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TO
THRU TRAFFIC

Chapter II

INCREASING THE RESILIENCE, RELIABILITY, SAFETY, AND ASSET SECURITY OF TS&D INFRASTRUCTURE

This chapter addresses a broad range of challenges to the resilience, reliability, safety, and asset security of transmission, storage, and distribution (TS&D) and shared infrastructures. The challenges vary among different types of TS&D infrastructure and among different regions of the United States. First, the electric grid is examined. The grid is especially vulnerable to extreme weather events. It also is vulnerable to low-probability/high-consequence events. Natural gas is the second TS&D infrastructure discussed. Here, in addition to the examination of vulnerabilities and interdependencies, is a discussion of safety issues. The third major section of this chapter addresses the resilience, reliability, and asset security of TS&D infrastructure for liquid fuels. This chapter concludes by presenting a series of major recommendations, a number of which cut across and address multiple infrastructures and challenges.

FINDINGS IN BRIEF:
Increasing the Resilience, Reliability, Safety, and Asset Security of TS&D Infrastructure

Mitigating energy disruptions is fundamental to infrastructure resilience. Mitigating energy disruptions is particularly important because other critical infrastructures rely on energy services to operate, and these interdependencies are growing. Should disruptions occur, it is essential to have comprehensive and tested emergency response protocols to stabilize the system and begin recovery.

Transmission, storage, and distribution (TS&D) infrastructure is vulnerable to many natural phenomena. These include hurricanes, earthquakes, drought, wildfires, flooding, and extreme temperatures. Some extreme weather events have become more frequent and severe due to climate change, and this trend will continue. Sea-level rise resulting from climate change, coupled with coastal subsidence in the Mid-Atlantic and Gulf Coast regions, increases risks and damages to coastal infrastructure caused by storm surge.

Threats and vulnerabilities vary substantially by region. In many cases, a particular natural threat or infrastructure vulnerability will be region specific (e.g., Gulf Coast hurricanes threatening refineries), dampening the utility of national, one-size-fits-all solutions for reliability and resilience. Regional solutions are essential.

Recovery from natural gas and liquid fuel system disruptions can be difficult. Although liquid fuels and natural gas disruptions are less likely than electricity disruptions, it is relatively more difficult to recover from disruptions to these systems than electric systems. Recovery from natural gas disruptions is particularly difficult because of the need to locate and repair underground breakages.

Cyber incidents and physical attacks are growing concerns. Cyber incidents have not yet caused significant disruptions in any of the three sectors, but the number and sophistication of threats are increasing, and information technology systems are becoming more integrated with energy infrastructure. There have been physical attacks; while some physical protection measures are in place throughout TS&D infrastructure systems, additional low-cost investments at sensitive facilities would greatly enhance resilience.

High-voltage transformers are critical to the grid. They represent one of its most vulnerable components. Despite expanded efforts by industry and Federal regulators, current programs to address the vulnerability may not be adequate to address the security and reliability concerns associated with simultaneous failures of multiple high-voltage transformers.

Assessment tools and frameworks need to be improved. Research has focused more on characterizing vulnerabilities and identifying mitigation options than on measuring the effects of best practices for response and recovery. In addition, assessment tools and frameworks tend to characterize the impacts of disruptions on system performance, but are less able to examine impacts on national or regional consequences like economic loss or loss of life.

Shifts in the natural gas sector are having mixed effects on resilience, reliability, safety, and asset security. The addition of onshore shale gas infrastructure benefits natural gas resilience by decreasing the percentage of infrastructure exposed to storms. The Energy Information Administration reports that the Gulf Coast percentage of natural gas production went from 18 percent in 2005 to 6 percent in 2013. On the other hand, overall reliance on gas for electricity has gone up, creating a new interdependence and grid vulnerability. Furthermore, additional export infrastructure resulting from the natural gas boom would increase vulnerabilities to coastal threats, such as sea-level rise.

Dependencies and interdependencies are growing. Many components of liquid fuels and natural gas systems—including pumps, refineries, and about 5 percent of natural gas compressor stations—require electricity to operate. The interdependency of the electricity and gas systems is growing as more gas is used in power generation.

Aging, leak-prone natural gas distribution pipelines and associated infrastructures prompt safety and environmental concerns. Most safety incidents involving natural gas pipelines occur on natural gas distribution systems. These incidents tend to occur in densely populated areas.

The Importance of Resilient, Reliable, Safe, and Secure TS&D Infrastructure

Building a resilient, reliable, safe, and secure energy infrastructure is a national priority and vital to American competitiveness, jobs, energy security, and a clean energy future. President Obama highlighted the importance of energy infrastructure in Presidential Policy Directive-21, in which energy infrastructures were described as "uniquely critical."

Presidential Policy Directive-21[a]

In February 2013, the President broadened the national effort to strengthen and maintain secure, functioning, and resilient critical infrastructure by issuing Presidential Policy Directive-21, *Critical Infrastructure Security and Resilience*. The directive applies to all critical infrastructures, but calls out energy infrastructures as being "uniquely critical" due to the enabling functions they provide across all other critical infrastructures. This document goes on to define resilience as"the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents." Threats may include natural or human-made hazards, such as hurricanes or physical threats. The consequences of these hazards to infrastructure broadly affect social welfare. They go beyond the ability of a system to operate and address the vitality of our national safety, prosperity, and well-being.

[a] The White House Office. "Presidential Policy Directive 21 - Critical Infrastructure Security and Resilience." February 12, 2013. http://www.whitehouse.gov/the-press-office/2013/02/12/presidential-policy-directive-critical-infrastructure-security-and-resil. Accessed February 2, 2015.

TS&D infrastructures—key components of the Nation's energy systems—include approximately 2.6 million miles of interstate and intrastate pipelines, 142 operable refineries, about 642,000 miles of high-voltage transmission lines, and almost 6.3 million miles of electricity distribution lines.[1] These vast energy TS&D networks reliably deliver electricity, transportation fuels, and heat to more than 300 million American consumers daily and provide industry with feedstocks for a large range of products. The U.S. bulk electric power transmission system, for example, had high availability (97–98 percent) during the period from 2008 to 2013.[2] In less than one decade, the U.S. natural gas and oil TS&D infrastructures have successfully connected significant new sources of supply to processing facilities and consumers. In addition, in just a few short years, ethanol has moved from a niche fuel to 10 percent of the Nation's gasoline supply, supported by a TS&D system that has been flexible enough to accommodate this growth.

The imperative for resilient TS&D infrastructures going forward is to maintain the high performance of the existing systems; to continue to accommodate significant growth in domestic supplies; and to manage and adapt to new technologies, threats, and vulnerabilities in cost-effective ways. These vulnerabilities are growing and exacerbated by climate change.

In addition, TS&D infrastructures are becoming increasingly interdependent and interconnected. These extremely complex systems consist of physical TS&D facilities (such as transmission lines, pipelines, and storage facilities); cyber-dependent communications or control networks; roadways, railways, and waterways; and human decision makers (such as consumers, legislators, investors, and CEOs).[3,4] A key interdependency (and vulnerability) for *all* sectors and critical infrastructures is reliance on electricity, making its reliability a fundamental need and requirement economy-wide.

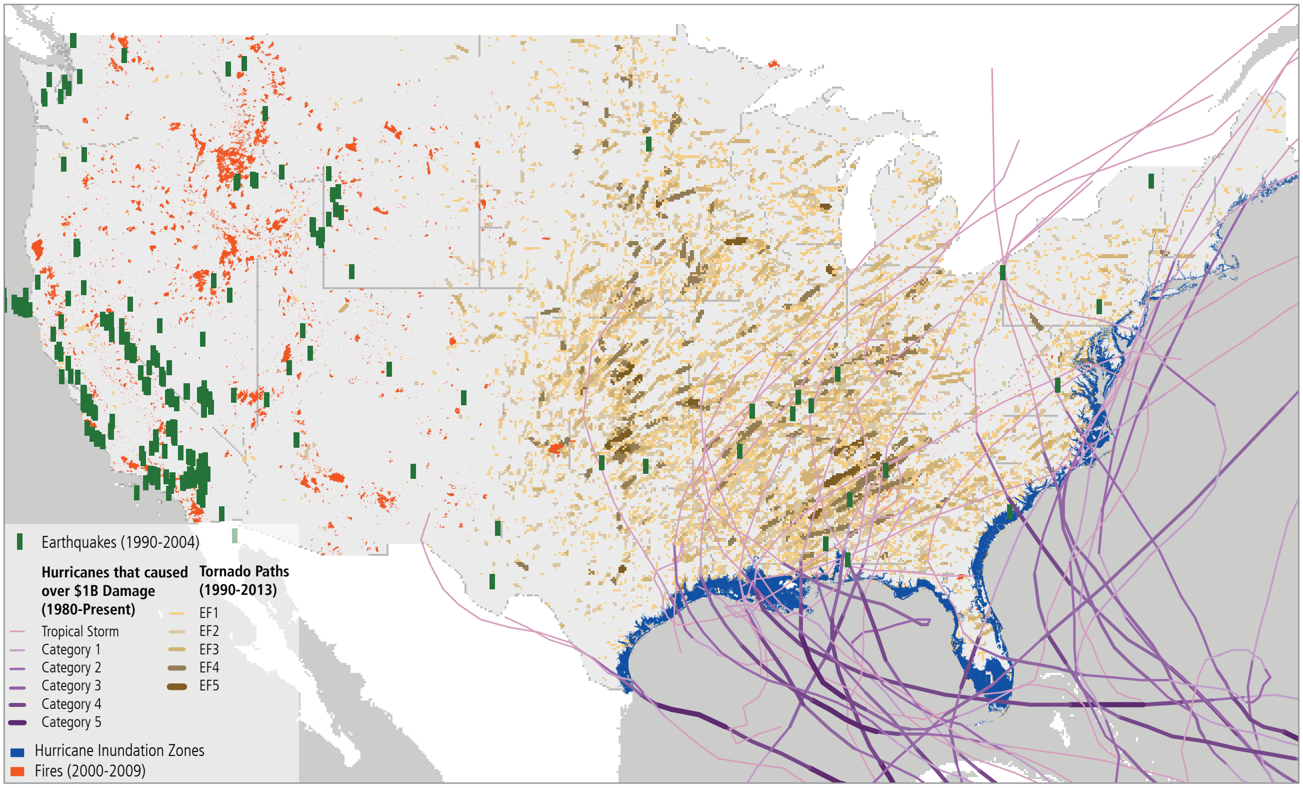
The private sector, states, and Federal Government all play crucial roles in ensuring that TS&D infrastructures are reliable, resilient, and secure. Responsibility for resilience, reliability, and safety of privately held TS&D infrastructure lies mostly with the state public utility commissions and other state energy regulators, but also with Federal regulators such as the Federal Energy Regulatory Commission, the Nuclear Regulatory Commission, and the Department of Transportation's Pipeline and Hazardous Materials Safety Administration. Given the national significance of these infrastructures to interstate commerce and the economy, the Federal Government regulates aspects of their operation and has other emergency authorities that it exercises in the public interest. Communication, coordination, and cooperation among all of these entities, in the exercise of their respective responsibilities, is essential. Key Federal emergency responsibilities relevant to energy infrastructure are highlighted in Appendix D.

- **Reliability** refers to the ability of a system or its components to operate within limits so that instability, uncontrolled events, or cascading failures do not result if there is a disturbance, whether the disturbance is a disruption from outside the system or an unanticipated failure of system elements. Reliability is also used by industry to mean that a system's components are not unexpectedly failing under normal conditions.
- **Resilience** refers to the ability of a system or its components to adapt to changing conditions and withstand and rapidly recover from disruptions. To the extent that actions improve a system's ability to withstand disruptions, they might be characterized as enhancing reliability, or resilience, or both. The ability to recover from a disturbance, however, is specific to resilience.
- **Safety** refers to achieving an acceptably low risk to life and health in the design, construction, operation, and decommissioning of a system. That level of risk is determined by taking into account the magnitude of potential consequences, the probability of those consequences occurring, and the costs of risk mitigation.
- **Security** refers specifically to the ability of a system or its components to withstand attacks (including physical and cyber incidents) on its integrity and operations. It overlaps, in part, with the concepts of reliability and resilience.

The Impacts of Disruptions on Energy TS&D Infrastructures

Disruptions of TS&D infrastructures have serious consequences for the Nation and many regions of the country. Extreme weather and climate change is a leading environmental risk to this infrastructure. Low-probability, extremely high-consequence events, such as geomagnetic distrubances, must also be anticipated and managed. Figure 2-1 shows the regional distribution of various natural disasters in the contiguous 48 states.

Figure 2-1. Illustration of Tornado and Hurricane Tracks, Wildfires, Earthquakes, and Coastal Inundation[5]



This figure maps the regional distribution of major natural disasters to help visualize regional vulnerabilities. This visualization shows the lower 48 states, but analysis was also completed on Alaska and Hawaii.

Energy Infrastructure Damage from Hurricane Sandy[b]

Hurricane Sandy made landfall in New Jersey and New York, as a post-tropical cyclone, on October 29, 2012. The storm destroyed neighborhoods along the coast and directly or indirectly killed at least 159 people. At its peak, it knocked out power to 8.66 million customers from North Carolina to Maine and as far west as Illinois and Wisconsin. Sandy's impact on the region's petroleum infrastructure was severe, with flooding and power outages at refineries, pipelines, and petroleum terminals in the New York Harbor area, leading to depressed petroleum product supply in the Northeast and stock drawdowns and temporary price increases. Nearly 2 weeks after the storm, product deliveries (outflows) from petroleum product terminals in the New York Harbor had returned to only 61 percent of their pre-storm levels. Breaks in natural gas lines caused fires in some locations, resulting in the destruction of many residences. The supply issues at New York Harbor terminals, combined with power outages at retail fueling stations, led to widespread gasoline shortages in the New York City area in the weeks after landfall. This was largely caused by flooding damage to major terminals and docks in the Arthur Kill area of New Jersey. As a result, portable generators sat unused and lines at fueling stations were long and problematic, while consumers struggled to identify which gas stations had power and were operational. Significantly, these fuel shortages delayed first responders and other response and recovery officials.

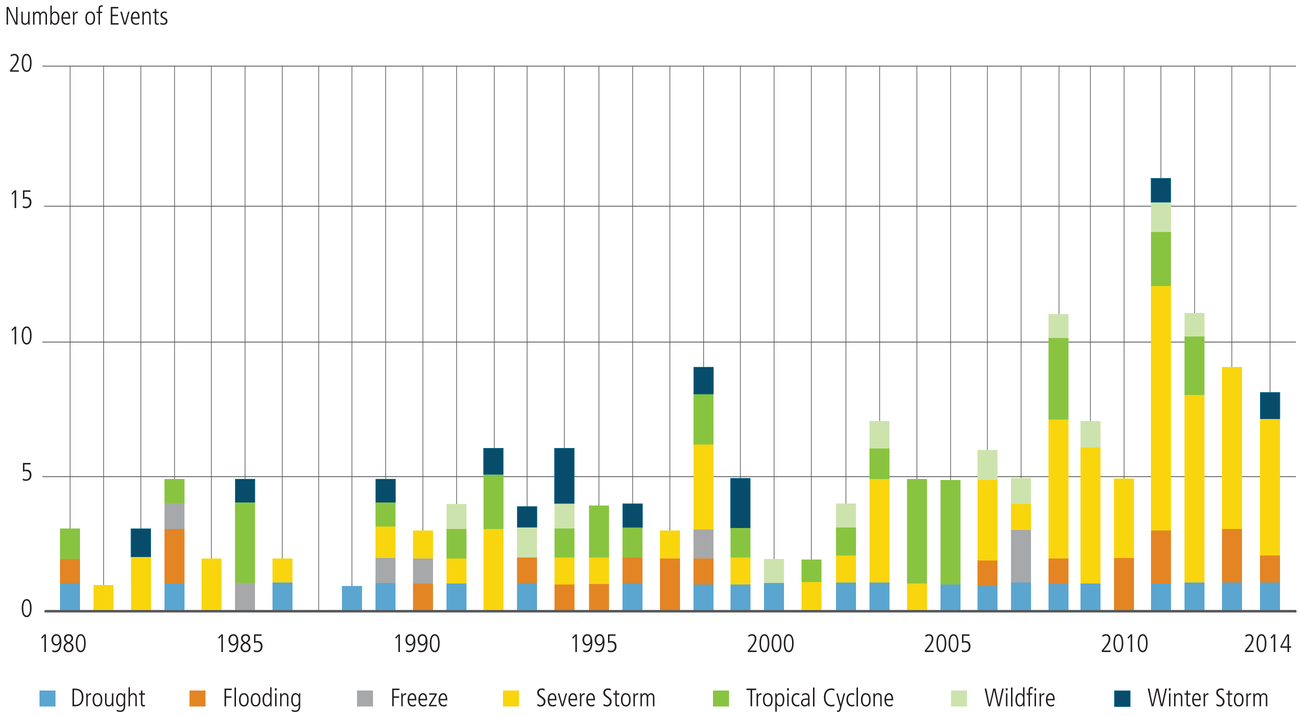
[b] Department of Housing and Urban Development. "Hurricane Sandy Rebuilding Strategy." p. 24. Hurricane Sandy Rebuilding Task Force. http://portal.hud.gov/hudportal/documents/huddoc?id=hsrebuildingstrategy.pdf.

Natural disasters, equipment and maintenance failures, and physical attacks come at a significant cost. A National Research Council study looking at the 2003 blackout that affected the Midwest, the Northeast, and Canada concluded that "the economic cost of the 2003 blackout came to approximately $5 per forgone kilowatt-hour, a figure that is roughly 50 times greater than the average retail cost of a kilowatt-hour in the United States."[6] Data suggest that electricity system outages attributable to weather-related events are increasing, costing the U.S. economy an estimated $20 billion to $55 billion annually.[7]

In the United States, there were 11 *individual* weather disasters costing $1 billion in 2012, second only to 2011 for the most on record.[8] Insurance data identifies almost $22 billion in *total* losses from a range of weather events in 2013, excluding self-insured losses.[9]

Extreme weather events resulting in more than $1 billion in damages are increasing, as seen in Figure 2-2. The damages represented in this figure are broader than energy infrastructure; these trends, however, must be considered in future energy infrastructure policy.

Figure 2-2. Billion-Dollar Disaster Event Types by Year[10, c]



Costly weather-related disasters have been increasing in frequency over the past decade.

Extreme weather has a range of impacts on TS&D infrastructure. The severity of hurricane impacts on all energy infrastructure is highlighted in Table 2-1. Heat waves—also extreme weather events—affect electric TS&D infrastructure in several ways, including reducing the efficiency of electric transmission and distrubution circuits; increasing the load on the grid associated with additional demand for air conditioning; and reducing the efficiency of cooling at thermal power plants that can result in lower power plant output.[11] Drought and extreme cold pose challenges to TS&D infrastructure by, for example, impeding barge transport of energy products. Drought also decreases the water available for natural gas processing.[12]

[c] Data from all original events were adjusted for inflation (using the Consumer Price Index, to 2014 dollars), prior to identifying events that exceeded $1 billion in damages. Caution should be used when interpreting long-term trends; data quality improves over time.

Continued increases in extreme weather can cause multiple stresses to energy systems more broadly, exacerbating direct effects on TS&D infrastructures. Sequential or compounded extreme weather events, such as Hurricanes Katrina and Rita, can result in significant nationwide economic and safety consequences that also affect TS&D infrastructures.

Table 2-1. Probability and Severity of Hurricane Damage to Liquid Fuels and Natural Gas Infrastructure[13, d]

Infrastructure	Tropical Storm (39-73 MPH)		Hurricane Cat 1-2 (74-95 MPH, 96-110 MPH)		Hurricane ≥ Cat 3-5 (111-129 MPH, 130-156 MPH, >157 MPH)	
	Probability of Damage	Severity of Damage	Probability of Damage	Severity of Damage	Probability of Damage	Severity of Damage
Loss of Electrical Power	Med	Significant	Med-High	Major	High	Catastrophic
Gulf of Mexico Platforms	Low	Insignificant	Med-High	Major	Med-High	Major
Pumping/Compressor Station	Low	Insignificant	Med	Significant	Med-High	Major
Pipelines	Low	Insignificant	Low-Med	Interrupting	Med-High	Major
Rail	Low	Insignificant	Low-Med	Interrupting	Med-High	Major
Ports	Low	Insignificant	Med-High	Major	High	Catastrophic
Crude Tank Farm	Low	Insignificant	Low-Med	Interrupting	Med	Significant
Refineries	Low	Insignificant	Med	Significant	Med-High	Major
Natural Gas Plants	Low	Insignificant	Med	Significant	Med-High	Major
Product Storage Terminals	Low	Insignificant	Low-Med	Interrupting	Med-High	Major
Propane Tanks	Low	Insignificant	Low	Insignificant	Low	Insignificant
Underground Storage	Low	Insignificant	Low	Insignificant	Low	Insignificant
LNG Terminals	Low	Insignificant	Med	Significant	Med-High	Major
Local Gas Distribution	Low	Insignificant	Med	Significant	Med-High	Major
Filling Stations	Low	Insignificant	Med	Significant	Med-High	Major
SPR/NEHHOR	Low	Insignificant	Low-Med	Interrupting	Med	Significant

This table is an example of infrastructure damage from natural disasters (here showing tropical storms and hurricanes). For three ranges of intensity of tropical storms and hurricanes, the severity of probable damage was rated qualitatively using a 5-point scale (i.e., insignificant, interrupting, significant, major, and catastrophic) and probability also on a 5-point scale (i.e. low, low-medium, medium, medium-high, high). These ratings were based on the extensive review of impacts from past events and judgment of industry experts.

[d] Damage severity is defined by ease of recoverability. Infrastructure damage categorized as insignificant includes damage that can be resolved with no outside help (i.e., clearing downed trees). Interrupting damage is associated with damage that probably requires outside assistance to repair. Recovery from significant damage is problematic and causes minor delays. Major damage requires replacements to resolve and causes major delays. Damage defined as catastrophic disrupts infrastructure for months, in addition to requiring rebuilding.

As a result of greater awareness of the direct and indirect effects of climate-change-related extreme weather, there has been growing interest in understanding and reducing the impacts of disruptions. There is evidence that pre-disaster hardening of critical energy infrastructures could help save lives and reduce economic losses to individuals, businesses, insurers, states, and the Federal Government. A statistical study of 5,500 Federal Emergency Management Agency mitigation grants awarded between 1993 and 2003, while not specific to energy, found that the benefit-cost ratio for mitigation investments was about 4:1.[14] In order to spend investment dollars more wisely, it is essential to focus on modernizing TS&D infrastructures at the same time that they are being hardened.

A barrier to progress on understanding and reducing the impacts of disruptions on TS&D infrastructures is that frameworks, tools, and metrics for assessing and prioritizing energy infrastructure resilience, reliability, and security actions and investments vary widely across industries and government agencies.[15, e] While resilience measures may be well-tailored for specific industries and sectors, they are not designed to aid policymakers and regulators in understanding current vulnerabilities; in deciding where to focus efforts and investment to increase resilience, reliability, and security; or in determining degrees of resilience that are needed. At the regional level, the lack of commonly used analytical methods for determining the appropriate level of resilience, as well as what resilience projects are prudent, can lead to difficulty in determining which resilience projects should be recoverable in rates.

The sections that follow analyze the vulnerabilities to disruption of each major TS&D infrastructure sector—electricity, natural gas, and liquid fuels—as well as the dependencies and interdependencies that could magnify the effect of any given disruption. There is substantial variability in the impact of natural threats on TS&D infrastrcutures, depending on the region in which they are located and on vulnerabilities inherent in the infrastructures of each sector.

Resilience, Reliability, Safety, and Asset Security for the Electric Grid: Analysis of Vulnerabilities

Resilience and reliability of the electric grid is essential to the economy and our way of life. Electricity transmission is vulnerable to many of the same types of threats as electricity distribution, but each sector also comes with discrete risks. Differences in risk arise from the purpose of the equipment, from technological differences, and from regulatory aspects of transmission versus distribution systems. Analysis to inform the Quadrennial Energy Review (QER) identified components of four categories of electricity TS&D[16] that are particularly vulnerable to hazards and ranked the vulnerabilities from low to high:

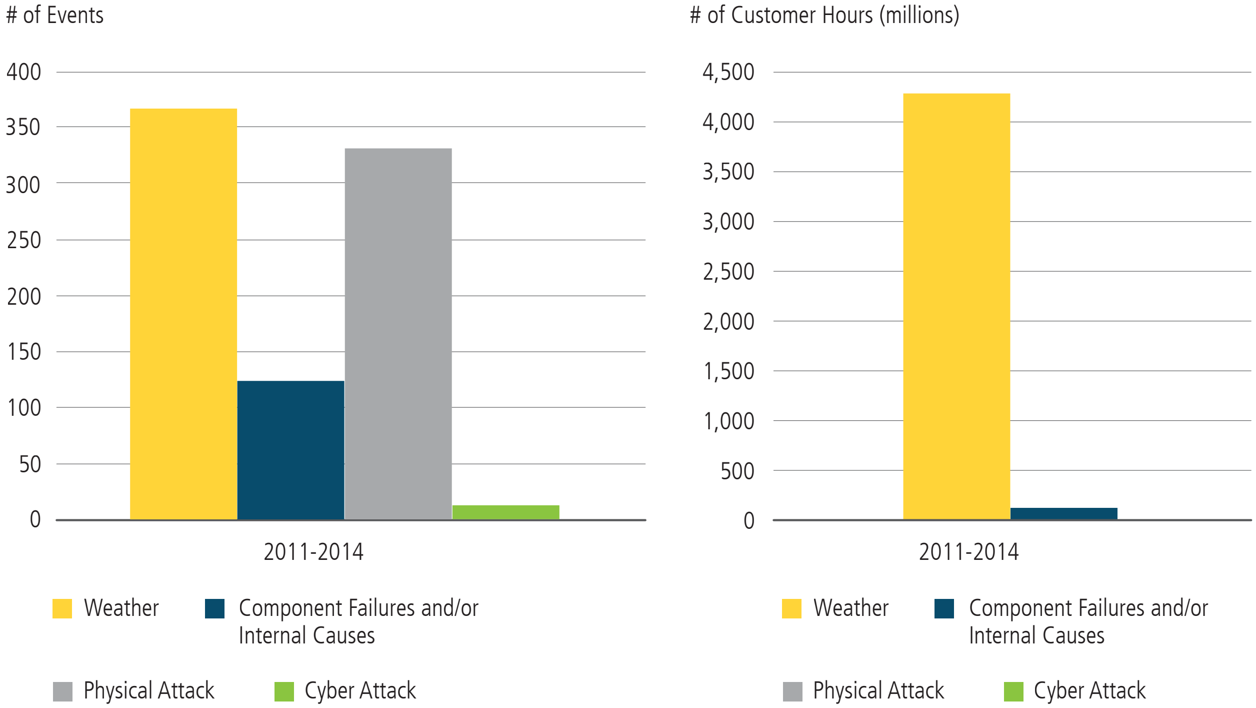
- **Electricity Transmission:** High vulnerability to physical attacks and wind; medium-high vulnerability to earthquakes, wildfires, snow and ice, extreme heat, and geomagnetic storms.
- **Electricity Substations:** Medium-high vulnerability to cyber and physical attacks and geomagnetic storms—large power transformers (LPTs) in such substations are a particular concern. A common vulnerability for substations is flooding, and flood vulnerability has a relatively high probability.
- **Aboveground Electricity Distribution:** High vulnerability to wind; medium-high vulnerability to earthquakes, physical attacks, wildfires, and snow and ice.
- **Control Centers:** Medium-high vulnerability to cyber and physical attacks.

[e] RAND documented 172 resilience metrics in peer-reviewed literature, and many others exist outside the literature, specific to single industries or even individual companies. There appear to be fewer metrics for liquid fuels and natural gas infrastructure than for electricity—this literature review found 105 metrics specifically related to electricity systems and only 67 for natural gas and oil. Existing metrics appear abundant for assessing resilience at the facility or system levels, but RAND found only 30 assessing regional or national resilience, many of which dealt with market factors rather than system performance. RAND also found that most metrics related to elements of disruption mitigation rather than system outcomes.

Weather-Related and Other Reliability Vulnerabilities

Historically, weather-related disturbances are the leading source of grid outages. For a 5-year period from 2008 to 2012, estimated costs of weather-related power outages ranged from $107 million to $202 billion.[17] Weather-related disturbances have a far greater impact on grid reliability—measured in terms of customer interruption hours—than component failures, physical attacks, and cyber incidents combined (see Figure 2-3).

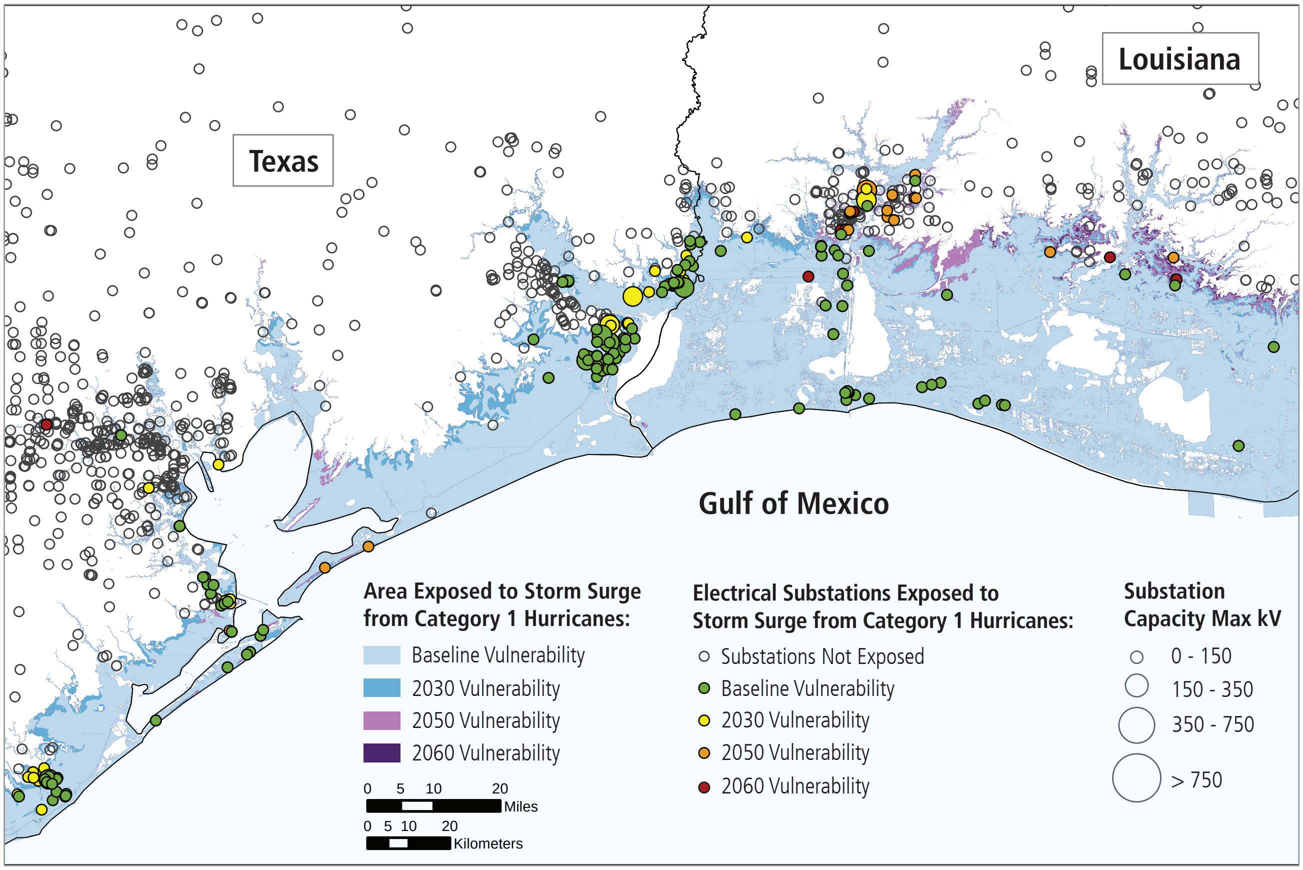
Figure 2-3. Left Figure: Electric Disturbance Events, January 2011–August 2014; Right Figure: Customer Hours Affected by Electric Disturbance Events, 2011–August 2014[18]



While weather was responsible for less than half of all reported incidents, weather accounted for the vast majority of customer interruption hours from 2011 to 2014. Not all reported events (shown on the left), such as voltage reductions and public appeals, result in actual customer outages (shown on the right).

The frequency and severity of certain types of extreme weather events have led to greater vulnerabilities for electric transmission and distribution systems.[19] Recent Department of Energy (DOE) analysis[20] examining the effects of climate change on infrastructure exposure to storm surge and sea-level rise found that vulnerabilities are likely to increase for many energy sector assets, including electricity. Figure 2-4 illustrates that, under the highest sea-level rise scenario from the National Climate Assessment,[21] by 2030 the number of electricity substations in the Gulf of Mexico exposed to storm surge from Category 1 hurricanes could increase from 255 to 337. Projected sea-level rise by 2050 would increase the number to roughly 400. Any significant increase in hurricane intensities in a warmer climate would greatly exacerbate exposure to storm surge and wind damage. Another important factor is current and projected development patterns, which is expected to have a larger effect on energy infrastructure vulnerability than rising sea levels, particularly in regions where energy distribution infrastructure is being built to serve growing populations in exposed coastal areas.[22]

Figure 2-4. Gulf Coast Electricity Substation Facilities' Exposure to Storm Surge under Different Sea-Level Rise Scenarios[23, 24, f, g]



Sea-level rise increases the vulnerability of electricity substations to inundation caused by hurricane storm surge. Future vulnerabilities correspond with a high-end sea-level rise scenario of 10 inches in 2030, 23 inches in 2050, and 32 inches in 2060. The baseline vulnerability corresponds with sea levels in 1992.

Other extreme weather events that are projected to increase with climate change and have regional and possibly national-scale impacts include extreme heat waves, droughts, and wildfires that can damage electricity infrastructure or reduce transmission efficiency. U.S. temperatures are projected to continue rising in the coming decades.[25] Electricity transmission and distribution systems carry less current and operate less efficiently when ambient air temperatures are higher.[26] Case studies indicate that sudden, extreme heat can cause transformers to malfunction or stop working.[27] Increasing temperatures also will likely increase electricity demand for cooling, which could increase utilization of transmission and distribution systems during peak demand periods. Increasing air and water temperatures also reduce the efficiency of power plant cooling, which increases the risk of partial or full shutdowns of generation facilities and loss of the grid services that they provide during heat waves.[28]

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[f] The Platts Electric Substation data contains point features representing a total of 55,819 electric transmission, sub-transmission, and some distribution substations in North America. These substations can be located on the surface within fenced enclosures, within special purpose buildings, on rooftops (in urban environments), or underground.

[g] Areas inundated by hurricane storm surge do not account for local land subsidence, which will further increase the exposure of infrastructure in this region. Note that 2030, 2050, and 2060 vulnerabilities correspond with 10 inches, 23 inches, and 32 inches of sea-level rise, respectively. Zero sea-level rise corresponds with sea levels in 1992.

Drought is also problematic. In 2014, California experienced its third driest year in 119 years of record keeping.[29] As a consequence, California hydroelectric generation—and the use of hydroelectric power for load leveling and energy storage—was significantly reduced. In June 2014, California hydroelectric generation was only 59 percent of the June average of the preceding 10 years.[30] In addition, annual temperature profiles can impact the timing of water availability.[31] A rapid spring thaw of the snowpack can overload reservoir capacity and lead to lost energy. Increasing frequency and severity of wildfires (also linked to droughts), particularly in the West, may damage electricity transmission and distribution infrastructure (such as utility poles, lines, transformers, and substations) and lead to power outages.[32]

Physical Attacks, Geomagnetic Disturbances, and Cyber Incidents: High-Consequence, Low-Probability Events

In addition to the impacts of severe weather and climate change, the electric grid is vulnerable to other events, including malevolent acts—such as physical attacks and cyber incidents—and geomagnetic disturbances.

Large Power Transformers Vulnerable to Attacks

LPTs can weigh hundreds of tons, are expensive, and are typically custom made with procurement lead times of 1 year or more.[33] In addition, due to their size and weight, moving LPTs presents logistical challenges requiring specialized equipment, permits, and procedures (see Chapter V, Improving Shared Transport Infrastructures, for more discussion of logistics challenges).

The loss of critical LPTs can result in disruptions to electricity services over a large area. Such a loss could be due to the customized nature of the components and the associated manufacturing requirements, as well as physical attacks (such as the Metcalf incident), natural hazards (such as geomagnetic disturbances, discussed below), or extreme weather (such as floods, salt water corrosion, and sudden heat waves). In the Metcalf attack on a substation in California, "multiple individuals outside the substation reportedly shot at the [high-voltage] transformer radiators … causing them to leak cooling oil, overheat, and become inoperative."[34]

The United States has never experienced simultaneous failures of multiple high-voltage transformers, but such an event poses both security and reliability concerns. The Edison Electric Institute, seeking to manage such vulnerabilities, has established a Spare Transformer Equipment Program, enabling utilities to stockpile and share spare transformers and parts. The inventory under this program is not large enough, however, to respond to a large, coordinated attack. Transformer design variations and the logistical challenges associated with their movement pose additional challenges to maximizing the effectiveness of the program. A National Research Council study referring to this effort noted that "... The industry has made some progress toward building an inventory of spares, but these efforts could be overwhelmed by a large attack" and that "it alone is not sufficient to address the vulnerabilities that the United States faces in the event of a large physical attack."[35]

The National Research Council study further included as its number one recommendation that the Department of Homeland Security (DHS) should work with DOE and industry to "develop and stockpile a family of easily transported high-voltage recovery transformers and other key equipment." The study acknowledged that the costs and benefits are hard to estimate, but noted that the benefits of such a stockpile would be "many times [the] cost" if available to respond to an event.[36] The Western Area Power Administration proposed a strategic transformer reserve pilot program and included a calculation of costs. Under this program, the Federal Government would purchase 110 large transformers at a cost of $324 million to provide backup units for the roughly 20,000 LPTs nationwide in emergency events. The Federal Government could mitigate the cost of the program by sharing the burden with industry. The benefits would accrue to the entire national grid (valued at more than $1 trillion) and directly to the U.S. economy by avoiding outages.

Large Power Transformers: Lack of "Off-the-Shelf" Options Could Impact Reliability[h]

Sometimes the challenge of completing infrastructure investment is dependent on the time and schedule associated with the manufacturing of large power transformers. The Western Area Power Administration experienced this situation with its most recent transformer procurement and installation. Scheduled delivery of this transformer was planned to be 1 year ahead of a critical deadline. In December 2013—13 months before the deadline—the transformer failed during testing in the factory. This resulted in an initial 4-month delay to the expected delivery date. The transformer was rebuilt and delivered to the site, but was compromised due to contamination. This required returning the transformer to the factory for further inspection and corrective measures. In the factory, the transformer was refurbished and ultimately passed factory testing 10 months after the original delivery date. Delivery to the site, final assembly, and onsite testing and commissioning was completed 1 year after the original scheduled in-service date. While the deadline for commercial operation was ultimately met, there was no room for error and significant uncertainty in the ability to meet the critical service deadline. The lack of off-the-shelf transformer options and industry practice of as-needed manufacturing is an ongoing concern.

[h] Email communication between Western Area Power Administration and Department of Energy, Office of Energy Policy and Systems Analysis staff. March 26, 2015.

The use of smaller, less-efficient, temporary replacement transformers may be appropriate for emergency circumstances. In 2006, the Electric Power Research Institute suggested building compact "restoration transformers" that would fit on large cargo aircraft and trucks.[37] Since then, DHS's Recovery Transformer Program has developed and tested a flexible transformer that is transportable by truck and can be installed within several days of an incident. These technologies could help address logistical concerns with moving large transformers in the event of disruptions.

Geomagnetic Disturbances

Geomagnetic storms are another high-consequence hazard for the electric grid that presents concerns due to the increasing reliance of many critical infrastructures on grid functions. These storms arise when charged particles and magnetic fields ejected from the Sun interact with Earth's magnetic field. The resulting geomagnetically induced currents create a significant threat to the reliability of the interconnected grid across North America. Though the probability of an extreme geomagnetic storm is relatively low in any given year, the occurrence is almost inevitable at some point in the future. Geomagnetic storms have the potential to damage transformers and other critical grid assets over large geographical areas. A geomagnetic storm in 1989 resulted in a blackout in Montreal and most of the Province of Quebec. In October 2003, an intense geomagnetic storm caused a blackout in Malmo, Sweden, and damaged several transformers in South Africa. Economic and societal costs attributable to impacts of geomagnetic storms could be very large. A 2013 Lloyds of London report indicated that geomagnetic disturbances could cost the economy as much as $2.6 trillion and take 1 to 2 years for a full recovery[38] (to put this in perspective, the Northeast blackout in 2003 was estimated to have cost between $4 billion and $10 billion).

Cyber Incidents

As seen in Figure 2-3, from 2011 through 2014 there were few reported cyber incidents on the electric grid and none reported that resulted in system outages. Cyber threats to critical infrastructure, though, are increasing. More than half of the cyber incidents to which DHS's Industrial Control Systems Cyber Emergency Response Team responded in 2013 related to energy installations.[39] Cyber events have the potential to cause significant and far-reaching problems on the power system.[40] Administration actions on cybersecurity are discussed in greater detail on page 2-37.

Electricity TS&D Vulnerabilities Vary by Region

While all regions of the country are susceptible to certain weather-related disruptions, grid TS&D infrastructure in three regions is expected to be particularly vulnerable to climate change and extreme weather events:[41]

Southeast: Due to increasing temperatures, heat waves, and humidity, the Southeast is expected to require the steepest growth in electricity transmission and distribution to meet cooling demand.[42] The region also is exceptionally vulnerable to sea-level rise and hurricanes (see Figure 2-4); challenges that are exacerbated by growing coastal populations.[43]

Southwest: Climate changes pose particular challenges for the Southwest, which is expected to get hotter and significantly drier; the regional population also is expected to increase 68 percent by 2050, further increasing electricity transmission and distribution load to meet higher cooling demands.[44, 45] The increased frequency and severity of wildfires are expected to have significant impacts on electricity transmission and distribution in the Southwest. In 2007, due to a wildfire, San Diego Gas & Electric and Southern California Edison had to reduce their electrical loads by 500 megawatts, nearly 80,000 customers lost power, and more than two dozen transmission lines were out of service with damage to 35 miles of wire.[46]

Atlantic and Gulf Coasts: Due to land subsidence, rising sea levels and shifts in ocean currents, heavier downpours, and the potential for more intense hurricanes in the future, coastal infrastructure in these regions is increasingly exposed to erosion, flooding, storm surge, and damage from high winds. Coastal development patterns that do not take these trends into account increase the vulnerabilities in these regions. Hurricanes Katrina and Rita combined downed more than 85,000 utility poles, 800 distribution substations, and thousands of miles of transmission and distribution lines, leaving more than 3.5 million customers along the Gulf Coast (especially in Louisiana, Mississippi, Florida, and Texas) without power at the height of the disruptions.[47] As another example, 75 percent of the net annual power generation in the New York City metropolitan region comes from 27 power stations that lie in the Federal Emergency Management Agency 100-year flood zone, a vulnerable position for a vast proportion of the region's energy infrastructure.

Dependencies of the Electricity Grid on Other TS&D Systems

As noted, all critical infrastructures depend on electricity; the electric grid also depends on other energy and related infrastructures within the scope of the QER. Coal, natural gas, and, to a limited extent, petroleum are used as fuels for power generation; the systems that move these fuels to generators are critical to the grid. Natural gas demand for power generation is expected to grow 30 percent by 2030, making electricity generation increasingly dependent on natural gas supply and transmission systems.[48] Generation from petroleum was only 0.6 percent of the total in 2013, but dual-fueled (natural gas and petroleum) plants in the Northeast increased electricity reliability in the winter of 2013-2014 when the extreme cold of the polar vortex threatened to constrain natural gas supplies. Power generation from coal is dependent on shared transportation infrastructures, especially rail; this dependency is discussed in greater detail in Chapter V (Improving Shared Transport Infrastructures).

Other key dependencies of the electric power sector include the following:

- The use of liquid fuels to power vehicles to repair and service transmission and distribution lines.
- Road, barge, and rail transportation networks used to deliver fuels, including liquefied natural gas for peaking facilities, and equipment supplies to generation stations.
- Transportation of LPTs, challenging because their large dimensions and heavy weight pose unique requirements to ensure safe and efficient transportation. Water is used for cooling and to reduce emissions.
- Natural gas, propane, and diesel to provide fuel for microgrids.
- Supervisory control and data acquisition and energy management systems that are essential to operations.

Actions for Managing Grid Vulnerabilities

Options for managing the vulnerabilities of the electric grid span a wide range of technological sophistication. To date, activities and investments have been primarily at the lower end of the technology range, focused on bulk changes in physical infrastructure, such as building physical barriers or moving equipment, building backup systems, building non-wooden or reinforced poles, and burying lines underground.[49] Reliability and resilience projects have also included operations and maintenance activities, such as aggressive vegetation management. While it might be considered low-tech, vegetation management is an essential activity; both the 1996 West Coast and 2003 East Coast-Midwest power outages started from trees along transmission lines.

A growing number of options for managing grid vulnerabilities to extreme weather use new technologies like smart meters and automated switching devices that allow for much quicker recovery times from disruptions. Microgrids and distributed generation technologies also provide options for improved resilience during storms.[50]

Incorporation of newer technologies is happening slowly. For example, about 90 percent of recent resilience project funds, in response to Hurricane Sandy, were spent on bulk infrastructure changes and additional operations and maintenance activities rather than on upgrading infrastructure components with advanced smart grid technologies.[51] Some utilities are doing more than bulk infrastructure changes. After Hurricane Sandy took out ConEdison's substation on the lower East Side, helping to throw lower Manhattan into darkness, for example, the utility's plan of action included construction of walls and barriers; installation of pumping equipment and submersible network equipment; and the deployment of smart grid tools to enhance network flexibility in emergencies.[52]

Barriers to Managing Electric Grid Vulnerabilities

As an integral part of risk management, utilities have proposed and completed projects to harden their infrastructures against wind and flood damage for many years; several state public utility commissions have issued rulemakings and other regulatory instructions related to electricity infrastructure resilience and hardening since 2005.[53] Yet, in some cases, procedural barriers to cost recovery for addressing vulnerabilities remain.

Rate-based cost recovery for repair of damages already incurred by storms and for future long-term investment programs remains the most common mechanism for paying for these damages. The criteria, process, and timing of this cost recovery vary widely between states. For example, states such as Oklahoma, New Hampshire, and Connecticut allow resilience project cost recovery through surcharges or other rate-adjustment mechanisms that allow utilities to immediately rate base their expenditures rather than waiting for the next rate case. Many states, however, have prohibitions against single-issue ratemaking, meaning that a utility that does not have a general rate case scheduled in the near future would have no recourse to recover its costs for resilience measures, perhaps for years.[54] Investments in efficiency and distributed generation are increasingly recognized as viable strategies for improving energy system resilience (see Chapter III, Modernizing the Electric Grid); for example, the New York State Department of Public Service recently approved such projects as part of a broader rate case focused on hardening and resilience.[55]

Beyond procedural barriers, there are problems with inadequate information and tools with which to manage for resilience. Quantitative measures of adequacy of resilience investments, or even a commonly accepted method for determining the appropriate level of resilience at either the transmission or distribution level, do not exist. For example, while the North American Electric Reliabilty Corporation develops and enforces mandatory reliability standards applicable to the bulk electric system (subject to Federal Energy Regulatory Commission review, approval, and independent enforcement authority) and, more recently, physical security and geomagnetic disturbance standards, there are no mandatory standards in place that speak directly to grid resilience against natural disasters. In addition, there is no common, generally accepted analytical method of determining whether it is prudent to implement alternative resilience projects.[56]

Distribution hardening projects are separately planned on a utility-by-utility basis; data are not systematically reported, which makes any central coordination difficult in the event of a large-scale regional or national problem. Resilience project metrics and analysis methods typically are defined on a locality-by-locality basis, starting with risk-assessment modeling of, for example, flooding or wind damage. The analysis may incorporate specific critical infrastructure, population, vulnerability, and duration to quantify the risk reduction and economic cost-benefit of alternative resilience projects.[57] Methods for analyzing the potential economic impact of weather-related damage is a topic of ongoing development,[58] and data for performing this analysis can be insufficient.[59]

The power industry's resilience-related risk assessments largely focus on physical and cybersecurity—rather than extreme weather and climate change—and currently rely on information from the Federal Government. Incomplete or ambiguous threat information may lead to inconsistency in physical security among grid owners, inefficient spending of limited security resources at facilities (e.g., to address overestimated threats), or deployment of security measures against the wrong threat. For example, while physical barriers could protect against one particular type of attack, incorporation of better communication technologies could simultaneously reduce vulnerabilities to multiple forms of risks, such as physical and cyber threats, geomagnetic disturbances, electromagnetic pulses, and natural disasters.[60] The Federal Government can fill gaps in creating data sets, tools, and assessments that provide a more complete and robust analytical approach to measuring resilience needs and investments. It can also step in where the utility industry is not well-positioned to make significant investments—such as where new, innovative technologies can be introduced, but they face barriers to cost recovery in the rate base.

Administration Initiatives on Electric Grid Resilience

The Build America Investment Initiative. This initiative is an interagency effort led by the Departments of Treasury and Transportation to promote increased investment in U.S. infrastructure, particularly through public-private partnerships. The Department of Energy has participated in the effort and included several recommendations related to resilience of the electricity sector that focus on data, information, and analytical tools. The initiative establishes an electricity resilience information portal at the Department of Energy to provide data, tools, and best practices to support investment in resilient electricity infrastructure; improve electricity sector data availability and data standardization; develop analytical tools to evaluate the potential impacts of climate change in assessments of electricity resilience investments; create standard metrics to account for the benefits of resilience in electricity infrastructure investment decisions; and establish a resilience course to educate state and local stakeholders on robust decision making related to new infrastructure.

Coordination and Outreach to Reduce Vulnerabilities of the Grid to the Loss of Large Power Transformers. The Administration has made it a priority to work with industry to identify challenges and create solutions for increasing the security and resilience of the electric grid, including the development of an integrated national plan to mitigate challenges pertaining to aging power transformers, the cyber and physical security of transformers, and the vulnerabilities of large power transformers. The Administration is working with trade association leadership and the private sector to improve the coordination of existing and planned transformer-sharing programs and to identify solutions for transformer replacement capabilities as part of its efforts to enhance the resilience of the Nation's electric grid. These efforts will be part of a formal national strategy (planned for release in 2015) for strengthening the security and resilience of the entire electric grid for threats and hazards. In its Recovery Transformer Program, the Department of Homeland Security's Science and Technology Directorate has developed, tested, and demonstrated a prototype rapidly deployable extra high-voltage transformer that is transportable by road and can quickly be installed within several days of an incident.

Enhancing Grid Resilience to Geomagnetic Storms. Ensuring that the United States is prepared to respond to and recover from severe space weather storms is a priority for the Administration. In November 2014, the Administration established an interagency Space Weather Operations, Research, and Mitigation Task Force. The Task Force is developing a National Space Weather Strategy with high-level strategic goals for improving forecasting, evaluating impacts, and enhancing national preparedness (protection, mitigation, response, and recovery) across all economic sectors to a severe space weather event.

Administration Initiatives on Electric Grid Resilience (continued)

In addition, a Space Weather Action Plan, coordinated across numerous Federal departments and agencies, will establish actions, timelines, and milestones for implementation of the national strategy. Both the strategy and the action plan will be complete in 2015. In addition to this work, the President's Fiscal Year 2016 Budget requests $10 million to conduct research to better understand the risks that ground-induced currents from geomagnetic storms or electromagnetic pulses could have on large power transformers. Also, in June 2014, the Federal Energy Regulatory Commission adopted the new reliability standard (EOP-010-1) developed by the North American Electric Reliability Corporation to mitigate the impacts of geomagnetic disturbances that can have potentially severe, widespread effects on the operations of the U.S. power system. The standard specifically addresses implementation of operating plans and procedures to mitigate effects of geomagnetic disturbances for reliability coordinators and transmission operators. This standard is in response to the Federal Energy Regulatory Commission's May 2013 final rule (Order No. 779) in which it directed the North American Electric Reliability Corporation to develop geomagnetic disturbances vulnerability standards in two phases. The second phase of pending standards will provide more comprehensive protections by requiring applicable entities to protect their facilities against a benchmark geomagnetic disturbance event.

Resilience, Reliability, Safety, and Asset Security of Natural Gas TS&D Infrastructure: Analysis of Vulnerabilities

The physical or operational vulnerabilities of natural gas TS&D infrastructures to threats vary among infrastructure components. Though generally less vulnerable than electric power infrastructure, the natural gas TS&D sector contains several components that could be ranked high in terms of their vulnerability to damage and failure from a given hazard. These high-ranking components include natural gas transmission pipelines, compressor stations (which provide the pressure needed to move gas through pipelines), and distribution systems. Disruptions of these components could result in significant infrastructure outages.

Pipeline and Storage Vulnerabilities

The vulnerability of natural gas pipelines is dependent on the type of pipeline. Offshore pipelines, from the perspective of natural threats, are most vulnerable to damage to platforms and risers from storms; during Hurricanes Katrina and Rita, the majority of the offshore pipeline damage occurred at or near platform interfaces. Onshore pipelines are vulnerable to landslides and earthquakes. Extreme cold temperatures adversely affect natural gas well production and the associated infrastructure; for example, when extreme cold in the southwestern United States in early February 2011 curtailed more than 7 billion cubic feet per day of natural gas production due to well freeze-offs (see more discussion of this on page 2-25).[61]

Another area of concern is aboveground pipelines in Alaska, which are becoming increasingly vulnerable to climate change and its associated temperature increases. This is contributing to the thawing of the permafrost, affecting the foundations of infrastructure, contributing to pipeline displacements, and increasing requirements for operations and maintenance.[62] Permafrost thawing could have serious implications for Alaska's energy infrastructure, such as the Trans-Alaska Pipeline System, transmission lines, fuel storage tanks, generators, and other large energy infrastructure. It is estimated that permafrost thaw could add between $3.6 billion and $6.1 billion (10 percent to 20 percent) to current costs of maintaining public infrastructure—such as buildings, pipelines, roads, and airports—over the next 20 years.[63]

Although pipelines above and below ground represent a highly dispersed element of the energy system that, like electric transmission lines, are difficult to protect, the underground portion of pipelines generally are difficult for non-professionals to locate; this reduces the possibility of physical attacks. The exception for pipeline systems is aboveground compressor stations. In addition, depending on their severity, earthquakes could have a major or catastrophic impact on both transmission and distribution pipelines (discussed later in this chapter; see Table 2-5).

There have been cyber incidents on natural gas systems, notably between February and March of 2013.[64] During this time period, there were brute force attacks (i.e., efforts to obtain passwords and personal identification numbers) on a natural gas compressor station, resulting in a warning from DHS to gas system and other critical infrastructure operators. This alert prompted reports of similar activities, broadly from gas system operators in the Midwest and the Plains. These attacks, while unsuccessful, continued for over 2 weeks. Vulnerabilities affecting natural gas resilience and reliability likely will grow given the increasing reliance of natural gas infrastructure on electricity and other electricity-dependent infrastructures, such as telecommunications.

In 2012, there were 414 underground natural gas storage sites in the United States.[65] Three-hundred-eighty of the facilities were primarily used to meet seasonal winter demand; the remaining facilities are high-deliverability facilities used to inject and flexibly withdraw large natural gas volumes over short periods.

In general, natural gas underground storage is minimally susceptible to natural hazards. Underground gas storage facilities are well protected from accidents or malicious acts and generally insensitive to natural events, such as earthquakes, owing to the depth of underground storage and the design of the systems connecting the storage to the surface.[66] However, the U.S. natural gas profile could change the economics of gas storage. Shale gas production has increased and gas price volatility has decreased; this may diminish economic incentives for storage.

Enhancing Natural Gas Transmission and Distribution Pipeline Safety

There were approximately 315,000 miles of transmission and gathering pipelines and a transmission capacity of approximately 443 billion cubic feet per day in the U.S. natural gas pipeline network in 2011. They form the backbone of the gas transmission infrastructure system and deliver natural gas directly to many high-volume customers, such as industrial plants and gas-fired electric generation. In 2013, the United States had 1,437 distribution systems comprised of more than 2.1 million miles of distribution lines, delivering gas from high-pressure pipelines to more than 68 million residential and 5 million commercial customers.[67]

Transmission Pipeline Safety

Operators of transmission pipelines and gathering lines have fewer requirements than distribution lines to ensure pipeline integrity and safety through damage prevention programs, routine inspection, leak detection, and the development of integrity management plans.[68] While there are industry standards, for example, for instrumentation, safety equipment, and metering, there are no comparable industry standards or industry-led systematic research program for external sensor-based leak detection.[69] Such a program and standards would be useful.

Administration Initiatives on Pipeline Safety

Transmission pipeline safety. The Obama Administration's Department of Transportation and the Pipeline and Hazardous Materials Safety Administration first responded to concerns about transmission pipeline safety by issuing a "call to action" on pipeline safety in 2011. Congress also responded to the same concerns by passing the Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011.[i] This act directed the Department of Transportation to reexamine many of its requirements, including the expansion of integrated management plans for transmission pipelines.[j] In addition, in 2011, the National Transportation Safety Board recommended that the Pipeline and Hazardous Materials Safety Administration require all operators of transmission and distribution natural gas pipelines to equip their pipeline monitoring systems with tools to assist in recognizing and pinpointing the location of leaks.[k] The Pipeline and Hazardous Materials Safety Administration is currently developing a proposed rule on integrity management for natural gas pipelines. Also, it continues to conduct and support research to provide the technical and analytical foundation necessary for planning, evaluating, and implementing its pipeline safety program. In addition, the Federal Energy Regulatory Commission has issued a policy statement[l] that will allow interstate natural gas pipelines to recover certain expenditures made to modernize pipeline system infrastructure in a manner that enhances system reliability, safety, and regulatory compliance.

Distribution pipeline safety. The Department of Energy, as part of the President's Strategy to Reduce Methane Emissions, convened a series of roundtable discussions with stakeholders (e.g., utilities, environmental groups, state officials, and academics) in 2014 focused on reducing methane emissions from gas transmission and distribution systems. Some stakeholders commented that it was both necessary and feasible to make further progress through additional efforts to modernize natural gas infrastructure in ways that improve safety and reduce emissions. For example, replacement programs for leak-prone pipelines achieve multiple benefits; they enhance safety, reduce methane emissions, and create jobs. One barrier to public utility commission approval of surcharges for infrastructure modernization is that consumer advocates typically oppose these mechanisms for cost recovery.[m,n] Some stakeholders noted that infrastructure replacements could be more cost effective and expeditious when state agencies and municipalities coordinate pipeline replacement with other public works projects (i.e., in conjunction with water and telecommunications modernization efforts). At the final stakeholder roundtable meeting, the Department of Energy announced a series of new initiatives that will help improve pipeline safety. Among them is a new partnership with the National Association of Regulatory Utility Commissioners to provide technical assistance for gas.distribution system modernization and a clearinghouse for related information on effective technologies and policy strategies.

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[i] Department of Transportation, Pipeline and Hazardous Materials Safety Administration. "Pipeline Replacement Updates: Call To Action." http://opsweb.phmsa.dot.gov/pipeline_replacement/action.asp.

[j] Regulatory Certainty and Job Creation Act of 2011, Public Law No. 112-90, 125 Stat. 1904 (2012).

[k] National Transportation Safety Board and Department of Transportation, Pipeline and Hazardous Materials Safety Administration. "Recommendation P-11-10." 2011. http://www.phmsa.dot.gov/pv_obj_cache/pv_obj_id_54F297878A5472F8CDF692407F40A9AC8A530300/filename/NTSB%20Reply%20to%20P-11-8%20thru%20-20.pdf.

[l] Federal Energy Regulatory Commission. "Cost Recovery Mechanisms for Modernization of Natural Gas Facilities." FR Doc. 2014–28015. 2014. http://www.federalregister.gov/articles/2014/11/26/2014-28015/cost-recovery-mechanisms-for-modernization-of-natural-gas-facilities.

[m] Popowsky, S. "Testimony before the House Consumer Affairs Committee of Pennsylvania; Regarding Special Session House Bill 40 and House Bill 41 Natural Gas Issues." November 9, 2007. http://www.oca.state.pa.us/Testimony/2007/00096290.PDF.

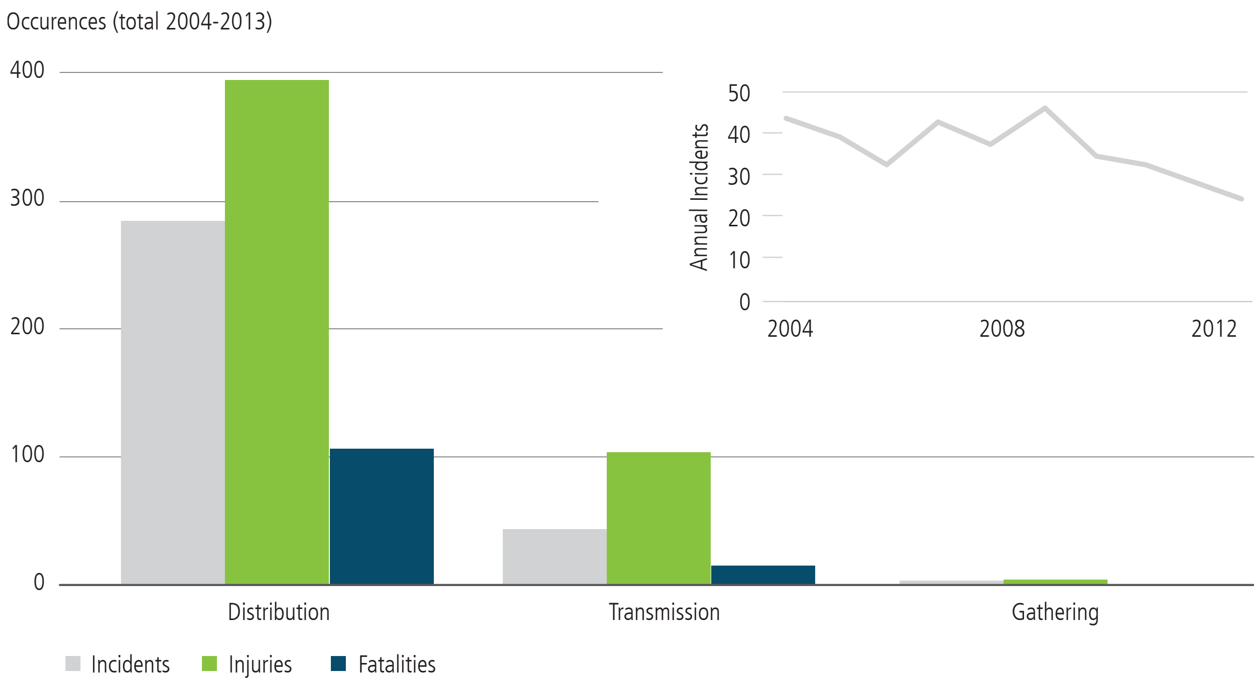
[n] Department of Transportation, Pipeline and Hazardous Materials Safety Administration. "Pipeline Safety: Safety of Gas Transmission Pipelines - Advanced Notice of Proposed Rulemaking (ANPRM)." Docket No. PHMSA-2011-0023. 76 Fed. Reg. 5308. August 25, 2011. http://www.phmsa.dot.gov/portal/site/PHMSA/menuitem.6f23687cf7b00b0f22e4c6962d9c8789/?vgnextoid=3d7248c521dd1310VgnVCM1000001ecb7898RCRD&vgnextchannel=2dd0d95c4d037110VgnVCM1000009ed07898RCRD.

Safety and Methane Emissions from Gas Distribution Systems

Natural gas distribution systems represent roughly 20 percent of all methane leaks from gas systems. Emissions from local distribution systems come largely from two sources—leak-prone pipelines and meters and regulators at city gates. Together, these two sources represent 70 percent of methane emissions from distribution systems.

Most safety incidents involving natural gas pipelines occur on the natural gas distribution system, as shown in Figure 2-5. These incidents tend to occur in densely populated areas. Excavation damage is the leading cause of serious incidents along natural gas pipelines; although, significant and preventable contributors also include equipment failure, incorrect operation, and pipeline corrosion.[70] Incidents are relatively infrequent, but increase as systems age.

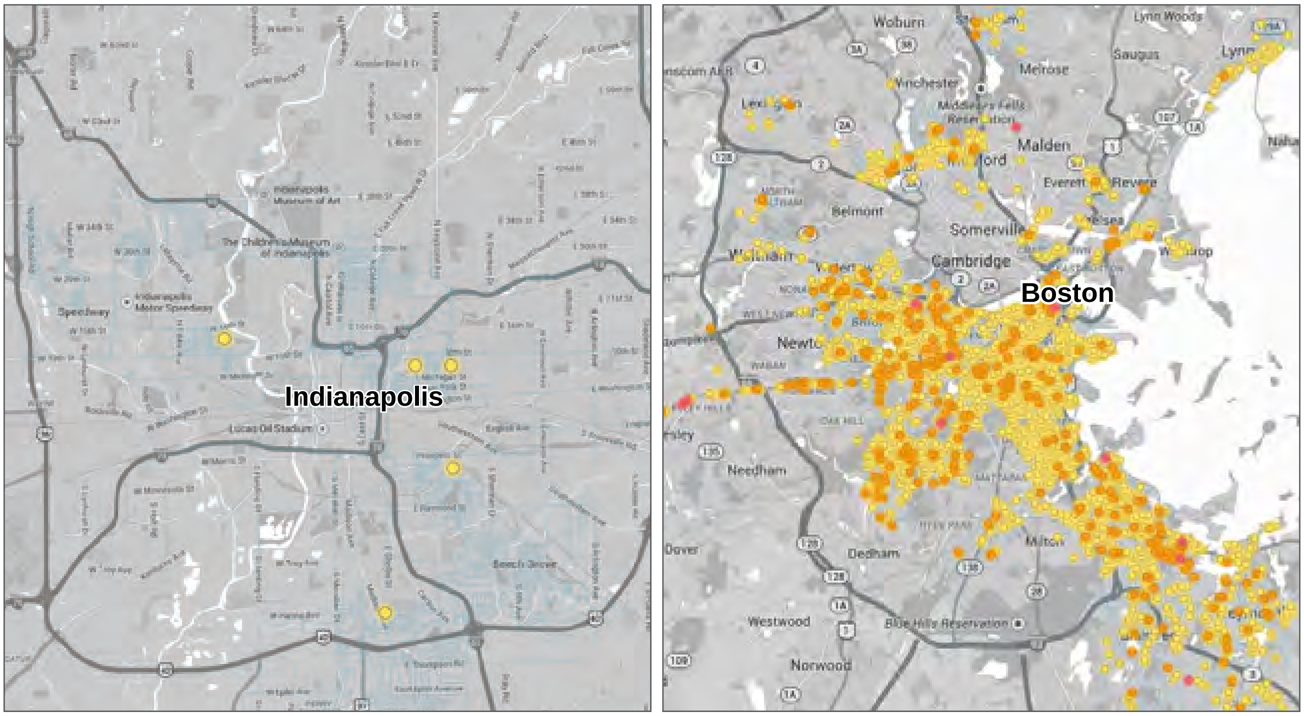
Figure 2-5. Total Incidents, Injuries, and Fatalities Associated with U.S. Natural Gas Pipelines, 2004–2013[71, o]



The majority of natural gas pipeline-related incidents involve distribution pipelines. The annual number of incidents associated with U.S. natural gas pipelines (shown in inset) declined between 2004 and 2013.

[o] Note that only a small portion of gathering lines are subject to reporting requirements; therefore, the Pipeline and Hazardous Materials Safety Administration data likely represent a significant underestimate of incidents on gathering lines.

Figure 2-6. Methane Emissions from Natural Gas Distribution Systems in Indianapolis and Boston, 2013[72, p, q]



Emissions Rate

- **Low** (The same near-term climate impacts as driving a car between 100 and 1,000 miles everyday. Rate: 700 to 9,000 liters/day.)
- **Medium** (The same near-term climate impacts as driving a car between 1,000 and 9,000 miles everyday. Rate: 9,000 to 60,000 liters/day.)
- **High** (The same near-term climate impacts as driving a car more than 9,000 miles everyday. Rate: More than 60,000 liters/day.)

After a pipeline explosion in Indianapolis, Indiana, in the 1980s, the city began a program to replace leak-prone natural gas pipelines. Massachusetts has more recently started a replacement program.

Many companies, states, and localities have taken action to improve safety by accelerating distribution pipeline replacement. After a natural gas explosion in the early 1980s, Citizens Energy Group, the local distribution company for Indianapolis, initiated an aggressive pipeline replacement program that reduced the proportion of pipeline-miles made from cast iron and steel from 16 percent in 1990 to less than 1 percent in 2013.[73, 74] Massachusetts ranks seventh in the Nation for leak-prone iron and steel gas system mains (see Table 2-2). The state has taken proactive measures to reduce these risks. In 2009, the Massachusetts Department of Public Utilities established a Targeted Infrastructure Recovery Factor to incentivize the accelerated replacement of leak-prone natural gas distribution infrastructure and to support "… benefits to public safety, service reliability, and the environment."[75] The agency subsequently approved a Targeted Infrastructure Recovery Factor mechanism for National Grid's Boston Gas in 2010.[76] While Boston's leak rates were higher than

[p] The study authors use isotopic analysis to confirm that the methane measured in this study are from fossil sources (i.e., not biologically produced). The methodology used to convert measurements of methane concentration into flux estimates is described in: Environmental Defense Fund. "Methodology: How the data was collected." www.edf.org/climate/methanemaps/methodology. Accessed February 27, 2015.

[q] While fixing and repairing pipeline leaks is critical for increasing public safety, it is important to note that not every leak is dangerous; effective safety programs take many factors into consideration.

Indianapolis' in 2013 (see Figure 2-6), the proportion of pipeline-miles made from cast iron and steel in Boston Gas has reduced from 60 percent in 2008 to 51 percent in 2013.[77] To further expedite pipeline replacement, Massachusetts recently enacted a law requiring utility classification and prioritization of pipeline leaks for replacement or repair.[78]

The most leak-prone distribution pipeline materials are cast iron and bare steel, accounting for approximately 9 percent of distribution pipes in the United States[79] and resulting in roughly 30 percent of methane emissions from natural gas distribution systems.[80] All regions of the country have some leak-prone distribution pipeline networks. Table 2-2 presents the top 10 states with the most miles of leak-prone distribution mains.[r] The magnitude of investment needed to replace all leak-prone distribution mains nationwide is more than $270 billion.[s]

Table 2-2. 10 States with the Most Miles of Leak-Prone Distribution Mains[81]

Rank	State	Leak Prone Iron Mains (mi)	Leak Prone Steel Mains (mi)	Total Leak Prone Mains (mi)	Total Leak Prone Mains (% of pipes in state)
1	PA	3,300	8,600	11,900	25%
2	NY	4,200	7,500	11,700	25%
3	OH	570	9,500	10,070	18%
4	CA	29	8,200	8,229	8%
5	NJ	4,900	2,200	7,100	21%
6	MA	3,600	2,600	6,200	30%
7	TX	820	5,000	5,820	6%
8	MI	3,000	2,300	5,300	9%
9	WV	13	3,000	3,013	29%
10	AL	1,200	820	2,020	7%

Of the 10 states with the most miles of leak-prone natural gas mains, nine have infrastructure modernization acceleration initiatives.

Despite progress in many states to help the replacement of leak-prone pipes in distribution networks,[82] some have limitations; many place caps on the magnitude of investments eligible for cost recovery and/or on the size of rate increases. Even with such special cost-recovery mechanisms,[83] at least one dozen utilities will require two decades or more to replace their leak-prone pipeline. Table 2-3 shows replacement time frames for select distribution systems.

[r] Distribution mains are pipelines that serve as a common source of supply for more than one service line. Source: 49 CFR § 192.3. In: Department of Transportation, Pipeline and Hazardous Materials Safety Administration. "Glossary." www.phmsa.dot.gov/staticfiles/PHMSA/Pipeline/TQGlossary/Glossary.html#main. Accessed March 9, 2015. Generally, these are gas pipelines running underground along streets, connecting to service lines that run to individual buildings.

[s] The American Gas Association reports that the total cost of replacing all cast iron pipe in the United States is $82,682,696,844 in 2011 dollars. According to Pipeline and Hazardous Materials Safety Administration data, cast iron pipes represent approximately 30 percent of the total leak-prone pipe in the United States. Assuming other pipe replacement has similar costs, the total cost for replacement of all leak-prone pipe is roughly $270 billion. Source: American Gas Association. "Managing the Reduction of the Nation's Cast Iron Inventory." 2013. www.aga.org/managing-reduction-nation%E2%80%99s-cast-iron-inventory. Accessed January 16, 2015.

Table 2-3. Expected Replacement Horizons for Select Utilities for Leak-Prone Mains[84]

Utility Company	Service Territory	State	Forecasted Timeframe (years)
Philadelphia Gas Works	Philadelphia, PA	PA	84
ConEd	New York, NY	NY	35
PECO	Greater Philadelphia, PA	PA	33
PSE&G	Newark, NJ	NJ	30
Pensacola Energy	Pensacola, FL	FL	30
Baltimore Gas Company	Baltimore, MD	MD	30
UGI	Rural Pennsylvania	PA	27
Consumers Energy	Detroit, MI	MI	25
DTE	Detroit, MI	MI	25
National Grid	New York, NY	NY	25
Dominion Hope Gas Co.	Ohio	OH	20
Yankee Gas Services Company	Rural Connecticut	CT	20
Peoples Gas	Chicago, IL	IL	20
National Grid - Niagra Mohawk	Rhode Island	RI	19
Peoples TWP	Southwestern Pennsylvania	PA	19
Peoples Natural Gas Co.	Southwestern Pennsylvania	PA	17
National Grid - Niagra Mohawk	Syracuse, NY	NY	16
Columbia Gas of Pennsylvania	Southwestern Pennsylvania	PA	15
Northern Utilities	Maine	ME	13
CenterPoint	Arkansas	AR	12

Projected pipeline replacement rates (from a select group of utilities) vary considerably and can range from about one decade to more than 80 years. Key factors affecting projected time frames include remaining miles of pipeline made of leak-prone materials (e.g., cast iron and unprotected steel) and the scale of existing replacement programs.

Another leading source of leaks is from meters and regulators at "city gate" station facilities that connect long-distance interstate transmission pipelines to local distribution networks. These account for 40 percent of methane emissions from natural gas distribution systems.[85] A recent study found that in cases where companies had invested in upgrades, emissions from city gate stations in 2013 declined to a fraction of emission levels measured at the same stations in 1992. Conversely, the one station that had not invested in upgrades over this 20-year period saw a 40-percent increase in estimated emission levels, illustrating the environmental benefits of such investments.[86] The Environmental Protection Agency's Natural Gas STAR program encourages voluntary actions to address these losses through directed inspection and maintenance programs that include leak detection and repair measures. Installing state-of-the-art measurement technologies could assist in leak management. In addition, it is estimated[87] that quarterly leak detection and repair, which requires little capital investment and could be scaled up quickly, could reduce emissions from city gate stations by 60 percent.

Natural Gas Infrastructure Dependencies

As noted, the electricity sector is increasingly reliant on natural gas as a fuel for power generation. On the flip side, many physical and operational components of natural gas TS&D infrastructures depend on electricity for key functions. In addition, other key sectors, such as industry and natural gas vehicles, depend on reliable and robust natural gas TS&D systems for a range of applications.

Gas System Dependencies on Electricity

Most pumps and compressors along natural gas gathering and transmission pipelines are fueled with gas flowing through the station,[88] with only about 5 percent of installed compression horsepower on interstate pipelines nationwide requiring electricity to run.[89,90] In some areas of the Nation where there are concerns about emissions and the increased speed of permitting of electric compressors, there is significantly greater reliance on electric compressors.[91,92] Pennsylvania, Ohio, and California, for example, have a higher percentage of compressors powered by electricity than the national average.[93] On the flip side, increased reliance on electricity-powered compressors could increase the vulnerability of the gas transmission system to power outages. During the 2011 "Big Chill" in the Southwest (see box), for example, rolling blackouts contributed to natural gas production outages (primarily affecting compressors on gathering lines), which in turn led to power generation curtailments.[94]

While compression facilities for underground natural gas storage generally are fueled by offtake gas, they may still require electric power.[95] Electricity is needed for dehydration of underground stored gas. Pipeline-quality natural gas is pumped into underground formations for storage; when the gas is withdrawn, it requires processing to remove water from the natural gas and to filter the gas all over again.

Also, most of the Nation's liquefied natural gas facilities store this gas for periods of peak demand or pipeline gas supply interruption. Cryogenic liquefaction of natural gas allows large volumes of gas to be stored and transported over long distances that cannot be technically or economically served by pipelines, and this process requires large amounts of electricity. These facilities are distributed across the Nation and generally are found near electric power stations.[96]

Centralized gas control stations monitor the flow of natural gas and collect, assimilate, and manage data received from compressor stations all along the pipeline. These control systems can integrate gas flow and measurement data with other accounting, billing, and contract systems. The data are transmitted through a communications network that could consist of company-owned, fiber-optic lines; leased telephone lines; ground- or satellite-based microwave; or radio communication systems.[97] The total loss of communications could result in manual operations of the affected pipeline. Many systems in the oil, gas, and alternative fuels infrastructures are increasingly monitored and controlled remotely through cyber networks that are also powered by electricity.[98]

Dependencies of Other Sectors on Natural Gas TS&D Systems

Dependencies of other infrastructures on the natural gas TS&D sector include the following:

- Supply of natural gas liquids for petroleum refining. Growth in production of natural gas liquids has stimulated renewed interest in petrochemicals production where ethane and propane are key feedstocks (see Chapter V, Improving Shared Transport Infrastructures, for a more detailed discussion).
- Natural gas as a transportation fuel. Compressed natural gas vehicles also rely on natural gas. Although there are only about 120,000 compressed natural gas vehicles in the United States today, the Energy Information Administration forecasts increases in natural gas vehicles over the next decades, especially in heavy-duty vehicles.[99]
- Industrial consumption of natural gas. Given low natural gas prices over the past several years and forecasts of abundant supplies at moderate prices in the future, there has been a resurgence of natural gas use in industrial applications in the United States, as seen in Table 2-4.

Table 2-4. Projected Incremental Natural Gas Demand for Select U.S. Industrial Sector Projects, 2015–2020[100]

Planned Operations Date	Chemical		Metals		Petroleum		Other Industrial		Total Demand	
Year	MMcf/d	# Projects	MMcf/d	# Projects	MMcf/d	# Projects	MMcf/d	# Projects	MMcf/d	# Projects
2015	246	57	118	54	355	21	24	179	743	311
2016	317	13	62	5	488	10	58	27	926	55
2017	261	5	79	3	325	3	2	8	668	19
2018	265	5	1	1	747	5	0	4	1,010	15
2019	-	-	-	-	1,350	4	-	-	1,350	4
2020	-	-	-	1	-	-	-	-	-	1
Project dates not announced*	179	6	2	3	872	5	-	-	1,050	14
Total	1,090	80	261	64	3,260	43	86	218	4,700	405

* Not announced at time of this analysis, 6/2014

Natural gas supply is projected to stimulate additional industrial construction and demand growth.

Natural Gas – Electricity Interdependencies

Nationally, natural-gas-fired power generation has increased by more than 40 percent since 2005, and carbon dioxide regulations may increase its use even further.[101] The increasing absolute demand for natural gas in the power sector has heightened the interdependence between gas and electric systems. In addition, fast-ramping requirements of natural-gas-fired generation, especially in response to the need to firm renewable generation, has increased the need for scheduling coordination between the gas and electricity sectors.

Gas Pipeline Transmission Capacity and Power Generation

An important question regarding natural gas transmission infrastructure is whether the existing gas transmission infrastructure can reliably accommodate increased use of natural gas in electric power generation, resulting from significant shifts in fuel utilization in the power sector. A recent DOE study for this QER on the adequacy of the national natural gas transmission system (there may be regional differences and needs, as discussed in the next section) to accommodate increased demand for natural gas[102] concluded the following:

- Higher utilization and repurposing of existing interstate natural gas pipeline infrastructure will reduce the need for new transmission pipelines. Pipeline flow patterns have already evolved with changes in supply and demand. Given the cost of building new pipelines, finding alternatives that utilize available existing pipeline capacity, such as adding compression to existing pipelines or reversing flow, is often less costly than building new pipeline capacity.

- The changing geography of natural gas supply, where diverse sources are now found closer to demand centers, is reducing the need for additional long-distance interstate natural gas pipeline infrastructure. There will be a need for expanded natural gas pipeline capacity as a result of new and expanded production of natural gas from shale formations and growth in natural gas demand, but it is lower than would be expected if the increased production were concentrated in traditional gas-producing regions.
- Incremental interstate natural gas pipeline infrastructure needs, even in a future that includes a national carbon policy, are projected to be modest. While a future carbon policy may significantly increase natural gas demand from the electric power sector, the projected incremental increase in natural gas pipeline capacity additions is modest relative to the reference case used in the analysis, which is based on projections from the 2014 Annual Energy Outlook. The rate of pipeline capacity expansion in the scenarios considered by the analysis is lower than the rate of natural gas pipeline capacity expansion that hs historically taken place.

The Big Chill: A Disruptive Event Made Worse by Infrastructure Interdependencies[t]

The "Big Chill" of 2011 illustrates the complicated relationship between natural gas and electric power, which had compounding effects during a period of extreme weather.

During the first week of February 2011, the U.S. Southwest was hit by an arctic cold front that was unusually severe in terms of its low temperatures, gusting winds, geographic extent, and duration. From January 31 to February 4, temperatures in Texas, New Mexico, and Arizona were the coldest experienced within the region since 1971. Dubbed the "Big Chill" in the media, it overwhelmed the routine preparations for cold weather that had been put in place by electric generators and natural gas utilities located in those states.

Within the Electric Reliability Council of Texas (ERCOT) Interconnection, starting in the early morning hours of February 2, the cold temperatures and wind chill caused a significant number of outages at generating plants, with approximately one-third of the total ERCOT generating fleet unavailable at the lowest point of the event. With electricity demand soaring because of the cold weather, ERCOT and some utilities in New Mexico instituted rolling blackouts to prevent collapse of their electric systems. For the Southwest as a whole, 67 percent of electric generator failures (by megawatt-hour) were due directly to weather-related causes, including frozen sensing lines, frozen equipment, frozen water lines, frozen valves, blade icing, and low-temperature cutoff limits on equipment.

Gas producers and pipelines were also affected in Texas, New Mexico, and Arizona. Natural gas production was diminished due to freeze-offs and the inability to reach gas wells (due to icy roads) to remove produced water and thereby keep them in operation. When rolling electricity blackouts hit gas producers and gas pipelines, it had the effect of causing further losses to natural gas supply. The ERCOT blackouts or customer curtailments caused or contributed to 29 percent of natural gas production outages in the Permian Basin and 27 percent of the production outages in the Fort Worth Basin, principally as a result of shutting down electric pumping units or compressors on gathering lines. As a result of all these factors, natural gas deliveries were affected throughout Texas and New Mexico. More than 30,000 customers experienced natural gas outages at some point during this period.

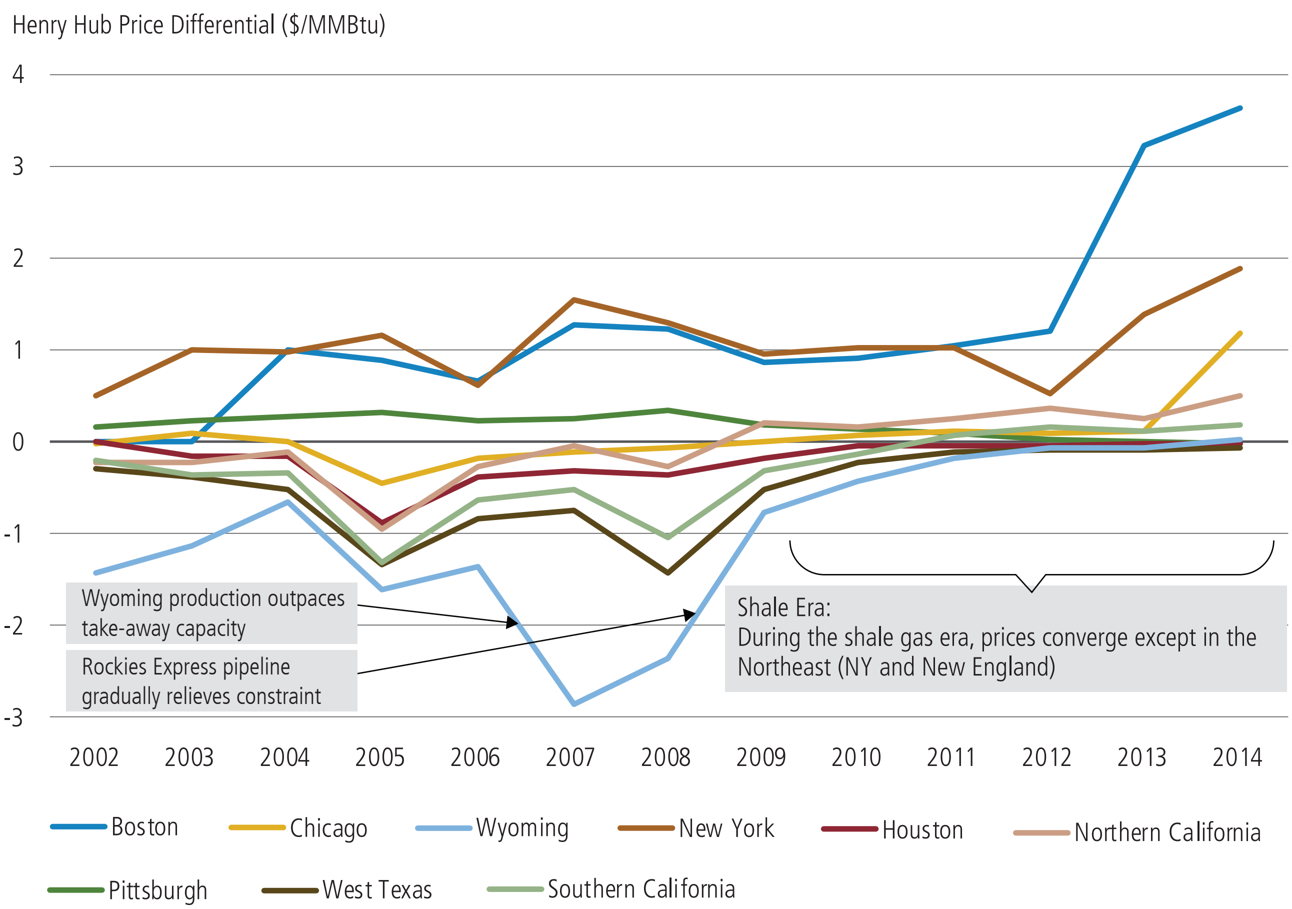
The majority of the problems experienced by the many generators that tripped, had their power output reduced, or failed to start during the event were attributable, either directly or indirectly, to the cold weather itself. However, at least another 12 percent of these problems were attributed afterward to the interdependencies between gas and electricity infrastructures (such as lost electricity generation due to natural gas curtailments to gas-fired generators and difficulties in fuel switching).

[t] Federal Energy Regulatory Commission and North American Electric Reliability Corporation. "Report on Outages and Curtailments During the Southwest Cold Weather Event of February 1-5, 2011: Causes and Recommendations." August 2011. http://www.ferc.gov/legal/staff-reports/08-16-11-report.pdf. Accessed February 2, 2015.

Natural Gas Infrastructure Constraints in the Northeast

The Northeast represents a region of the country where natural gas transmission constraints have caused price differentials to rise during periods of peak demand.[103] While, in the past few years, construction of natural gas pipelines in other parts of the country have caused natural gas price differentials to decrease in those regions, the Northeast has seen its price differentials increase (see Figure 2-7). Much of the northeastern Atlantic region (New England, New York, and—to some extent—the Mid-Atlantic States) continues to see natural gas supply constraints due to gas transmission capacity limits, especially during cold winter periods. However, the actions undertaken by the Independent System Operators, Regional Transmission Organizations, and market participants, such as PJM's Cold Weather Preparation Guidelines and the continuation of Independent System Operator New England's Winter Reliability Program for a second winter, have improved operational performance and moderated prices.[104]

Figure 2-7. Natural Gas Price Differentials between Henry Hub and Key Trading Points[105, u]



Basis differentials reflect regional gas infrastructure constraints and the price signal that spurs infrastructure investment. These constraints persist in New England and New York.

The Northeast region is located at the end of major pipeline routes from traditional natural gas producing areas. Its supplies of natural gas have tended to be constrained during winter peak periods, allowing prices to rise much higher in this region than in the rest of the country in recent years.[106] For example, natural gas prices

[u] The 2014 increase in Chicago city gate prices relative to Henry Hub is attributable to cold winter weather and deep drawdowns of gas in storage, rather than systemic infrastructure constraints, and is less likely to persist.

rose to greater than $34 per million British thermal unit during cold snaps in the winter of 2012-2013 and increased to more than $73 per million British thermal unit during the southward shifts in the polar vortex in the winter of 2013-2014.[107] These capacity constraints are being exacerbated by a large increase in the use of natural gas in the electric power sector in New England. Despite large volumes of new unconventional gas resources available from the Marcellus Shale in nearby Pennsylvania, pipeline constraints have not allowed sufficient supplies of this gas to reach New England, resulting in upward pressure on prices at gas delivery points in the region.[v] The New York metropolitan area, by contrast, has alleviated some of the winter congestion it had faced by adding new pipeline capacity.

The underlying issues affecting natural gas prices and reliability in New England are caused by several complex factors. One area of concern has been the role of capacity markets in the challenges associated with assuring access to adequate fuel supplies. Independent System Operator New England has taken a number of steps to address this issue, including implementing changes to its capacity markets to enhance generator performance and adopting winter reliability measures designed to address this concern.[108, 109] Another issue has been public acceptance of new pipelines, especially in New England, which presents a substantial challenge to natural gas pipeline development.[110] Several pending pipeline projects would alleviate infrastructure constraints into New England. In addition to the capacity market changes by Independent System Operator New England described above, the New England governors are formulating proposals to pay for new natural gas pipeline and electric transmission capacity and services.

Resilience, Reliability, and Asset Security of Liquid Fuels TS&D Infrastructure: Analysis of Vulnerabilities

The U.S. liquid fuels system is diverse, robust, and resilient. In 2014, it produced an average of 8.7 million barrels per day (million bbl/d) of crude oil and 3.0 million bbl/d of natural gas liquids, as well as imported an average of 7.3 million bbl/d of crude oil.[w, 111] In 2014, this system refined an average of 15.8 million bbl/d of crude oil into products in 142 operable refineries. While refining is concentrated on the Gulf Coast, the remainder is well-distributed between the East and West Coasts and the Upper Midwest and supplemented by product imports that enter through both coasts and from Canada. Its TS&D infrastructure consists of both dedicated pipelines and facilities and infrastructures shared with other major commodities.

Liquid Fuel Vulnerabilities Vary by Region

Despite the robustness of the system, the Nation's liquid fuel infrastructure has vulnerabilities. These vulnerabilities are determined by the types of natural disasters that occur in a region, as well as by the types of infrastructure within the region. Regions have supply vulnerabilities if they are dependent on fuel supplies from outside the region. This section describes the relationship between the functions of the liquid fuel infrastructure in a given region and the geographically based vulnerabilities that it faces for regions defined by Petroleum Administration for Defense District (PADD) groupings, a subdivision of the petroleum sector that is commonly used by the Energy Information Administration and other energy analysts.[112] The following are profiles of liquid fuel systems and vulnerabilities by PADD.[113]

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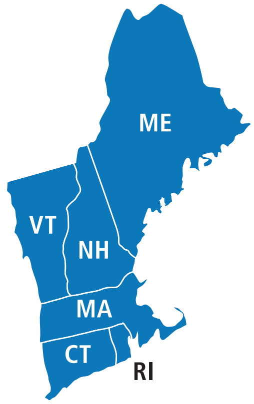
[v] For a more detailed discussion of infrastructure constraints in the New England area, see the documents relating to the April 21, 2014, Quadrennial Energy Review Stakeholder Meeting, "New England Regional Infrastructure Constraints:" energy.gov/epsa/downloads/qer-public-meeting-providence-ri-hartford-ct-new-england-regional-infrastructure.

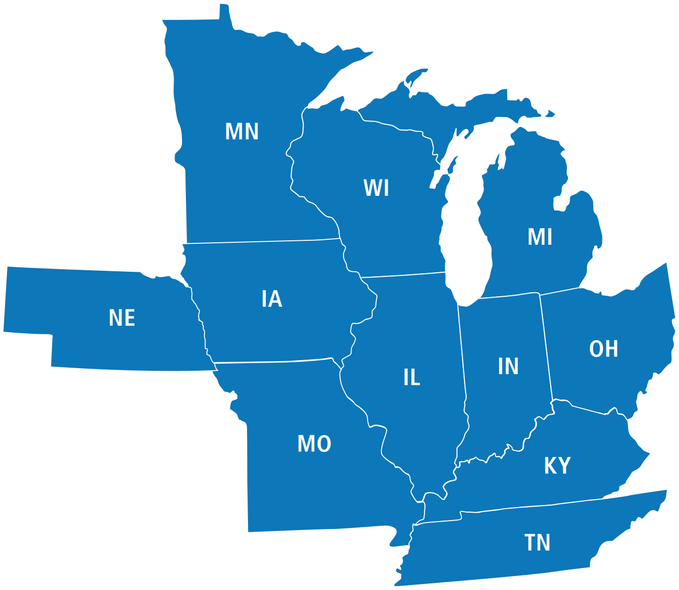
[w] Data are based on cumulative daily averages through December 26.



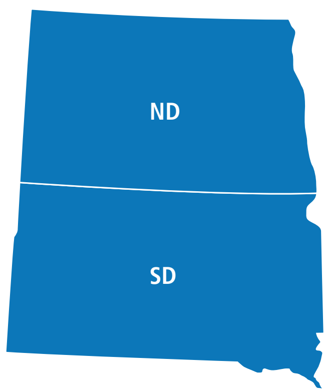
Atlantic Coast-North (PADD I, Subdistrict A): This region (the Atlantic Coast north of New York) has no crude oil production or refining capacity and is not served by large pipelines from the Gulf Coast. The region predominantly receives its supply of liquid fuels by waterborne transport. It is consequently susceptible to weather disruptions of ports. Infrastructure in this region is also susceptible to extreme cold.

Atlantic Coast-Central (PADD I, Subdistrict B): This region has only a small amount of capacity for producing or refining crude oil, relative to its consumption. It is heavily dependent on receiving water shipment of crude oil and refined products at coastal ports and on pipeline shipments of refined products from the Gulf Coast on the Colonial and Plantation pipeline systems. It has a relatively high level of storage for refined products. Liquid fuels shipments are susceptible to weather disruption of ports, flooding of coastal refineries and terminals, and disruptions to flows on Colonial and Plantation pipelines. During the past century, land subsidence has contributed to rising relative sea levels along the Mid-Atlantic Coast as high as 5.0–10.0 millimeters per year (mm/yr), which is more than twice the global average (1.7 mm/yr).[114]

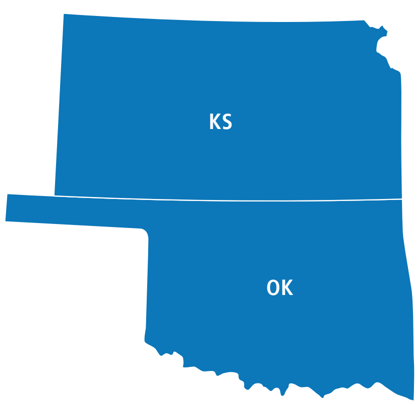
Atlantic Coast-South (PADD I, Subdistrict C): The southern part of this region (Florida and the coastal regions of Georgia, South Carolina, and North Carolina) has very little crude production or refining capacity and is not served by the large pipelines from the Gulf Coast. All coastal areas are supplied by waterborne deliveries, and Florida is heavily dependent on receiving water shipments of refined products. The interior portions of Georgia, South Carolina, North Carolina, and Virginia are dependent on pipeline shipment of refined products from the Colonial and Plantation pipeline systems. The region is susceptible to weather disruptions of receiving ports, pipeline shipments, as well as events that disrupt loading and departures of barges from the Gulf Coast. Over the past century, sea levels have increased by as much as 3–6 mm/yr in the Atlantic Coast-South region.[115]



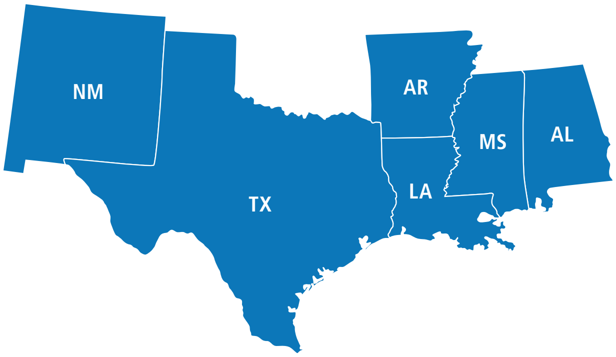
Great Lakes/Midwest Region (Part of PADD II): Refineries in this region have historically relied on crude oil shipped via pipeline from the Gulf Coast. Now almost all oil moved to refineries in the region comes from more recently developed supplies of Midcontinent and Canadian crude oil. This shift has diminished the need for pipelines to deliver crude oil from the Gulf of Mexico to the region, and many have been reversed to move additional Midcontinent and Canadian oil supplies south to the Gulf Coast (PADD III) refining complex. Weather events are less likely to affect multiple refineries in the Midwest compared to, for example, the refineries concentrated along the Gulf of Mexico. An earthquake in the New Madrid Seismic Zone could disrupt product deliveries, but it would be less likely now to disrupt crude oil supplies into the region than 5 years ago. Extreme cold can hinder refining and distribution.



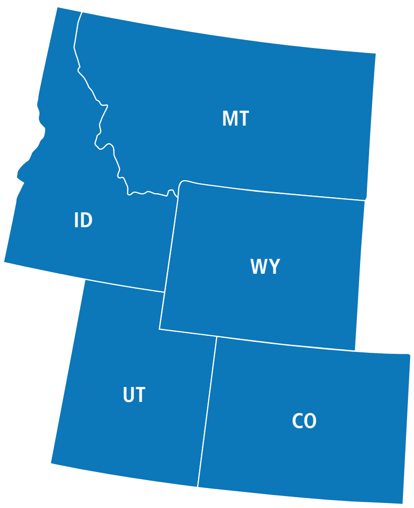
Williston Basin (Part of PADD II): Recent development of technology to produce oil from shale formations (in this case, the Bakken formation) has made the Williston Basin an important producing area. The area is not highly susceptible to natural disasters, but is susceptible to extreme cold. The East and West Coasts and the Gulf Coast rely on this region for rail transport to bring its crude to their refineries.



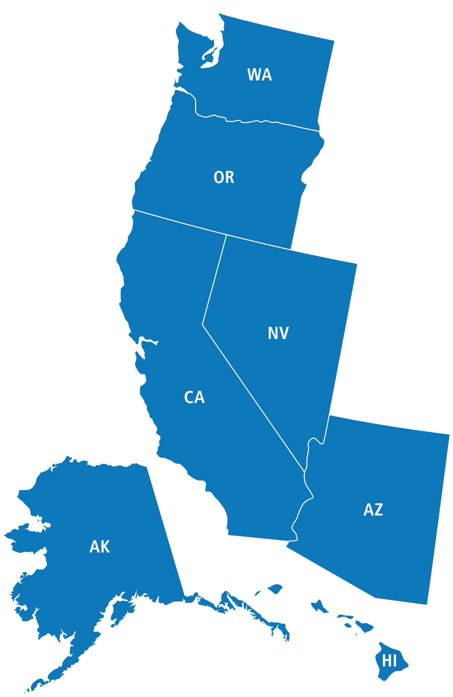
Oklahoma/Kansas (Part of PADD II): This region is a relatively large producer of crude oil and, more importantly, a national hub for trading, storing, and transporting crude oil. One of the largest oil storage and pipeline junction centers in the world is located near Cushing, Oklahoma. Tornados likely are the highest-impact hazard that could strike this area.



Gulf Coast (PADD III): This region is a major center for onshore and offshore production, refining, and loading and unloading of water shipments of crude oil and refined products. Fifty-two percent of the Nation's operable refinery capacity is in PADD III. It is susceptible to tropical storms and hurricanes, flooding, and sea-level rise. During the past century, land subsidence in the Gulf Coast region has caused relative sea levels to rise by 5–10 mm/year, which is more than the twice the global average. The highest rates of land subsidence within the Gulf Coast region are estimated to be in the vicinity of the Mississippi River Delta.[116]



Northern Rocky Mountain Region (PADD IV): This region consumes fuels from refineries in the Salt Lake and Denver areas that mainly process crude oil produced from within the region. The main hazards are earthquakes and perhaps tornados. It is susceptible to extreme cold. Pipelines networks are less dense in the less populated regions of PADD IV. This leads to cities that are far from refining centers often being served by long dedicated pipelines. These cities are more dependent on the operation of single pipelines than typically is the case in regions of the country with higher-density populations. An example in PADD IV is Boise, Idaho, which is dependent on a single pipeline from Salt Lake City.



West Coast Region (PADD V): Although this region still produces much of the crude oil processed in its refineries, it increasingly depends on receiving shipments by water from other regions and from ports within PADD V, including Alaska. PADD V is not well-connected to other PADDs by pipeline, but it does receive an increasing amount of its oil by rail. The level of imports to PADD V is stable. This region is susceptible to earthquakes and wildfires. Cities that are on the downstream edge of supply from West Coast refineries and depend on long dedicated pipelines include Phoenix, Arizona; Las Vegas, Nevada; and Reno, Nevada. During the past century, sea levels along the West Coast have generally risen at or below the global average rate.[117]

Vulnerability of Fuel Supply Disruptions from Gulf Coast Hurricanes

As noted, the Gulf Coast region is home to more than 50 percent of the Nation's refining capacity. Damage to liquid fuels infrastructure in this region can lead to significant impacts on much of the rest of the country, as the Gulf supplies oil products to the Northeast, Midwest, Mid-Atlantic, and South Atlantic regions.[118] Many U.S. regions are vulnerable to severe weather in the Gulf of Mexico or other threats to infrastructure in the Gulf of Mexico or on the Gulf Coast. Land subsidence also is a widespread issue throughout the Gulf Coast (and Mid-Atlantic coastal areas). During the past century, global sea-level rise has averaged about 1.7 mm/yr, though the rate in the Gulf has been faster (at 5–10 mm/yr, in part due to subsidence).[119] Between now and 2030, the average global sea-level rise could accelerate to as much as 18 mm/yr in worst-case scenarios.[120]

Gulf Coast refineries in the path of a major hurricane typically shut down in advance of a storm and restart after the storm has passed. While an undamaged refinery is likely to return to operation within 1 week of hurricane landfall, a severely damaged refinery might take several months to recover. Hurricanes Katrina and Rita provide examples of such impacts. The combined consequences of these two hurricanes in 2005 caused refinery outages of more than 4.5 million bbl/d. More than 20 refineries were shut down on the worst day, representing a loss of 67 percent of the Gulf's capacity and 28 percent of national refinery capacity. While the refineries recovered, the outage was still 2 million bbl/d 3 weeks after Rita's landfall and remained at 1 million bbl/d for over 2 months. This caused a sharp, temporary increase in regional and national gasoline and diesel fuel prices.[121]

In response to these hurricanes, 30.0 million bbl of crude oil from the Strategic Petroleum Reserve (SPR) were offered to the market and 20.8 million bbl were ultimately sold; it took 20 days for the first oil to move. While the International Energy Agency, in a coordinated effort, released petroleum product stocks to assist with the U.S. supply disruption, these supplies were not easily distributed to the Southeast region; truck deliveries to the Southeast region were made hundreds of miles from ports on the Atlantic Coast.

Similar petroleum product outages occurred in 2008 as a result of Hurricanes Gustav and Ike, leading to significant increases in motor fuel prices in all regions of the United States. In these instances, no SPR emergency release or International Energy Agency coordination action was taken.[x] In 2012, Hurricane Sandy caused numerous fuel supply and distribution problems in New York and New Jersey, involving refineries, marine terminals, petroleum product terminals, and retail service stations. As with the 2005 and 2008 hurricanes, an SPR crude oil release would have provided little remedy to the fuel supply problems. Also, all four U.S. facilities are located in the Gulf Coast region and may be exposed to hurricane damage, including inundation caused by storm surge.[122] In September 2008, for example, the Big Hill and West Hackberry sites sustained significant damage caused by Hurricane Ike.[123]

Industry has taken actions to harden Gulf Coast infrastructures after hurricanes in 2005 and 2008. Aboveground product storage tanks represent a particular vulnerability in hurricanes as they can float off their foundations and spill product, creating environmental and supply concerns. At least four companies surveyed by DOE in 2010[124] indicated that they had "taken steps to ensure a minimum volume of product is in their storage tanks before a storm arrives." The refinery and pipeline operators interviewed for this study all confirmed that they maintain confidential hurricane preparedness plans. State public utility commissions also have responded in a variety of ways, initiating studies of and rulemakings for storm hardening. On the power side, the actions of Entergy during Hurricane Gustav in 2008 provide an example of the efforts by utilities to maintain service to customers. Entergy's use of grid sensors enabled it to identify and warn of islanding conditions[y] in order to manage their impacts on its systems in four states. Entergy's success during Gustav provides a replicable example for the effective use of technologies to manage storm impacts.[125]

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[x] Some SPR sites sustained significant damage. While the SPR was able to conduct a test exchange of 5.4 million bbl of crude in response to requests for supplies from several refiners, it took weeks to restore SPR sites to their pre-storm levels of mission capability.

[y] Islanding is an unsafe situation for utility workers, where a distributed generator, when not appropriately monitored or understood, continues to provide power when electricity from the utility is cut off.

Vulnerabilities to Non-Weather-Related Refined Product Disruptions

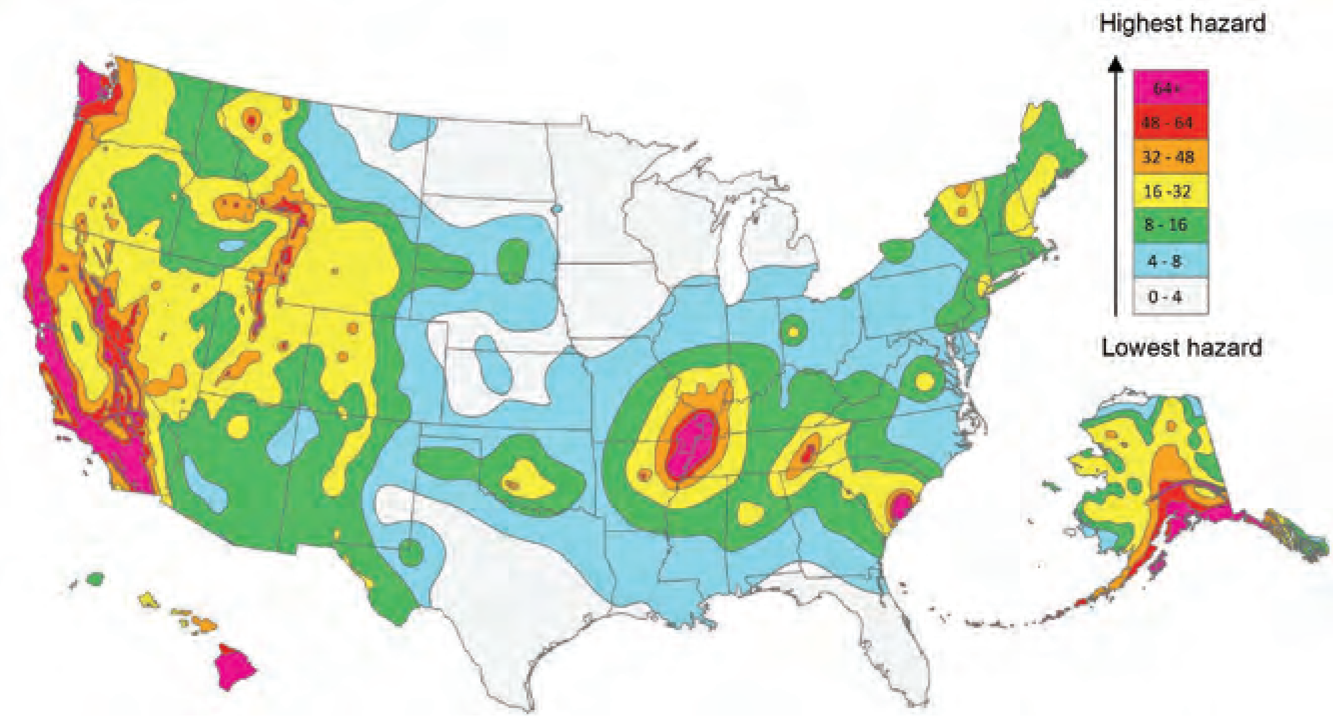
In addition to storms on the East and Gulf Coasts, other natural disasters can cause interruptions of petroleum products. While the U.S. West Coast is not as vulnerable to hurricanes, a severe earthquake in the Los Angeles Basin or San Francisco region would cause significant disruptions of fuel supplies. For example, Table 2-5 and Figure 2-8 show (1) the potential impacts of severe earthquakes on a variety of energy infrastructures, and (2) regions that are prone to damaging earthquakes. The greatest infrastructure risks occur when the probability of damage and severity of damage are high, the risk of the event is high, and the infrastructure involved is critical. Western pipelines and refineries are both at risk in major earthquakes.

Table 2-5. Probability and Severity of Earthquake Damage to TS&D Infrastructure[126]

Infrastructure	Magnitude<5		Magnitude >5	
	Probability of Damage	Severity of Damage	Probability of Damage	Severity of Damage
Loss of Electrical Power	Med	Significant	High	Catastrophic
Gulf of Mexico Platforms	Low-Med	Interrupting	Med	Significant
Pumping/Compressor Station	Low-Med	Interrupting	Med	Significant
Pipelines	Low-Med	Interrupting	Med-High	Major
Rail	Low	Insignificant	Med	Significant
Ports	Low	Insignificant	Med-High	Major
Crude Tank Farm	Low	Insignificant	Med	Significant
Refineries	Low	Insignificant	Med-High	Major
Natural Gas Plants	Low	Insignificant	Med	Significant
Product Storage Terminals	Low	Insignificant	Med	Significant
Propane Tanks	Low	Insignificant	Med	Significant
Underground Storage	Low	Insignificant	Low-Med	Interrupting
LNG Terminals	Low	Insignificant	Med	Significant
Local Natural Gas Distribution	Low	Insignificant	High	Catastrophic
Filling Stations	Low	Insignificant	Med	Significant
SPR/NEHHOR	Low	Insignificant	Low	Insignificant

For two magnitudes of earthquake intensity, the severity of probable damage was rated qualitatively using a five-point scale (i.e., insignificant, interrupting, significant, major, and catastrophic) and probability also on a 5-point scale (i.e., low, low-medium, medium, medium-high, and high).

Figure 2-8. Earthquake Vulnerability Hazard Regions Severity Indices for Earthquakes[127, z]



Analyzing the impacts of earthquake on TS&D infrastructure involved a review of the probability of damage and severity of damage on infrastructure components (Table 2-5) and the probability of an event occurring in a region. Comparing this to the types and amounts of energy infrastructure in the region (e.g., limited liquid fuels pipelines in the Rocky Mountain region) identified regional TS&D infrastructure vulnerabilites.

Responding to Liquid Fuels Disruptions

There is a range of actions that could be taken to address the vulnerabilities outlined in the previous section. One is to develop strategic and regional stockpiles of oil and refined petroleum products to help respond to shortfalls caused by breakdowns in the liquid fuel infrastructure, regardless of cause. Another is additional hardening. Hardening can consist of flood protection (e.g., berms, eves, and floodwalls), self-sufficient electric power (e.g., a generator sited at a facility that is configured to operate in a safe "island mode" disconnected from the local electricity grid to supply that facility with electricity during a local grid blackout[aa]), and other measures. A combination of these actions may provide the most cost-effective approach to avoid the loss of fuel supplies after a natural disaster, recognizing that government and industry (refiners, pipeline companies, utilities, power providers, the Army Corps of Engineers, and DOE) have different roles in implementing different measures.

[z] For a range of intensities of the event (e.g., earthquakes with a magnitude less than 5), the likely damage was rated on a qualitative 1–5 score (i.e., minor, interrupting, significant, major, and catastrophic). These ratings were based on the extensive review of impacts from past events and judgment of industry experts.

[aa] "Island" facilities are used at facilities such as hospitals, office buildings, and sometimes individual's homes; they can operate independently from the grid to provide electricity during a power outage.

Administration Activities for Liquid Fuels Resilience, Reliability, Safety, and Asset Security

Operations of Regional Oil Product Reserves. The President's Fiscal Year 2016 Budget requests $7.6 million to continue operation of the Northeast Home Heating Oil Reserve. The Northeast Gasoline Supply Reserve will continue to be funded out of prior-year balances.

Southeast Refined Product Reserve Cost-Benefit Analysis. In 2011, the Department of Energy (DOE) carried out a cost-benefit study of the establishment of a Southeast Refined Product Reserve. This study estimated that such a Refined Petroleum Product Reserve would reduce the average gasoline price rise by 50 percent to 70 percent in the weeks immediately after a hurricane landfall, resulting in consumer cost savings.[ab] DOE is updating this study to reflect recent economic research and to examine whether currently available analyses of refinery hardening and climate change alter the study's estimates of the likelihood of Gulf Coast refinery outages.

West Coast Regional Refined Product Reserve Cost-Benefit Analysis. DOE has launched a Refined Petroleum Product Reserve study for Petroleum Administration for Defense District (PADD) V (the West Coast, Alaska, and Hawaii). It will review current and projected oil and refined product demand in southern California, northern California, Arizona, Nevada, Washington, Oregon, Hawaii, and Alaska. It also will describe storage capacities; how and where stocks are stored; and how refined products move from refinery, to storage, to end-use markets. The study will evaluate the physical and market vulnerabilities that could cause a supply disruption or shortage to PADD V markets and estimate the probability of the occurrence of natural events at various locations within PADD V. The potential impacts on crude oil and petroleum product supplies from events of various intensity or duration will be estimated. The physical vulnerabilities to be considered will include earthquakes, tsunamis, and storms. Refined Petroleum Product Reserve configurations that could provide a relatively effective fuel supply relief, in light of the estimated likelihood of fuel supply interruptions, will be evaluated using a cost-benefit methodology similar to that used in DOE's 2011 study,[ac] but will be updated to reflect recent economic research, especially concerning the impact of sudden increases of petroleum product prices on the U.S. economy.

Emergency Preparedness Study. The National Petroleum Council, in response to a request from the Secretary of Energy, recently completed an Emergency Preparedness Study. This study will help industry and government achieve a more rapid restoration of motor fuel supplies after a natural disaster.

[ab] Department of Energy, Office of Fossil Energy and Office of Policy and International Affairs. "Refined Petroleum Product Reserve, Assessment of Energy Security Needs, Costs and Benefits." September 2011.

[ac] Department of Energy. "Regional Petroleum Product Reserve: Assessment of Energy Security Needs, Costs, and Benefits." September 2011.

The United States has created two regional petroleum product reserves (RPPRs) during the last 15 years—the Northeast Home Heating Oil Reserve (NEHHOR) and the Northeast Gasoline Supply Reserve. NEHHOR is a 1-million-barrel reserve of ultra-low sulfur diesel, stored at terminals in Connecticut and Massachusetts. It is intended to provide a buffer to compensate for interruptions in heating oil supplies during severe winter weather. NEHHOR has a trigger mechanism established by the Energy Act of 2000 that requires a 60 percent price differential over the 5-year average price of heating oil, that the differential be sustained for 7 days, and that it continues to increase thereafter. A second authority for a release from NEHHOR is available to the President for a "regional supply shortage of significant scope and duration."[128] These release authorities have never been used. After Hurricane Sandy, however, NEHHOR distillate was provided to the Department of Defense. The Defense Logistics Agency distributed this fuel to support emergency operations and other priorities.

Also, the Northeast Gasoline Supply Reserve currently contains about 1 million barrels of gasoline in five locations in New Jersey, Massachusetts, and Maine to serve consumers in the northeastern United States. This gasoline reserve operates under the same release authorities as the SPR, but under different authorities than the NEHHOR; depending on the nature and degree of the emergency, the threshold for use of these facilities in concert could prove difficult to reach.

Liquid Fuel TS&D Dependencies on Electricity

In 2013, U.S. refineries consumed a total of 46 million megawatt-hours of purchased electricity in their operations. One of the biggest vulnerabilities for Gulf Coast and East Coast refineries can be the lack of electricity supply. Without power, refineries cannot continue to operate, and petroleum products cannot be moved through pipelines. A number of refineries have invested in portable generators; however, the majority has only established plans for leasing generators in advance of the hurricane, and even the largest 2-megawatt mobile generators cannot provide enough electricity to operate a refinery. During electrical outages, these generators provide electricity to critical facilities—the data control center, critical information technology facilities, and the water pumps required to remove storm water from the plant and refinery equipment. The high probability of electricity outages after hurricanes has caused refiners to initiate controlled shutdowns in advance of landfalls to avoid "cold shutdowns" that result in refinery damages.

Crude oil and refined product pipelines also rely on electricity to move petroleum products, such as gasoline, through their systems. As noted, power outages from Hurricane Katrina caused the complete shutdown of three major pipelines for 48 hours and forced these pipelines to operate at reduced capacities for an additional 2 weeks.[129] In 2006, Colonial Pipeline responded to the need to keep pipelines operating during emergencies by installing trailer-mounted portable generators, some transformers, and additional cables. The generators are staged at a site in Mississippi and can be moved to any of Colonial's pump stations depending on emergency needs.[130]

Even these actions, however, have limitations, as they assume uninterrupted supplies of product from refineries and terminals. Evidence suggests this is problematic, as transmission pipelines depend on many independent and interconnected pipelines and terminals for delivery of supplies; the overall network feeding major transmission pipelines may not be able to meet supply needs in the event of a disruption. Also, this intermediary infrastructure is often co-owned by refineries; if a refinery is disrupted and vulnerable, so too are the interconnecting pipelines and ultimately the transmission pipelines that move product to consumers.[131]

Refineries, pipelines, and distribution systems also rely on electricity to power supervisory control and data acquisition and other monitoring systems that ensure that their operations are efficient, safe, and secure. Finally, the loss of electricity can have a significant impact on retail gasoline distribution (see the Hurricane Sandy box on page 2-5).

Vulnerabilities of Shared Transportation Infrastructures

Transportation infrastructure (such as railroads, barges, tankers, and ports) that liquid fuels and coal share with other commodities also face resilience challenges from extreme weather and climate change. As noted, extreme weather events are increasing. Intermodal crossing points, such as grade crossings and waterway-railroad trestle intersections, will be vulnerable, as will stretches of rail far removed from observational networks.[132]

Rail Vulnerabilities Associated with Extreme Weather

Railroads are vulnerable to structural damage and track misalignment where the roadbed has been affected by extreme weather. Railroad operations also are affected by weather conditions such as snow, flash floods, heat waves, and extreme wind. Extreme heat, for example, causes materials to expand, leading highways and roads to buckle and rails to kink (see Figure 2-9). A 1,800-foot section of rail can expand by a foot with an 80-degree temperature change.[133] These kinks can be highly dangerous and require vigilant track inspections. Some rail operators also issue "heat orders" during high temperatures that require trains to slow their speed along the tracks.[134]

Barge and Tanker Transport Are Affected by Extreme Weather

More than 4,500 tank barges transport liquid fuels and coal nationwide.[136, 137] They are vulnerable to damage by storm surge, as well as river flow fluctuations (e.g., on the Mississippi River) that can impede traffic or reduce barge fuel carrying capacity. During Hurricane Katrina, the Coast Guard closed parts of the Lower Mississippi River to traffic for more than a week as inspectors surveyed the river obstructions. More than 300 barges along the river were set adrift, sunk, or damaged, posing further risks to navigation.[138] Increased storm surge and flooding could interrupt barge navigation by flooding inland marine transportation infrastructure and increasing the velocity of flow on rivers, forcing channels to shutdown intermittently. In the long term, increased incidents of storm surge and coastal flooding may cause sand formations to build up in channels, forcing operators to shutdown channels that have become too shallow.

Figure 2-9. Rail Thermal Misalignment[135]

Track buckling is typically caused by a combination of high compressive forces due to temperature stresses, weakened track conditions, and mechanical stress from train braking and rolling friction. Safety and operations are therefore impacted by both extreme high and low temperatures, by causing track creep, and by making track more susceptible to the mechanical stresses that cause buckling.

Flooding by itself can have an impact on pump stations, control rooms, oil tanks, well pads, and barges or tankers travelling on flooded navigable waterways, such as the Mississippi River. High water conditions can disrupt barge and tanker traffic by, for example, barring navigation under bridges. In addition, if port and terminal facilities were flooded and shutdown, barge shipments that require loading or unloading at the terminals would be delayed.[139]

Drought can also affect some port facilities and some navigation channels that are inland, such as the Great Lakes. If water levels are too low, barges risk running aground, causing either disruptions to liquid fuel transport or lower draft limits. This forces barges to carry lighter loads, thereby reducing available supply.[140] Low water levels also can be caused by freezing temperatures upstream, leaving less water available downstream.[141] Climate change is expected to cause more frequent and severe weather in the future, which in some regions will lead to droughts and floods that may create further vulnerabilities for barge transport.

Vulnerabilities of Energy TS&D and Shared Infrastructures to Physical Attack

The lack of controlled standoff distances[ad] or adequate barriers for a range of oil and gas transmission and distribution facilities and infrastructures makes them especially vulnerable to physical attacks. Much of the liquid fuel TS&D infrastructure in the central Atlantic Coast region, for example—including gas production, ports and terminals, and processing and refining facilities—is geographically concentrated, visible, and potentially accessible from major and ancillary transportation routes, making it vulnerable to intentional damage.[142] Physical attacks on this type of infrastructure could have outsized impacts because of the concentration of refining and product storage facilities that serve other domestic markets.

[ad] "Controlled standoff distance" refers to the distance maintained between an asset and a potential detonation site.

Results from an Argonne National Laboratory analysis of DHS survey data[ae] on critical infrastructure energy facilities showed that at many facilities vehicles may pose a risk by being placed (legally or illegally) inside a safe standoff perimeter.

Increasing standoff distance is an effective way to mitigate potential consequences of certain types of threats. Other measures include fencing, barriers, access control points, and security personnel. Notably, only a portion of energy facilities has barriers in place sufficient to limit vehicle access and approach. The DHS critical infrastructure survey also assessed the existence of security forces at facilities. The prevalence of security forces is highly dependent on the energy subsector. Refineries generally have a security force, but liquid fuel product transport facilities tend to have less security.

Improving Cybersecurity in the U.S. Energy Sector

This installment of the Quadrennial Energy Review did not carry out original analysis of cyber threats to energy infrastructure because significant work is being done elsewhere. It is noted, however, that cyber threats to energy delivery systems are growing and evolving. In 2013, there were 151 cyber incidents involving the energy sector that were reported to the Department of Homeland Security's Industrial Control System Cyber Emergency Response Team. Cybersecurity is a shared responsibility among Federal, state, local, tribal, and territorial entities, as well as public and private owners and operators of critical infrastructure.

In February 2013, President Obama issued Executive Order No. 13636, *Improving Critical Infrastructure Cybersecurity*, and Presidential Policy Directive-21, Critical Infrastructure Security and Resilience. These policies reinforce the need for holistic systems thinking about security and risk management in the energy sector. In February 2014, the Obama Administration launched the Cybersecurity Framework to assist organizations in enhancing critical infrastructure cybersecurity.

While the Department of Homeland Security coordinates the overall Federal effort to promote the security and resilience of the Nation's critical infrastructure, in accordance with Presidential Policy Directive-21, the Department of Energy serves as the day-to-day Federal interface for sector-specific activities to improve security and resilience in the energy sector. This Quadrennial Energy Review report does not go into detail about cybersecurity; the U.S. government and others have activities underway to improve cybersecurity of critical infrastructure. Improving security and resilience includes accelerating progress in the following areas relevant to the Quadrennial Energy Review:

Build robust information-sharing architecture across the energy sector. Robust information sharing between government and industry (including owners and operators) is critical for addressing cyber threats. Information Sharing and Analysis Centers help propagate information on cyber threats, vulnerabilities, incidents, and solutions in the energy sector.

Expand implementation of best practices and sound investments by owners and operators. The Cybersecurity Capability Maturity Model, developed by the Department of Energy in partnership with industry and others, can identify and assess various practices for energy sector cybersecurity. In many cases, there is an opportunity for owners and operators of critical infrastructure to invest more in people, processes, and technology that can improve security and resilience. The model can assist those responsible for overseeing cybersecurity decisions.

Develop and deploy cutting-edge technical solutions. Experience indicates that proactive measures taken on the basis of advanced research and development can provide a defensive edge. The Department of Energy has partnered with energy sector owners, operators, and vendors since 2006 to research, develop, and deploy cybersecurity solutions according to a set of near-, mid-, and long-term objectives outlined in the "Roadmap to Achieve Energy Delivery Systems Cybersecurity," which was developed through government-industry partnership.

Build a strong incident management capability. Government and industry are developing a strong capability to respond to serious cybersecurity incidents in the energy sector. Incident response plans need to be developed, vetted, and tested through progressively challenging exercises, culminating in a capstone-type exercise like GridEx, which is hosted by the North American Electric Reliability Corporation. Future exercises could address the interdependency between the electricity subsector and the oil and gas subsector.

[ae] DOE's Office of Energy Policy and Systems Analysis requested that Argonne National Laboratory's Infrastructure Assurance Center conduct an analysis of the protection and resilience information collected through DHS's Enhanced Critical Infrastructure Program Initiative, which conducts facility site visits and surveys. The primary objective of this analysis was to identify gaps in preparedness and rapid recovery measures for surveyed energy facilities. The analysis was conducted on 273 energy facilities (170 electricity, 45 liquid fuels, and 15 natural gas) using data collected from January 2011 through September 2014.

QER Recommendations

This chapter has laid out a broad range of crucial issues and questions relating to improving the resilience, reliability, security, and safety of energy TS&D infrastructures. To continue to drive progress toward improving these key energy infrastructures, we recommend taking the following additional actions:

Develop comprehensive data, metrics, and an analytical framework for energy infrastructure resilience, reliability, and asset security: Multiple gaps in federally accessible data impede decision making on policies and investment related to resilience, reliability, and security. These data are critical for understanding the extent to which our existing energy infrastructure is resilient and for better informing resilience investments. DOE, in collaboration with DHS and interested infrastructure stakeholders, should develop common analytical frameworks, tools, and metrics to assess the resilience, reliability, and security of energy infrastructures. The purpose of this work will be to help inform, coordinate, set priorities for, and justify expenditures across Federal agencies to increase the resilience, reliability, and security of energy infrastructure.

Establish a competitive program to accelerate pipeline replacement and enhance maintenance programs for natural gas distribution systems: The proposed DOE program would provide Federal competitive financial assistance to states to incentivize cost-effective improvements in the safety and environmental performance of natural gas distribution systems. Specifically, it would target transitional assistance (for a 3- to 4-year period) to help low-income households absorb initial rate increases related to these activities; it would also provide incentives to accelerate the reduction of methane emissions through repairs of other system components. This includes programs to accelerate the rate of replacement and repair of pipelines made of leak-prone materials and direct inspection and maintenance to reduce emissions from regulators and meters at city gate facilities. Providing rate assistance to low-income customers could incentivize states to expand current special regulatory cost-recovery programs, which in turn would facilitate increased private investment in infrastructure modernization. (See additional discussion on employment and workforce training in Chapter VIII, Enhancing Employment and Workforce Training).

The program would be implemented through financial assistance to states awarded on a nationwide competitive basis. State applicants would be required to demonstrate how the proposed financial assistance would be integrated with rate-setting programs that would ensure that the funds are applied to the targeted beneficiaries. Applications could be prioritized for funding based on estimated net benefits of the proposal, considering factors such as enhancement of public safety, magnitude of methane emission reduction, innovation in technical and policy approaches, number of beneficiaries, and overall cost effectiveness. DOE would establish specific guidelines for each of the evaluation criteria.

The estimated cost for this program is $2.5 billion to $3.5 billion over 10 years.

QER Recommendations (continued)

Support the updating and expansion of state energy assurance plans: DOE began a State Energy Assurance Planning Initiative in 2009 with funding from the American Recovery and Reinvestment Act of 2009. The President's Fiscal Year 2016 Budget proposes $35 million to establish a State Energy Assurance grant program to finance state, local, and tribal governments to continue this important task. DOE should continue a multi-year program of support for state energy assurance plans, focusing on improving the capacity of states and localities to identify potential energy disruptions, quantify their impacts, and develop comprehensive plans that respond to those disruptions and reduce the threat of future disruptions.

- The specific objectives of this initiative should be as follows:
    1. Strengthen and expand state, local, and tribal energy assurance planning and resilience efforts by incorporating innovative technologies and measures to improve resilience.
    2. Build state in-house energy assurance expertise.
    3. Build regional energy assurance capability to allow states, localities, and tribes to better identify the potential for energy disruptions, quantify the impacts of those disruptions, and develop comprehensive mitigation and response plans.
    4. Address the disproportionate impacts of potential energy disruptions on vulnerable or underserved communities.
- Energy assurance plans funded under this recommendation should be continually updated to reflect changing conditions and new threats and should be tested for adequacy in simulations or exercises to maintain staff capacity to implement the plans.
- As part of updating the state energy assurance plans, states would be encouraged to work with industry and each other to identify locations where energy infrastructure is particularly vulnerable to disruption (e.g., by physical attack) and craft effective strategies to reduce vulnerability and coordinate preparedness and response plans.
- As part of these plans, states should also assess needs for backup electricity at retail gasoline stations along emergency evacuation routes.
- DOE should encourage strong intergovernmental coordination to ensure state and local energy assurance plans interface with one another, as well as with Federal and private sector disaster and emergency response plans.
- Having a state energy assurance plan that meets a threshold of completeness and rigor should be an eligibility requirement for other kinds of Federal funding related to energy infrastructure.
- This program should be supported on either a 2-year or 3-year cycle.

On a 3-year cycle, the estimated support needed for this program over 10 years is $350 million. On a 2-year cycle, the estimated support needed for this program over 10 years is $500 million.

QER Recommendations (continued)

Establish a competitive grant program to promote innovative solutions to enhance energy infrastructure resilience, reliability, and security: DOE should establish a program to provide competitively awarded grants to states to demonstrate innovative approaches to TS&D infrastructure hardening and enhancing resilience and reliability. A major focus of the program would be the demonstration of new approaches to enhance regional grid resilience, implemented through the states by public and publicly regulated entities on a cost-shared basis, incorporating lessons learned from new data, metrics, and resilience frameworks.

- An example of such a project is the NJ TRANSITGRID, which incorporates renewable energy, distributed generation, and other technologies to provide resilient power to key NJ TRANSIT stations, maintenance facilities, bus garages, and other buildings. Through a microgrid design, NJ TRANSITGRID will also provide resilient electric traction power to allow NJ TRANSIT trains on critical corridors, including portions of the Northeast Corridor, to continue to operate even when the traditional grid fails.[143] This project received $410 million from the Department of Transportation in late 2014 and partnered with DOE on project design.
- The Department of Housing and Urban Development's National Disaster Resilience Competition, which supports innovative resilience projects at the local level, could also serve as a model for types of projects to be funded, with a specific focus on energy.
- The grant program should also include incentives to establish mandatory resilience standards and codes. States, tribes, and local governments with resilience standards in place would be eligible to receive cost-shared grant funding. Approved state energy assurance plans could also be a criterion for eligibility.

The estimated cost for this program is $3 billion to $5 billion over 10 years.

Analyze the policies, technical specifications, and logistical and program structures needed to mitigate the risks associated with loss of transformers: As part of the Administration's ongoing efforts to develop a formal national strategy for strengthening the security and resilience of the entire electric grid for threats and hazards (planned for release in 2015), DOE should lead—in coordination with DHS and other Federal agencies, states, and industry—an initiative to mitigate the risks associated with the loss of transformers. Approaches for mitigating this risk should include the development of one or more transformer reserves through a staged process.

- The staged process should begin with an assessment of technical specifications for reserve transformers, where transformers would be located and how many would be needed, how transformers would be secured and maintained, how transformers might be transported, and whether new Federal regulatory authorities or cost share are necessary and appropriate. These reserves may include smaller, deployable transformers.
- The analysis under this process should both recognize significant efforts already underway by industry to share transformers and parts, including planning for surge manufacturing and long-term standardization of transformer designs, and build on policy work already underway by Federal regulators.

QER Recommendations (continued)

Analyze the need for additional or expanded regional product reserves: The benefits of an RPPR derive from its ability to replace lost product supplies in emergency situations and mitigate sharp increases in petroleum product prices. DOE should undertake updated cost-benefit analyses for all regions of the United States that have been identified as vulnerable to fuel supply disruptions. Additional or expanded RPPRs could be supported, depending on the outcome of these studies.

Integrate the authorities of the President to release products from RPPRs into a single, unified authority: Congress should amend the trigger for the release of fuel from NEHHOR and from the Northeast Gasoline Supply Reserve so that they are aligned and properly suited to the purpose of a product reserve, as opposed to a crude oil reserve.

RECOMMENDATIONS IN BRIEF:
Increasing the Resilience, Reliability, Safety, and Asset Security of TS&D Infrastructure

Develop comprehensive data, metrics, and an analytical framework for energy infrastructure resilience, reliability, safety, and asset security. The Department of Energy (DOE), in collaboration with the Department of Homeland Security and interested infrastructure stakeholders, should develop common analytical frameworks, tools, metrics, and data to assess the resilience, reliability, safety, and security of energy infrastructures.

Establish a competitive program to accelerate pipeline replacement and enhance maintenance programs for natural gas distribution systems. DOE should establish a program to provide financial assistance to states to incentivize cost-effective improvements in the safety and environmental performance of natural gas distribution systems, through targeted funding to offset incremental costs to low-income households and funding for enhanced direct inspection and maintenance programs.

Support the updating and expansion of state energy assurance plans. DOE should undertake a multi-year program of support for state energy assurance plans, focusing on improving the capacity of states and localities to identify potential energy disruptions, quantify their impacts, share information, and develop and exercise comprehensive plans that respond to those disruptions and reduce the threat of future disruptions.

Establish a competitive grant program to promote innovative solutions to enhance energy infrastructure resilience, reliability, and security. DOE should establish a program to provide competitively awarded grants to states to demonstrate innovative approaches to transmission, storage, and distribution (TS&D) infrastructure hardening and enhancing resilience and reliability. A major focus of the program would be the demonstration of new approaches to enhance regional grid resilience, implemented through the states by public and publicly regulated entities on a cost-shared basis.

Analyze the policies, technical specifications, and logistical and program structures needed to mitigate the risks associated with loss of transformers. As part of the Administration's ongoing efforts to develop a formal national strategy for strengthening the security and resilience of the entire electric grid for threats and hazards (planned for release in 2015), DOE should coordinate with the Department of Homeland Security and other Federal agencies, states, and industry—an initiative to mitigate the risks associated with the loss of transformers. Approaches for mitigating this risk should include the development of one or more transformer reserves through a staged process.

Analyze the need for additional or expanded regional product reserves. DOE should undertake updated cost-benefit analyses for all regions of the United States that have been identified as vulnerable to fuel supply disruptions to inform subsequent decisions on the possible need for additional regional product reserves.

Integrate the authorities of the President to release products from regional petroleum product reserves into a single, unified authority. Congress should amend the trigger for the release of fuel from the Northeast Home Heating Oil Reserve and from the Northeast Gasoline Supply Reserve so that they are aligned and properly suited to the purpose of a product reserve, as opposed to a crude oil reserve.

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