was caused by an earthquake and subsequent tsunami, not by an extreme weather event. Indeed, there have been no weather-related nuclear accidents or releases of radioactive material at any of the 104 U.S. nuclear plants operating today in 31 states.<sup>48</sup> That said, weather and climate events can cause interruptions in the operation of a nuclear plant, with all the related impacts of power outages for the communities that a plant services, as well as for the plant itself. The recent crisis in Japan gives impetus to review safety precautions at U.S. nuclear plants, especially to identify vulnerabilities associated with power outages.**

**The siting, design, and upgrades to nuclear plants already take into account extreme weather events. The International Atomic Energy Agency has issued guidance about how to site and design nuclear plants to be resilient to floods;<sup>49</sup> extreme wind, precipitation, snow pack, temperature and seawater level; and tornadoes, tropical cyclones, and lightning.<sup>50</sup> As an example, the guidance recommends that nuclear facilities plan for a range of flooding impacts, including the failure of emergency power supply systems, damage to structures, and disruptions in the communication and transportation systems that provide access to the plant. As climate change brings more extreme weather conditions, it will be crucial for nuclear plants to regularly update the design standards and upgrade their facilities accordingly.**

## MAJOR ELECTRIC POWER DISRUPTIONS



Large-scale electricity disruptions in the United States and southern Canada have increased significantly since the early 1990s, even as changes in electric power generation have been modest. Most of the increase can be attributed to weather-related outages, which affect 180,000 customers on average, as compared to about 50,000 customers for non-weather incidents (excluding the massive August 2003 blackout).<sup>51</sup> Disruptions in the chart were tabulated by hand from annual reports issued by the North American Electric Reliability Corporation,<sup>52</sup> and include outages and public appeals to reduce electricity consumption. Note that utilities are only required to report large-scale disruptions, for example those affecting at least 50,000 customers for at least 1 hour or a loss of at least 300 MW for at least 15 minutes. This chart does not include outages in local distribution networks, which are much more common but affect fewer people. Note that the 2010 data is preliminary and does not include public appeals.

DATA SOURCES: North American Electric Reliability Corporation,<sup>52</sup> U.S. Energy Information Administration<sup>53</sup>

have declined slightly over the United States since in the last 30 to 50 years.<sup>42</sup>

Future changes in windiness and storms will likely depend on the season and location, as well as how the large-scale circulation of the atmosphere and sea-surface temperatures respond to increasing global temperatures.<sup>43</sup> Current climate models are able to accurately represent strong winds in some locations, but it is still unclear what increasing global temperatures might mean for wind storms in the

United States.<sup>44</sup>

Changes in the power transmission infrastructure and maintenance practices can probably explain some of the increase in weather-related outages, although it is hard to figure how such changes could explain the 10- to 20-fold increase since the early 1990s. Power companies often blame inadequate tree trimming, yet even changes in these practices have not stemmed the increase in weather-related outages.<sup>45</sup> Another potential

problem is the aging transmission infrastructure, which may be more vulnerable to weather-related outages. Indeed annual investments in new construction of transmission facilities have not kept up with increases in demand.<sup>46</sup> At the same time, total electricity generation has increased, though this trend is unlikely to explain the significant increase in outages: the total electricity generated each year in the United States has only increased by 30 percent over this time period.<sup>47</sup>

# Oil and Gas Infrastructure Vulnerable to Tropical Storms

About 30 percent of the U.S. oil supply and 20 percent of the natural gas supply is produced in the Gulf of Mexico region, an area highly vulnerable to tropical storms and hurricanes.<sup>54</sup> As climate change makes it likely that these storms will become more intense and bring more severe flooding,<sup>55</sup> the billions of dollars worth of infrastructure invested in this region are at risk. This includes some 4,000 offshore oil and gas platforms, 31,000 miles of pipeline,<sup>56</sup> and more than 25 onshore refineries.<sup>57</sup> To make matters worse, much of this infrastructure is aging, making it even more susceptible to failures.<sup>58</sup>

Hurricanes and tropical storms can cause significant disruptions in oil and gas imports and production in the Gulf of Mexico. At a minimum, facilities in the expected path of a storm begin shutdown processes as much as 3 days in advance of a storm's arrival and require 2 to 3 days to power back up once workers are able to return.<sup>59</sup> If the facilities are damaged, it can take weeks to months to return to operation. In fact, 6 months after Hurricanes Katrina and Rita, 46 percent of the affected facilities were still shut down.<sup>60</sup> A total of 113 platforms were destroyed and 52 were significantly damaged, while 457 pipelines were damaged

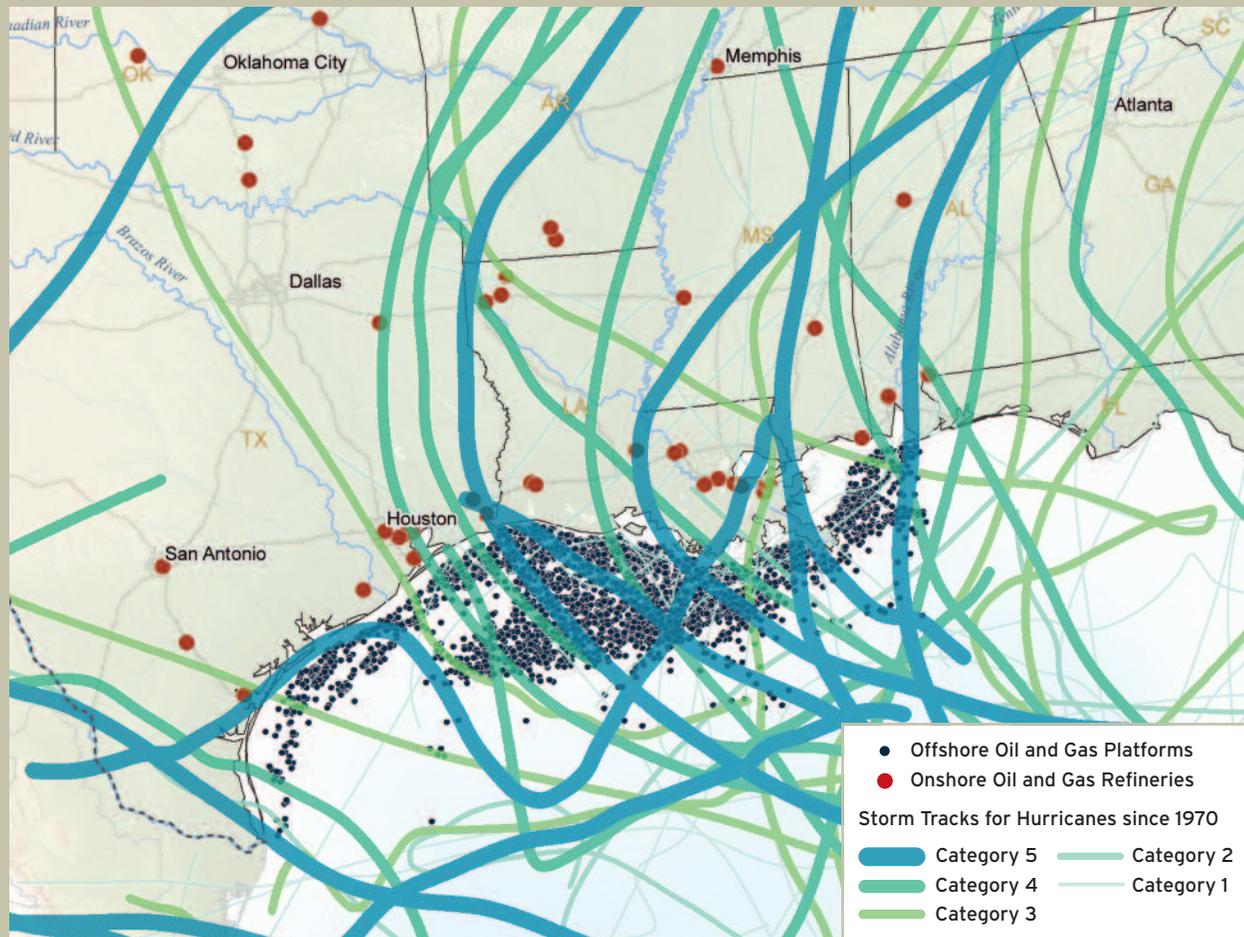
because of these two storms.<sup>61</sup> The energy industry is estimated to have lost \$15 billion in 2005, not including the costs for restoration and recovery.<sup>62</sup>

Oil spills and other hazardous materials releases are an often overlooked impact of hurricanes and tropical storms. Yet, beginning with Hurricane Ivan in 2004, such environmental contamination has become more common.<sup>63</sup> Hurricanes Katrina and Rita caused more than 400 offshore releases, for a combined spill of 30.2 million liters,<sup>64</sup> nearing the 41 million liters released by the Exxon Valdez spill.<sup>65</sup> Most of these releases occurred within 31 miles of the shore,

## HURRICANE DAMAGES TO OIL AND GAS INFRASTRUCTURE<sup>73</sup>

SEVERE WEATHER	IMPACTS ON OIL AND GAS INFRASTRUCTURE
Wind	<ul style="list-style-type: none"> <li>■ Topped processing units or storage facilities</li> <li>■ Dislodged roofs on refinery structures</li> <li>■ Damaged piping and connections between storage and process units</li> <li>■ Power failure or short circuiting, leading to the failure of steam boilers and cooling water towers</li> <li>■ Damaged equipment, pipes, and tank roofs from projectiles, such as tree branches, signs, and rooftops</li> <li>■ Pipelines damaged by dislocation of risers or host platform</li> </ul>
Flooding	<ul style="list-style-type: none"> <li>■ Short circuiting or power failure of electrical equipment (e.g., electrical lines, pumps), causing shut down of steam boilers, cooling towers, pumps, and electrically operated safety control mechanisms</li> <li>■ Hazardous material releases from flooded internal plant drainage systems, compromised containment dikes, storage units damaged by storm surge, or torn pipe connections</li> <li>■ Floating tank roofs can sink or tip, exposing oil on tank tops, vulnerable to fires in the case of lightning</li> </ul>
Waves and subsea mudslides	<ul style="list-style-type: none"> <li>■ Strong surface winds and currents can create significant underwater forces that damage pipelines<sup>74</sup></li> <li>■ Subsea mudslides, initiated by destabilization of shallow water areas in the Mississippi River delta, can destroy compressor platforms<sup>75</sup></li> </ul>
Lightning	<ul style="list-style-type: none"> <li>■ Ignition of spilled oil could cause a fire or explosion</li> </ul>

## OIL AND GAS INFRASTRUCTURE CO-LOCATED WITH HURRICANE PATHS



**The extensive oil and gas infrastructure located in the Gulf of Mexico region is vulnerable to the increasing severity of hurricanes. Since 1970, about two dozen major hurricanes (categories 3-5) have made landfall on the shores of Texas, Louisiana, Mississippi, and Alabama, the four states where both off-shore and on-shore infrastructure is concentrated.**

SOURCES: Bureau of Ocean Energy Management, Regulation, and Enforcement (BOEMRE);<sup>76</sup> U.S. Energy Information Administration (EIA);<sup>57</sup> National Oceanic and Atmospheric Administration<sup>77</sup>

largely affecting facilities built before more stringent design standards went into effect in 1977.<sup>66</sup> In addition, there were 166 onshore releases of petrochemicals and other hazardous materials.<sup>67</sup> For example, about 1,800 homes were affected when an above-ground storage tank was dislodged at the Meraux Murphy Oil Refinery and released about 25,000 barrels of crude oil,<sup>68</sup> resulting in a class action settlement for \$330 million.<sup>69</sup>

Interconnections between the oil and gas industry and other infrastructure —

especially electricity and transportation can delay recovery following major storms. Power outages affect transportation of oil and gas via pipelines, which typically need electricity to pump gas from one compressor platform to the next.<sup>70</sup> Flooding of near-shore roadways can also hinder recovery. About a quarter of roadways in the Gulf Coast region will be inundated if sea level in the region rises by 4 feet,<sup>71</sup> which could reasonably happen by 2100 if carbon pollution continues unabated. Of

particular concern is Louisiana Highway 1, the only highway connecting Port Fourchon, the location of a major offshore oil port, with the rest of the nation.<sup>72</sup>



# Coal Transport Depends on Railway Lines and Barge Routes Vulnerable to Flooding

The nation presently depends on coal for nearly half of all electric power generation.<sup>78</sup> This coal is mined primarily in three areas: (1) a band of western states extending from Montana and North Dakota southward to New Mexico, which supplies 54.5 percent of the nation's coal; (2) Appalachia, which supplies 31.6 percent; and (3) several states in the Midwest and central United States, which supply 13.7 percent.<sup>79</sup> Since the 1970's, the Powder River Basin located in southeast Montana and northeast Wyoming has emerged as the primary coal-producing region because of the lower sulfur content of its coal, which helps power plants comply with sulfur-dioxide emissions limits.<sup>80</sup>

Once mined, coal is typically transported long distances to power plants throughout the nation. About 71 percent of coal is transported by rail, 9 percent by barges, and 11 percent by trucks.<sup>81</sup> The Energy Information Administration (EIA) forecasts that more coal will be transported for longer distances by 2030, especially from western mines, where extraction of coal is projected to increase by 76

percent (an additional 435 million tons a year).<sup>82</sup> The capacity and reliability of the rail infrastructure will be a major determinant of whether these forecasts of increased coal production are realistic.<sup>83</sup> These forecasts also do not account for changes in energy policy, such as a transition from coal to renewable energy sources, which would reduce the reliance on and deterioration of rail, barge, and road infrastructure.

With many rail lines built in river valleys or needing to cross major rivers to reach their destinations, both rail and barge transportation modes can

experience major disruptions due to flooding. The cost of delays and rerouting trains because of flooding can cost in the millions. As climate change increases the frequency of very heavy precipitation events, chances are that such disruptions of coal deliveries will become more common. At the same time, major floods can disrupt mining operations or cause dangerous contamination of surface waters with mining waste.

The coal from the Powder River Basin is transferred primarily eastward on rail lines that traverse major waterways such as the Mississippi and

## HEAVY RAIN IN WYOMING MEANS HIGHER ELECTRICITY PRICES IN ARKANSAS

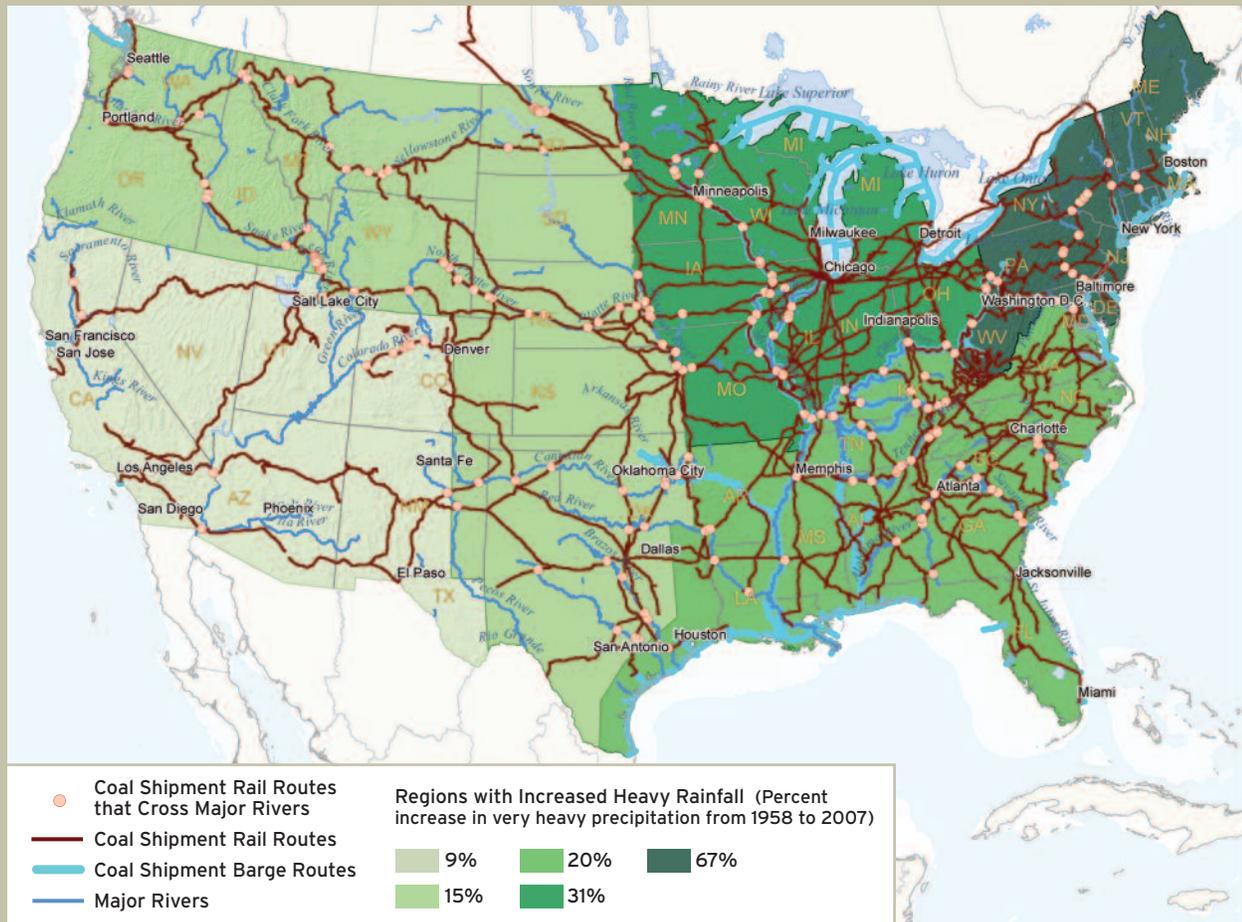
**The "Joint Line" — owned and operated by Burlington Northern Santa Fe Railroad and Union Pacific Railroad — is the only rail line used for coal transportation leading out of the Powder River Basin. This coal transportation rail line extends 103 miles along the southern part of the Basin. Although only traversing a short distance, the Joint Line is the only connection to the major rail railways that take coal to points across the nation.**

In Spring 2005, heavy rain and snow combined with coal dust accumulation to destabilize these tracks which resulted in the derailment of two separate trains. It took two years to repair these tracks.<sup>92</sup> Coal deliveries to power plants across the nation experienced substantial delays. For example, the Electric Cooperative of Arkansas reported that coal deliveries to the state were down 15 percent during the summer and fall of 2005. Electric cooperatives in the area, as well as others, had to find alternative sources of energy, such as coal from Indonesia, to keep up with the electricity demands.<sup>93</sup> The disruptions cost Arkansas millions of dollars, and are estimated to have racked up at least \$228 million nationwide.<sup>94</sup>



Flickr: Templarion

## COAL SHIPMENT ROUTES CO-LOCATED WITH AREAS EXPERIENCING MORE HEAVY RAINFALL



**Increases in extremely heavy rainfall events are presenting increased risk for coal transportation. The northeastern parts of the United States are most vulnerable because heavy rainfall events have increased by 30 to 67 percent there and transportation of coal in this region must accommodate several major river systems. This map shows the rail and barge routes used for coal transportation and highlights the locations where the railroads cross major rivers.**

SOURCES: U.S. Army Corps of Engineers,<sup>90</sup> Federal Railroad Administration,<sup>91</sup> U.S. Global Change Research Program<sup>5</sup>

Missouri Rivers.<sup>84</sup> Flooding has disrupted the rail transportation of coal several times in recent decades, most notably in the 1993 and 2008 Mississippi floods. In 1993, floods from the Missouri and Mississippi river affected over 500 miles which had a profound effect on all modes of transportation including rail.<sup>85</sup> The Association of American Railroads estimates that railroads incurred direct losses of \$131 million, largely associated with destruction of rail

lines, bridges, and signaling equipment, and \$51 million due to re-routing of trains.<sup>86</sup>

Appalachian coal is often transported on barges or rail lines built along riverbeds, which can be prone to flooding and subsequent washing out. For example, barge transportation in 2005 was restricted in part due to flooding.<sup>87</sup> Barge traffic was closed on a 42-mile stretch of the Ohio River when January 2005 floods caused three barges to break free and get

lodged in a dam downstream, costing West Virginia about \$4.5 million a day.<sup>88</sup> In recent decades, barge reliability is tied to the condition and limitations of waterway infrastructure, much of which is aging and in need of refurbishment.<sup>89</sup> Future investments in waterway infrastructure will need to account for changing precipitation and flood regimes associated with climate change, ideally using non-structural approaches that are resilient to extremes.

# Drought and Heat Limit Thermoelectric Power Production

Electricity production and water availability are on a collision course in many parts of the United States, but nowhere as dramatically as in the Southwest. Even ignoring the projected climate impacts on precipitation and drought, water demand from the energy sector is projected to increase by 32 percent by 2030.<sup>95</sup> Much of this increase in water demand is expected in West, where intense competition for freshwater resources is already the norm.<sup>96</sup> Climate change makes the situation even more alarming: the Southwest is expected to experience more frequent and severe droughts under current climate projections.<sup>97</sup> Droughts already have been very costly for the Southwest during the last couple decades.<sup>98</sup>

About 89 percent of electricity in the United States is generated in thermoelectric power plants that require water for cooling.<sup>99</sup> These plants rely on steam turbines, technology that was initially introduced for electric power generation in the 1880s and 1890s.<sup>100</sup> Fuel sources — ranging from coal, oil, and natural gas to nuclear and solar — are used to heat up water, making steam that drives a turbine connected to a generator. Water is also used to cool that steam, returning it to liquid water so that the process can be repeated. Thus, this approach to electricity generation requires significant water inputs, typically from rivers, ground water, or lakes. In 2005, thermoelectric power accounted for 44 percent of all

freshwater withdrawals in the United States, second only to agriculture.<sup>101</sup>

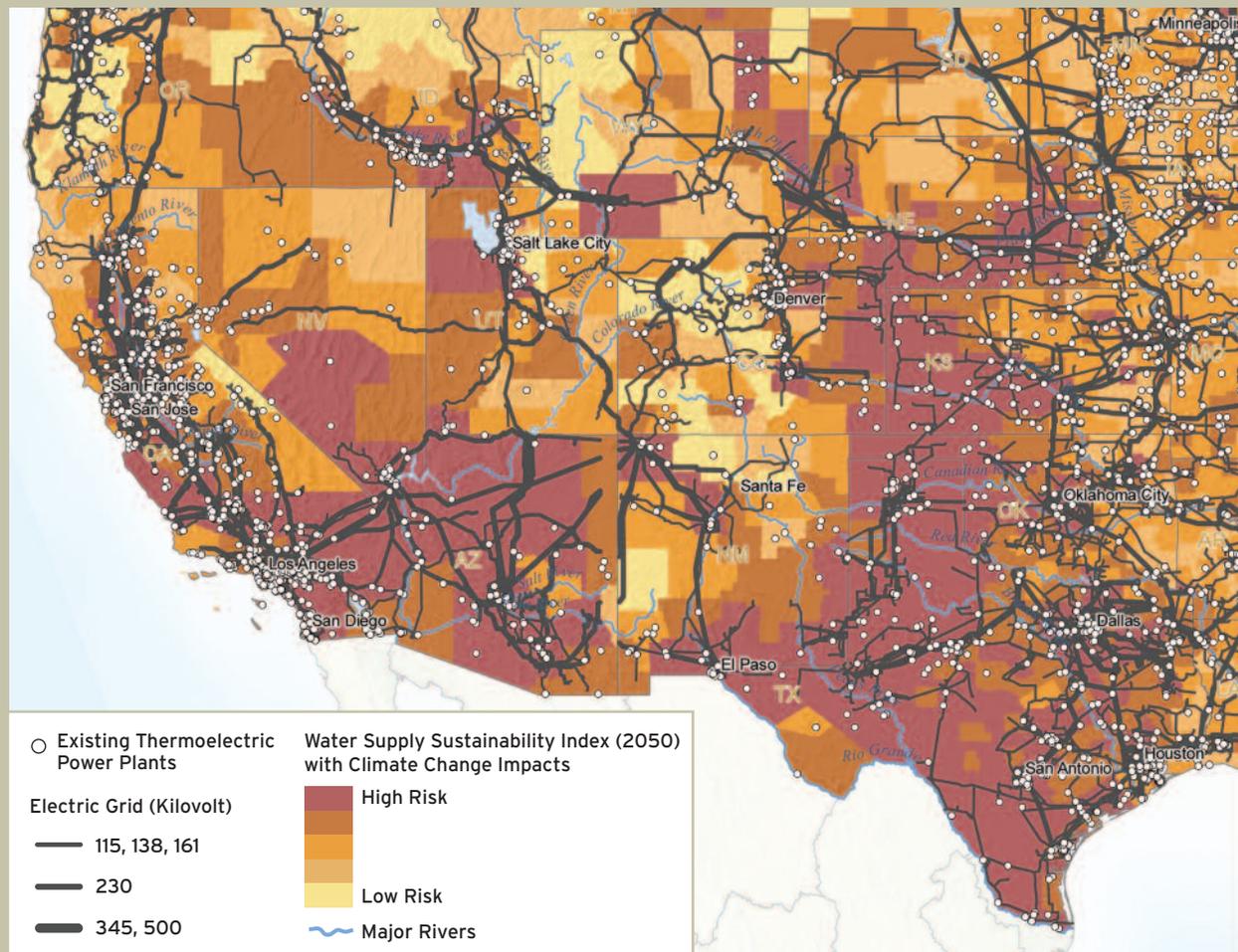
Older thermoelectric plants typically use a “once-through” system, in which water is extracted from a local source, used in the power plant, and then returned to the water source. Although the majority of this water is returned to the source, it is often at a higher temperature, with potential negative effects for freshwater fish and other species.<sup>102</sup> Once-through cooling systems require a continuous water supply, making them particularly vulnerable to low stream flow conditions.<sup>103</sup>

Power plants built since 1980 typically use evaporative-cooling technologies that withdraw less, but consume more water.<sup>104</sup> After the water is diverted from a local water body and used in the power plant, it is moved to a tower or pond for reuse.<sup>105</sup> This shift to evaporative cooling technology is expected to continue, contributing to significant increases in energy sector water consumption.<sup>106</sup> In fact, the Electric Power Research Institute (EPRI) projected that 446 counties nationwide, with the Southwest being hit especially hard, would face water constraints on thermoelectric cooling by 2025, even if climate change has no effect on water supply.<sup>107</sup>

Looming water shortages are not the only threat that climate change poses for electricity generation. Many thermoelectric plants become less efficient on extremely hot days, when more energy needs to be expended on cooling the boiler water.<sup>108</sup> Every part of the country is expected to see significant increases in hot days; many areas in the Southwest are projected to have more than 75 days each year when the temperature tops 100°F, if



## POWER PLANTS CO-LOCATED WITH AREAS PROJECTED TO BE AT RISK OF FUTURE WATER SHORTAGES



The southwestern parts of the United States are likely to experience increased water stress in the future, setting the region up for increasing water-use conflicts. With hundreds of thermoelectric power plants already in the region and increasing population likely to increase electricity demand, power generation is likely to face critical water-availability limitations.

SOURCES: U.S. Energy Information Administration (EIA),<sup>117</sup> Federal Emergency Management Administration (FEMA),<sup>118</sup> National Resources Defense Council (NRDC)<sup>119</sup>

climate change continues unabated.<sup>109</sup> Such hot days are typically when power plants have their peak demand as customers turn up their air conditioning. At the same time, the extreme heat can stress power system components, causing them to fail more quickly.<sup>110</sup> Many transformers are designed to cool off at night and may be unable to cool down sufficiently.<sup>111</sup> This design choice could be especially problematic because night-time

temperatures have been increasing faster than day-time temperatures.<sup>112</sup>

Choices about how we produce electricity in the coming decades could have a big impact on water consumption. For example, if the nation were to get 20 percent of its electricity from wind by 2030, water consumption could be reduced by about 10 percent, compared to 2005 consumption.<sup>113</sup> On the other hand, if carbon capture and sequestration

(CCS) technologies are widely adopted, water consumption could increase by 7.5 to 19 percent.<sup>114</sup> CCS uses cooling water for the capture and compression processes, as well as to generate the extra electricity needed to perform CCS.<sup>115</sup>

Developing concentrated solar power plants also presents tradeoffs between water consumption and power generation efficiency, especially if dry-cooling approaches are used in

hot climates. Because some of the electricity generated must be used to operate fans, electricity from a dry-cooled plant can cost about 10 percent more than that from a wet-cooled plant. These effects are especially acute when ambient temperatures exceed 100°F. Hybrid wet-dry cooling approaches are currently being developed as a promising alternative. These systems use dry cooling unless temperatures exceed a certain threshold, at which point they switch over to evaporative cooling. Such systems can use 90 percent less water than plants that rely only on evaporative cooling, and only see a 3 percent drop in energy performance.<sup>116</sup>



Flickr: nathansandiego

## ENVIRONMENTAL IMPACTS OF ELECTRICITY SOURCES

Fuel Source	Water for Fuel Mining, Production, or Processing (gal/MWh)	Water for Evaporative cooling (gal /MWhr)	Other Water Used for Power Plant Operations (gal/MWh)	Average Total Water Intensity (gal/MWh)	Carbon Dioxide Emissions (lbs/MWhr)
Coal	5-74	243-884	19-120	336-557	2,249
Natural Gas	11	192-338	0	203-349	1,135
Nuclear	45-150	720	30	848	0 *
Solar - concentrated	0	750-920	80-90	840-920	0
Solar - photovoltaic	0	N/A	4	4	0
Wind	negligible	N/A	N/A	0	0

Different electricity sources have trade-offs in terms of their water usage, carbon emissions, reliability, cost, and other environmental impacts. For example, the average coal plant in the United States has very high carbon emissions and moderately high water requirements, whereas concentrated solar electricity production has no carbon emissions, but high water requirements. Photovoltaic solar power and wind power are two energy sources that provide a win-win in terms of both water usage and carbon emissions.

SOURCES: Congressional Research Service,<sup>96</sup> Environmental Protection Agency<sup>120</sup>

\*Nuclear power plants do not emit carbon dioxide, however, some emissions are associated with uranium mining, enrichment, and transport to the nuclear plant.

# Building a New Energy Infrastructure that Is Less Vulnerable to Extreme Weather

The U.S. energy infrastructure must tackle the current climate-related vulnerabilities and prepare for an intensification of these vulnerabilities. Addressing these challenges requires more than a band-aid. This is the time to be innovative and avoid the trap of building more of the same infrastructure with incremental improvements. The long-term solution is not to harden the existing infrastructure to transport more coal or produce more oil and gas. Instead, we need to rethink how we produce and distribute energy to meet the dual goals of reducing carbon emissions and ensuring reliable, timely, and cost-efficient delivery of energy. Shifting to renewable energy can address both of these concerns, especially if new infrastructure is designed and located in a way to minimize the possibility of extreme weather and climate disruptions. Furthermore, a more resilient energy system that need not rely as much on foreign fuel supply improves our national security.<sup>121</sup>

The following recommendations are important steps for implementing the needed transition in our energy system:

## **Conduct a national climate vulnerability assessment for the energy industry and require development of climate adaptation plans to address vulnerabilities.**

This report and others have only begun to identify potential vulnerabilities of the U.S. energy infrastructure to climate change. The nation needs a more detailed assessment to identify specific threats to the energy infrastructure and delivery mechanisms from more severe storms and floods, more extremely hot days, more frequent

and severe droughts, sea level rise, and other changing climate conditions. Such an assessment would allow utilities, energy companies, and the nation to make more informed decisions about how to invest in future energy infrastructure. It is important that this assessment looks beyond just make existing technology sturdier, which would be a missed opportunity to make the overall system more robust by transitioning to renewable energy sources as the aging infrastructure is replaced.

Once the vulnerability assessment is complete, it is critical to develop climate adaptation plans that identify steps to ensure robust service delivery and consider how changing climate may influence choices in the sorts, design, and locations of new infrastructure. For example, careful consideration of potential increases in storm intensity may lead electric utilities to favor buried power lines, less subject to outages caused by falling trees and other wind damage.

Such adaptation plans will be needed at the national level to inform national energy policy and by individual utilities and energy companies to inform their own strategic decision making.

## **Reduce large-scale vulnerability by promoting distributed electricity generation and increased energy efficiency.**

In considering how to meet future energy demands, alternative energy sources provide natural ways to avoid some of the vulnerabilities of the existing energy infrastructure. Off-shore wind and distributed solar photovoltaic are particularly attractive in that (1) they require negligible water to operate, a factor that promises to become more critical as water shortages become more common; (2) they do not require transporting fuel long distances across the country, thereby avoiding disruptions from flooding or storms; and (3) they do not rely as heavily on an extensive power grid subject to



Ryan Hawk/Seattle City Light



weather-related outages. As the nation installs this new technology, it should be designed and strategically located to be more resistant to weather and climate impacts. For example, wind turbines could be designed to withstand higher wind speeds, off-shore wind farms could be sited in areas where hurricanes are infrequent, or new electricity distribution networks could be buried to minimize wind and heat disruptions.

Improving energy efficiency of buildings, vehicles, appliances and industrial processes is the most cost effective way to both reduce our greenhouse gas emissions and make our communities and industry more resilient to possible disruptions to energy production and distribution.<sup>122</sup> With greater energy efficiency, we can build fewer power plants, mine less coal, and use less oil and gas. Improving vehicle fuel efficiency, for example, is among the most effective means to insulate consumers from the

effects of spikes in oil prices due to extreme weather as well as other external influences, such as political instability in oil producing regions, manipulation of supply by OPEC, or changes in demand.<sup>123</sup> Vehicle fuel efficiency standards currently under development would cut gasoline demand (and the economic impact of any changes in price) by nearly a third, dwarfing the scale and potential impact of domestic drilling or related efforts to increase supply.<sup>124</sup>

**Reduce carbon pollution to minimize future vulnerability to more extreme weather.** To limit the magnitude of changes to the climate and the impacts on the energy industry, we must curb carbon pollution as much and as quickly as possible. It is important that policy makers, industry, and individuals work together to reduce this pollution from today's levels by at least 80 percent by 2050. This target is achievable with

technologies either available or under development, but we must take aggressive action now to avoid the most worrisome impacts.

The Environmental Protection Agency (EPA) has determined that carbon dioxide endangers human health and public welfare, and therefore is subject to regulation under the Clean Air Act.<sup>125</sup> This finding has been upheld by the U.S. Supreme Court.<sup>126</sup> EPA is beginning to move forward to promulgate specific regulations to control carbon pollution, building on a long history of protecting human health while bringing benefits to the U.S. economy.<sup>127</sup> It is essential that EPA continue to use its mandated authority to control pollution, without interference from Congress, both to protect human health and to reduce the vulnerabilities of the energy industry and other sectors of the economy to future climate change.

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**We gratefully acknowledge the following experts for helpful input and review comments:**

Ken Casavant, Washington State University  
Ana Maria Cruz, Disaster Prevention Research Institute (DPRI) of Kyoto University  
Joel Michalski, Washington State University  
Vicki McCracken, Washington State University  
Sara C. Pryor, Indiana University

**In addition, we would like to extend special thanks to:**

Tim Sinnott, GIS analyst, GreenInfo Network  
Amy Tujague, U.S. Army Corps of Engineers  
Raquel Wright, Federal Railroad Administration  
Tony Iallorardo, Zoe Lipmann, Joe Mendelson, Corey Shott, Felice Stadler, and Tim Warman from National Wildlife Federation

Barbara Raab Sgouros, who skillfully handled the design and layout of the report

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