United States Fuel Resiliency

Volume II

U.S. Fuels Supply Infrastructure Vulnerability to Natural and Physical Threats

FINAL REPORT

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INTEK Inc.

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Data related to fuels supply and movements and descriptions of infrastructure were current at the time this report was prepared. The global and U.S. oil, natural gas, and refined products markets, supply patterns, and infrastructure are changing rapidly.

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List of Units

Bbl	Barrel (1 barrel = 42 gallons)
MBbl	Thousand barrels
MMBbl	Million barrels
Bbl/d	Barrels per day
MBbl/d	Thousand barrels per day
MMBbl/d	Million barrels per day
Mcf	Thousand cubic feet
MMcf	Million cubic feet
Bcf	Billion cubic feet
Tcf	Trillion cubic feet
Mcf/d	Thousand cubic feet per day
MMcf/d	Million cubic feet per day
Bcf/d	Billion cubic feet per day
Gyr	Gallons per year
MGyr	Thousand gallons per year
MMGyr	Million gallons per year
BGyr	Billion gallons per year
Btu	British Thermal Unit (~1055 joules)
Mph	Miles per hour

List of Abbreviations

DOE	U.S. Department of Energy
E&P	Exploration and Production
EF	Enhanced Fujita Scale
EIA	U.S. Department of Energy Energy Information Administration
EPA	U.S. Environmental Protection Agency
F	Fujita Scale
GOM	Gulf of Mexico
LNG	Liquefied Natural Gas
LOOP	Louisiana Offshore Oil Port
LPG	Liquid Petroleum Gas
MMI	Modified Mercali Intensity
NEHHOR	Northeast Home Heating Oil Reserve
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
PADD	Petroleum Administration for Defense Districts
PGA	Peak Ground Acceleration
QER	Quadrennial Energy Review
SAC	Safety Alliance of Cushing
SPR	Strategic Petroleum Reserve
TS&D	Transportation, Storage, and Distribution
USACE	U.S. Army Corps of Engineers
USDA	United States Department of Agriculture
USGS	United States Geological Survey

I. Introduction

A. The Nation's Vulnerability Profile

The nation's oil and natural gas and refined products infrastructure faces threats from a variety of sources both natural and man-made. High-profile weather events such as Hurricane Sandy, Hurricane Katrina, the 2012 Mid-Atlantic Summer Derecho, and the recent Polar Vortex event have placed a spotlight on the nation's fuel resiliency and the need to mitigate the effects of such disasters. The hurricanes damaged infrastructure, caused large production losses, and led to supply disruptions both for refiners and consumers. The derecho and polar vortex events introduced the nation to these previously nearly unheard-of disasters which had similar consequences, causing disruptions throughout the system. The Northeast was particularly hard hit by extreme winter weather as demand for natural gas and propane both for heat and electricity outstripped supply and caused major pipeline congestion.

Compounding the nation's vulnerability to natural disasters is climate change. Average global temperature has risen 1.4 degrees Fahrenheit in the past century and is predicted to rise further in the coming decades. Warming could cause sea levels to rise, putting coastal cities and infrastructure at greater risk and exacerbating the effects of such natural disasters as hurricanes and tsunamis. Rising temperatures can contribute to extreme weather events, creating more frequent heat waves, longer droughts, and possibly a rise in the number of hurricanes and disruptions in the polar vortex. Either climate change or the changing and expanding fuels supply infrastructure, alone, would merit a rethinking of vulnerabilities and mitigation approaches. Considered in tandem it is clear that key infrastructure vulnerabilities must be identified and addressed to ensure future system resiliency.

Concerns about terrorism also require the nation's attention. While there have been no high-profile incidents of terror attacks on oil and gas infrastructure, its importance to a robust economy and national security makes this infrastructure a prime target, and a critical point of focus when considering vulnerability and resiliency issues.

Visible and historic events have shaped the concerns addressed in this study, yet not to the exclusion of others. One key goal in infrastructure and fuel resiliency is to identify and address potential issues before they become problems. Another facet of vulnerability is the nation's aging infrastructure. All currently active refineries were built before 1976. Subsequent capacity growth is due to numerous refinery expansions. Transportation infrastructure also presents vulnerabilities. Almost 60% of gas transmission lines and 56% of oil pipelines were built before 1970.[1] Most of the locks, which conduct the flow of traffic on the country's waterways are over 50 years old, and much needed maintenance has been delayed or deferred.[2]

Part I of this study analyzed some of the key changes in the nation's fuels supply system and infrastructure. Domestic oil production has increased rapidly in recent years, reducing a heavy reliance on overseas imports. The Bakken and Eagle Ford shale plays, in particular, have contributed much of the growth, adding 2.44 MMBbl/d (million barrels per day). While seaborne imports have fallen, oil imports from Canada have increased with the increased availability of heavy synthetic syncrudes produced from oil sands.

Concurrently, the rapid development of U.S. shale gas resources has increased domestic natural gas supply significantly, requiring development of new underground storage, construction of new gas processing capacity, and new pipeline transportation capacity. The growing natural gas supply has stimulated fuel switching by domestic consumers and power generators and created opportunities for export of liquefied natural gas (LNG) to foreign markets. Together, this rapidly expanding North American production is reducing the nation's reliance on crude oil imports from countries in the Middle East, Africa, and Central and South America regions and strengthening North American energy security.

As the nation's fuel supply and infrastructure changes, a new landscape exposes new and different. For instance, shifts in the sources of petroleum supply resulted in bottlenecks and chokepoints at major hubs in the existing crude oil storage and transportation system, accompanied by wellhead oil price impacts. The U.S. fuels infrastructure is changing rapidly to respond to changing storage, transportation, and processing requirements. Pipelines flows are being reversed, pipeline capacity is being expanded, and new storage capacity is being added. Expanded transport of crude oil by rail and barge to refining centers in the Midwest, East Coast, West Coast and Gulf Coast allows pipeline chokepoints to be bypassed until new pipeline capacity can be constructed.

B. Purpose of Study

Established in 2013, Office of Energy Policy and Systems Analysis (EPSA) is the primary energy policy advisor to the Secretary and Deputy Secretary on domestic energy policy development and implementation as well as the Department of Energy (DOE) policy analysis and activities. The fundamental role of EPSA is to deliver unbiased energy analysis to DOE leadership on existing and prospective energy-related policies, focusing in part on integrative analysis of energy systems. In addition, EPSA serves as the Secretariat of the Quadrennial Energy Review (QER) across the U.S. Government, with primary responsibility for supporting the White House interagency process and providing to it data collection, analysis, stakeholder engagement, and data synthesis.

To support this effort, INTEK Inc. was contracted to conduct a detailed technical and analytical assessment of the nation's oil and gas infrastructure, focusing on assessing and making recommendations to EPSA regarding the resiliency and vulnerability of the U.S. fuel supply system. In the context of the EPSA vision for infrastructure, resiliency is a sub characteristic of the trait of robustness. A robust energy system will continue to perform its functions under diverse policies and market conditions, and has its operations only marginally affected by external or internal events. Resiliency is the ability to withstand small to moderate disturbances without loss of service, to maintain minimum service during severe disturbances, and to quickly return to normal service after a disturbance.

Part I of this study characterized the U.S. fuels infrastructure. The purpose of Part II of this study is to assess regional vulnerabilities impacting and potentially undermining the U.S. Fuel Supply System in the form of natural disasters, physical security system vulnerabilities, interdependencies of various systems, and choke points within the systems.

C. Approach

This study describes vulnerabilities to natural disasters and human acts that can impact the nation's fuel infrastructure and supply. For natural disasters, a description of each event will be given, followed by the types of impacts that event could have on fuels supply infrastructure, a description of recent historical disasters in the U.S., the probability and severity of the impact on various infrastructure components, and an analysis of key regions likely to be impacted by the disaster. These events will then be consolidated to pinpoint regional vulnerabilities.

In addition to natural disasters, the U.S. fuels infrastructure faces vulnerabilities due to physical human threats, chokepoints, and interdependencies within and between the various systems. Human threats to key infrastructure will be characterized and analyzed to determine the most vulnerable parts of the infrastructure which, if damaged, could result in supply disruptions. Chokepoints in the crude, refined products, and natural gas fuel supply chains will also be analyzed to determine key places of disruption and if there are any alternatives that need to be considered. Finally, a discussion of interdependencies will allow for a "big picture" analysis of the fuels infrastructure and how any one vulnerability might create ripple effects throughout the system. Identifying and addressing interdependencies can stop a small issue from becoming a much larger one. To analyze U.S. regional fuels resiliency, especially with respect to infrastructure, it is important to define disasters, regions, fuels, infrastructure, vulnerability and resiliency.

Natural Disasters Evaluated

The natural disasters considered in this study are:

- Hurricanes
- Earthquakes
- Tsunamis
- Tornados
- Heat Waves and Droughts
- Derechos
- Wildfires
- Floods
- Cold Waves and Polar Vortex events

The scope, probability, and severity of damage for each natural disaster will be considered on a regional (PADD/Sub-PADD) basis. The natural disasters will often further be broken down into regional affects if their characteristics for the region alter their threat or if the event takes on a different characteristic depending on where it occurs. For example, Gulf Coast and East Coast hurricanes will be differentiated because of their historical differences in terms of intensity, path, and impacts.

The main areas of concern for each natural disaster are presented here. Hurricanes, earthquakes, tsunamis, and tornadoes comprise highly-dangerous, region-specific events and are depicted in Figure 1.

Figure 1: Major Natural Disaster Hazard Regions in the Continental U.S.

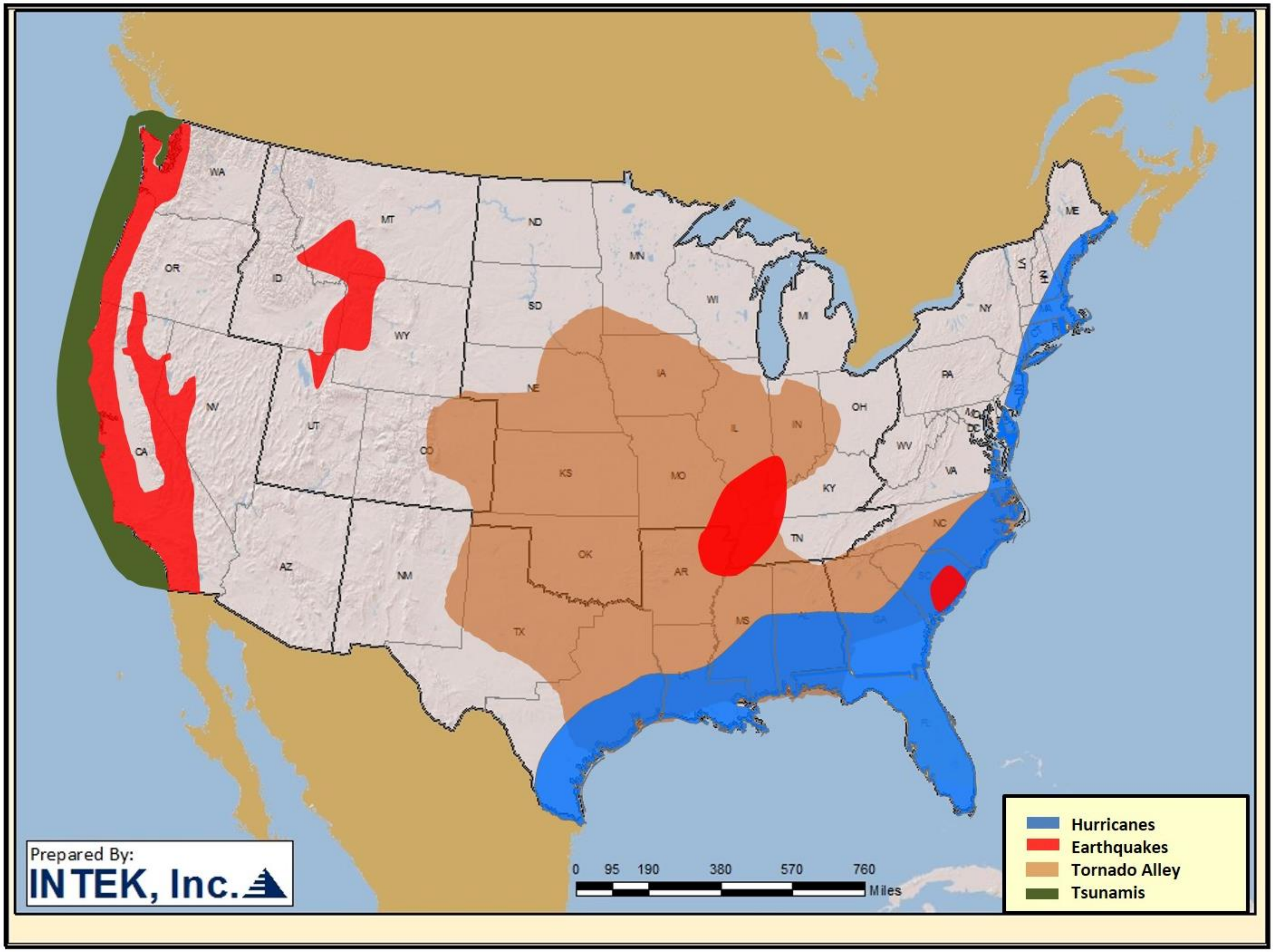


Figure 2: Wildfire and Flood Risks in the United States

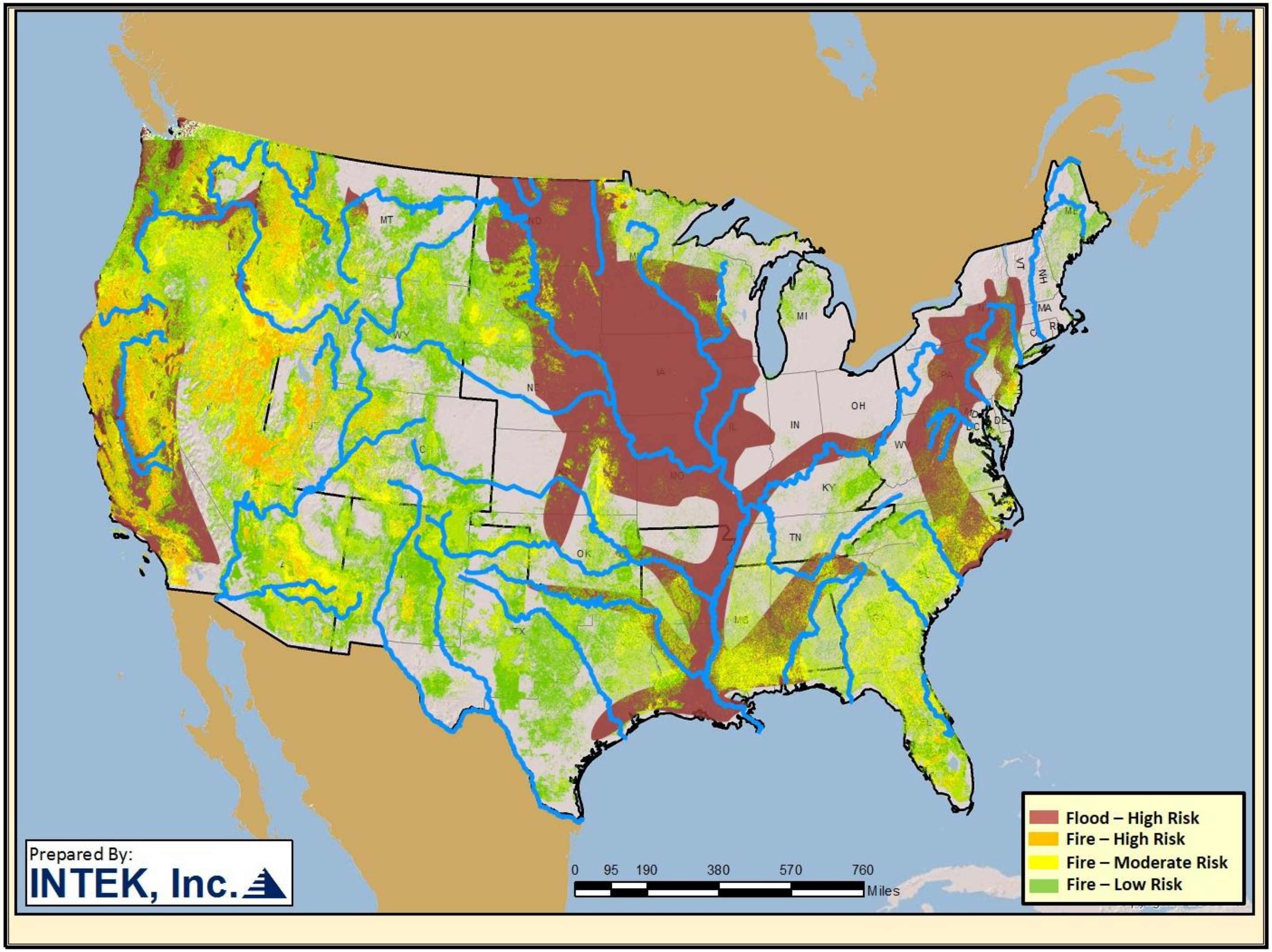
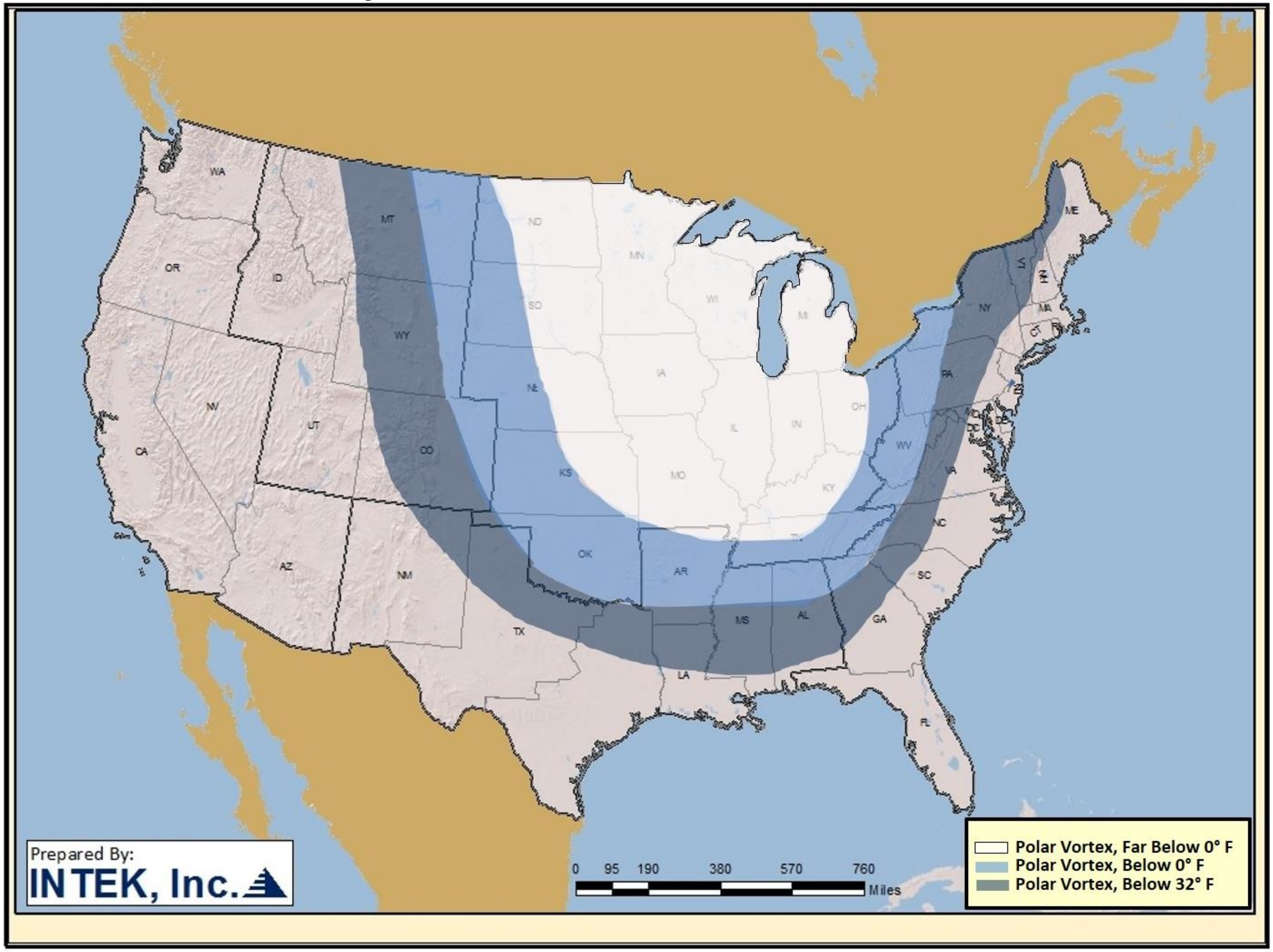


Figure 3: 2013-2014 Polar Vortex Effects in the United States



Hurricanes affect nearly the entire Gulf Coast and East Coast. There are occasional hurricanes on the West Coast, but they rarely travel far enough north to affect the continental United States. Earthquakes occur primarily along the West Coast, yet there are also pockets of serious seismic hazards in the Tennessee Valley Region and South Carolina. Tsunamis are large waves that can devastate the coastline. They are often associated with earthquakes and therefore pose a threat to the West Coast. Tornadoes are traditionally associated with "Tornado Alley" in the Great Plains region, yet also occur frequently throughout the Southeast and Midwest, leading some to call the expanded region, "New Tornado Alley."

Wildfires and floods are the most pervasive natural disasters covered in this report (Figure 2). They occur throughout the country in nearly every region with their probability of appearance largely a product of the weather in the region. Some areas might be more prone to a wildfire due to a concentration of dense and dry vegetation, or more prone to floods due to large rivers and flood plains, yet the overall risk for each event varies from season to season and year to year. They are also the only two events discussed that can be directly caused by humans either by accident or through malevolence.

Hazard Levels

The threat of each natural disaster examined to specific infrastructure will also be rated in terms of both probability and severity. These risk assessments will then be integrated into a detailed table to highlight key areas of vulnerability by disaster, area, and section of infrastructure.

Table 1: Hazard Level Definitions

Hazard Level	Severity	Recoverability
Low	Insignificant	Negligible – no outside help needed, i.e. clearing downed trees
Low-Med	Interrupting	Easy – outside help probably needed
Med	Significant	Problematic – will cause Insignificant delays
Med-High	Major	Challenging – will cause major delays, replacements required
High	Catastrophic	Difficult – infrastructure out for months, rebuilding required

Regions Evaluated

There are multiple definitions of U.S. regions relevant to energy supply and demand. The regions frequently used for liquid fuels are the Petroleum Administration for Defense Districts (PADDs), created during World War II for the allocation of petroleum products. The regional breakdown used in this study is generally consistent with the PADD regions, although the exact geographic breakdown may be more detailed, at the Sub-PADD level, depending on the energy system and infrastructure. This sub-regional breakdown with more detail is provided in PADDs II and III (Figure 4 and Table 2).

Figure 4: PADDs and Further Subdivisions for Fuels Infrastructure Inventory and Analysis

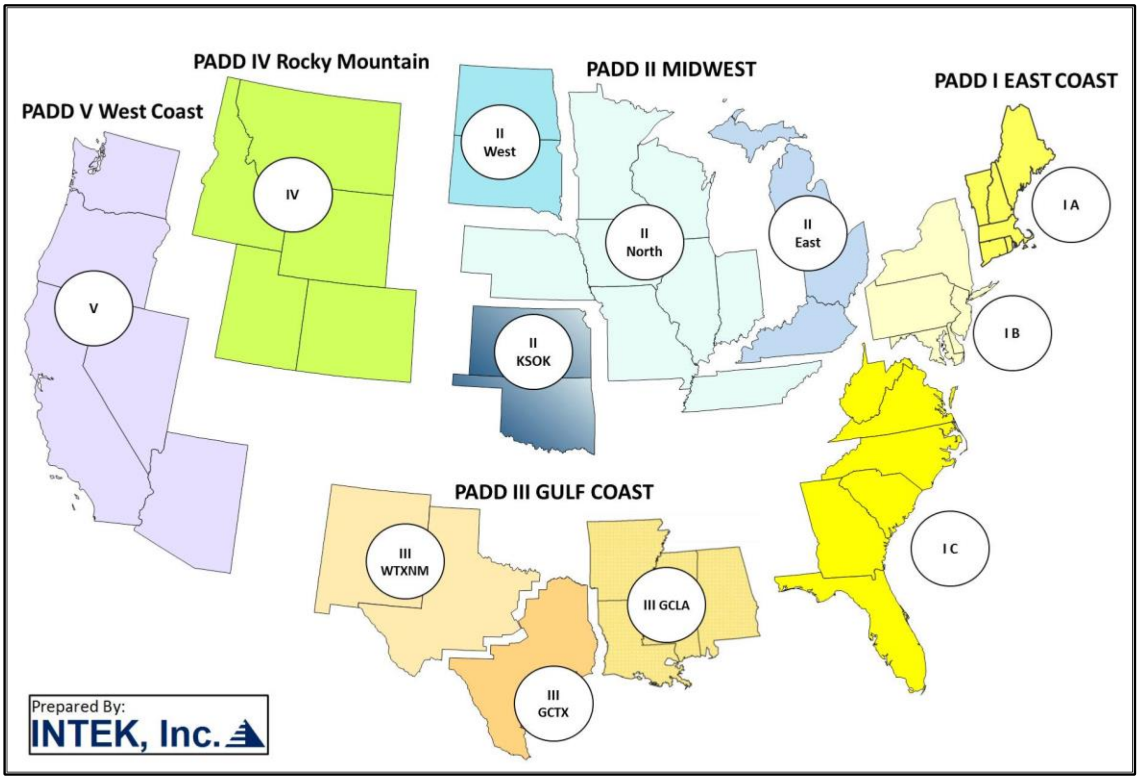


Table 2: Description of PADDs and Sub-PADDS

PADD	Sub PADDs	States / Regions
PADD I (East Coast)	Sub-district A (New England)	Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont.
	Sub-district B (Central Atlantic):	Delaware, District of Columbia, Maryland, New Jersey, New York, and Pennsylvania.
	Sub-district C (Lower Atlantic)	Florida, Georgia, North Carolina, South Carolina, Virginia, and West Virginia.
PADD II (Midwest)	Sub-district EAST	Michigan, Ohio and Kentucky
	Sub-district NORTH	Illinois, Indiana, Iowa, Minnesota, Missouri, Nebraska, Tennessee, and Wisconsin
	Sub-district KS/OK	Kansas and Oklahoma
	Sub-district WEST	North Dakota and South Dakota
PADD III (Gulf Coast)	GCLA	Alabama, Arkansas, Louisiana, Mississippi (Includes LA, MS, And AL Federal offshore)
	GCTX	East Texas (RRC districts 1-6, including Texas Federal Offshore
	WTX/NM	West Texas (RRC Districts (7b-10) and New Mexico.
PADD IV (Rocky Mountain)		Colorado, Idaho, Montana, Utah, and Wyoming.
PADD V (West Coast)		Alaska, Arizona, California, Hawaii, Nevada, Oregon, and Washington.

Each region is subject to various threats. Table 3 breaks down the natural disaster threats in Figures 1, 2, and 3 by Sub-PADD. These threats are discussed in greater detail within each chapter and in a regional disaster profile summarized at the conclusion of Part II.

Table 3: Regional Risks of Natural Disasters

PADD	Sub-PADD	Disasters								
		Hurricane	Earthquake	Tsunamis	Tornado	Heat Waves /Droughts	Derechos	Wildfires	Floods	Winter Weather
I	A	X				X	X	X	X	X
	B	X				X	X	X	X	X
	C	X	X		X	X	X	X	X	X
II	NORTH		X		X	X	X	X	X	X
	EAST		X		X	X	X	X	X	X
	WEST				X	X	X	X	X	X
	KS/OK				X	X	X	X	X	X
III	GCLA	X	X		X	X	X	X	X	X
	GCTX	X			X	X	X	X	X	X
	WTX/NM				X	X		X		X
IV			X		X	X		X	X	X
V			X	X		X		X	X	

Fuels and Infrastructure Considered

The fuels and infrastructure covered in Part I will form the basis of the vulnerability analysis in this section. They include natural gas, crude oil and condensates, refined petroleum products, and alternative fuels. Infrastructure characterized in Part I is primarily the nation's fuels Transportation, Storage, and Distribution infrastructure including crude, gas and fuel delivery systems, as well as processing and storage.

- Fuel delivery systems considered included pipelines for natural gas, crude oil, refined petroleum products, natural gas liquids (NGLs) and condensates; compressor/pumping stations; storage and distribution hubs; rail; barges; and ports.
- Fuel processing and storage infrastructure considered included: natural gas storage, treatment and processing; LNG terminals (liquefaction and regasification); crude oil storage, including the Strategic Petroleum Reserve (SPR); refineries; refined product storage, including the Northeast Home Heating Oil Reserve (NEHHOR); and petroleum and alternative fuel retail stations.

This infrastructure is summarized in Table 4 below and discussed in greater detail in Part I of this analysis.

Table 4: Summary of U.S. Oil and Gas E&P and Fuels Transport, Supply and Distribution Infrastructure

Infrastructure Type	Summary as of 2013, Reported June 2014
Exploration and Production Infrastructure	
Oil Wells	>560,000 producing wells
Natural Gas Wells	482,822 producing wells
Offshore Platforms	> 3,500 Gulf of Mexico platforms (85% in shallow waters)
Crude Oil and Refined Products Infrastructure	
Oil Refineries	143 total refineries 139 operating, 4 idle
Crude Oil Pipelines	51,349 miles of crude distribution 597 MMBbl/d
Oil Product Pipelines	6 major systems with capacity of 4.29 MMBbl/d
Oil Rail Terminals	113 terminals Upload capacity: 2MMBbl/d
Oil Ports	334 Crude & petroleum product ports
Waterborne Transport	4500 inland tank barges 275 coastal tank barges and Articulated Tank Barges 192 lock systems
Storage Terminals - Crude Storage Terminals - Products	1,414 crude and product terminals
Petroleum Reserves	SPR: 691 MMBbl NEHHOR: 1 MMBbl
Natural Gas Transport, Storage, and Distribution Infrastructure	
Natural Gas Plants	516 processing plants Total capacity: 64,659 MMcf/d
Natural Gas Pipelines	~210 Pipeline systems 315,000 miles of transmission pipeline
Underground Storage	414 Storage Facilities / 9.0 Tcf capacity
LNG Facilities and Import/Export Terminals	110 LNG Facilities - mostly storage for peak shaving and back-up. 11 Import terminals (17.6 Bcf/d capacity) (3 with I/E capability 3 Export terminals (7.3 Bcf/d capacity)
Propane Storage and Delivery	13,500 bulk/storage distribution sites
Propane Stocks	141 Terminals ~37 MMBbl
Alternative Fuels	
Alternative fuels production facilities	269 existing or proposed ethanol plants; Capacity: 15,600 MMGyr 134 biodiesel plants; Capacity: >954 MMGyr
Alternative fuel transportation	89 CSX east coast rail ethanol terminals 27 CSX rail Uploading Facilities
Fueling Stations	
Conventional fueling stations	110,830 gas stations
Unconventional fueling stations	17,840 stations Include E85 electric, CNG, hydrogen, LPG, LNG, and biodiesel

II. Natural Disasters and Energy Infrastructure

Natural disasters have threatened societies since the dawn of civilization. Their catastrophic effects have been forever etched into human consciousness through stories like the Biblical deluge and the collapse of Atlantis. Cities and nations throughout millennia have been obliterated by natural causes. The Bronze Age Collapse in the 2nd millennium BC is thought to have been triggered by an unusually frequent spell of disasters that drove nearly all the Mediterranean civilizations to ruin. Throughout the ages disasters have brought down the prominent historic cities of Knossos, Pompeii, Teotihuacan, Angkor, Port Royal, Imperial Lisbon, and Progressive-Era San Francisco. Most recently, nearly 80% of New Orleans was inundated in the aftermath of Hurricane Katrina.

Natural disasters affect all parts of the world; each region may face different threats. The costs are rising as populations grow and property values increase. In 2013, there were seven natural disasters in the United States that exceeded $1 billion in damages. There have been 144 others since 1980 with their total cost exceeding $1 trillion.[3]

Natural disasters pose a considerable risk to energy supply and infrastructure. In the following sections, this report will examine each natural disaster that poses a threat to United States fuels supply infrastructure. The disaster and its general effects will be introduced, followed by a discussion of the types of impacts that each can have on the fuels supply chain, a historical overview of past events, and an analysis of the likely impacts of future events. Part III of this report will discuss what steps might be taken to mitigate the effects of each disaster on the fuels system.

While each natural disaster poses different risks to infrastructure and supply, three general effects commonly occur with every weather event. These are:

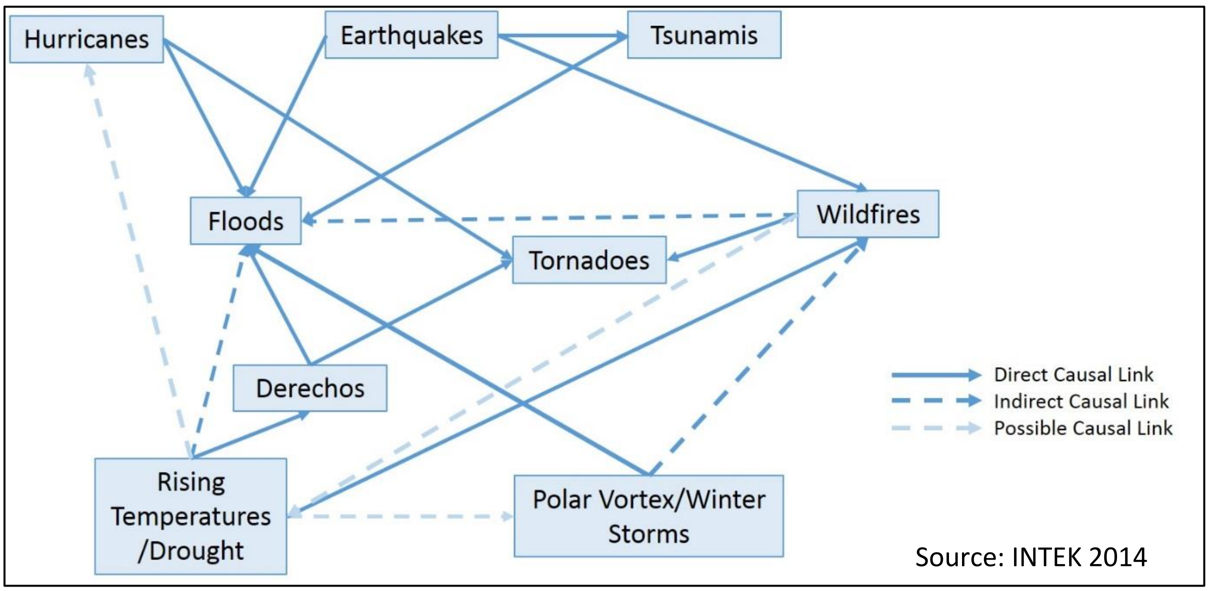
- **Power Loss:** Any event can knock out power supply to residences, industry, and energy infrastructure. Without power refineries can't operate, pumping stations can't move oil and gas through pipelines, and consumers can't pump gas into their cars. Lack of electricity and failure of the power grid is the most ubiquitous threat faced from all natural events.
- **Physical Damage:** Nearly all the natural disasters discussed in this report carry some sort of physical threat. High winds can damage exposed infrastructure, flooding can cause impact damage and corrosion, and temperature changes can put stress on equipment to the point of malfunction and deformation.
- **Supply Interruption:** Natural disasters may also affect supply without causing any physical damage to the infrastructure. A storm may knock down trees and block access to roads or rail terminals and floods may make any number of routes impassable. Crops used in ethanol feedstock might also get damaged and interrupt supply.

Natural disasters are rarely singular events. Before the effects of individual phenomena are discussed, it's useful to view them the complex interactions between geologic and meteorological systems.

A. Cascading Disaster Effects

Each of the natural disasters examined in the following sections brings unique effects, risks, and challenges to developing and maintaining fuel resiliency in the oil and gas industry. However, these events rarely occur in isolation. Many of the events cause, or may be caused by, the others. They were either indirectly over time, or by directly creating another natural disaster in their wake. In other words, these connections occur wither through shared root conditions or one disaster causing new conditions that make another event more likely. In some cases, preparing to meet challenges to any single type of weather event misses the interconnected nature of these events and any additional pressures and strains that infrastructure might encounter. Figure 5 illustrates how the events may be related.

Figure 5: Causal Relationships Between Natural Disasters



B. Independent Natural Disasters

Natural disasters that do not have any direct causes in other weather events include hurricanes, earthquakes, and rising temperatures/drought/heat waves. They may have other direct causes that fall outside relationships to other weather events but are not considered for the purposes of this analysis.

Hurricanes

Gulf and East Coast hurricanes may also cause floods and tornadoes. The tropical cyclones bring large amounts of rain causing local flooding, but their real threat to infrastructure comes from storm surges which can raise the ocean level substantially along the coast. Such was the case with Hurricane Katrina and Hurricane Sandy during which large parts of Southern Louisiana and the New Jersey seaboard, respectively, were submerged. Hurricanes also create ideal conditions for tornadoes to form and will often cause tornado outbreaks after they pass through an area. In 2004, Hurricane Ivan produced a record-setting 120 tornadoes as it passed over land, including at least one F3.

Earthquakes

Earthquakes are often the cause of tsunamis. Coastal areas in proximity to an offshore earthquake will often go under alert for a possible tsunami. Shifts in tectonic plates underneath the ocean floor can cause large amounts of water to displace and create waves that build as they approach the shoreline. Tsunamis can cause flooding up to ten miles inland depending on their strength and the coastal geography. Earthquakes can also cause flooding if dams, levees, or reservoirs are damaged or broken. Furthermore, earthquakes may cause "seiches" in lakes which push a large amount of water to one side and cause it to overflow. Lastly, earthquakes may cause wildfires when damaged infrastructure, such as broken gas lines or downed power lines ignite debris. If water lines are also damaged, unquenched fires may spread quickly. Southern California is an area prone to both earthquakes and wildfires.

Rising Temperatures/Droughts/Heat Waves

Rising global temperature, often referred to as global warming, has been linked to a number of natural disasters in the form of extreme weather and rising sea levels.[4] Rising temperatures are also predicted to intensify hurricanes by the end of the century[5] and have been linked to disrupting the polar vortex, although more research is still needed to firmly establish a connection.[6] Figure 5 shows these effects as tentative because they occur over a long time period and no single event can be directly linked to a warmer climate. Warm weather in the form of heat waves and droughts can directly cause other significant natural disasters. Wildfires in 2014 in California have been linked to severe drought as dry forest conditions increase the ease of a conflagration starting. Heat waves also create ideal conditions for derechos to form when a cool jetstream at high altitudes passes over a lower- front of hot air. The 2012 Midwest and Atlantic derecho followed a heat wave, which also exacerbated efforts to restore power and fuel access to those in affected regions.

C. Other Weather Effects

While weather events like derechos, tornadoes, floods, severe winter weather, tsunamis, and wildfires may be caused by hurricanes, earthquakes, and rising temperatures, they also occur on their own. These events may also trigger other disasters to create a third or even fourth level of cascading effects such as:

- Derechos regularly create tornado outbreaks.
- Derechos bring large amounts of rain that can lead to flooding.
- The heat from wildfires creates swirling updrafts and can form tornadoes.
- In turn, tornadoes can help spread wildfires or create fires in their path of destruction through downed power lines and ruptured gas lines.
- Wildfires can burn away vegetation that would help soils absorb water, thereby leading to increased flood risks in areas.
- Winter storms and cold waves can kill crops and leave areas vulnerable to wildfires.

- Snow and ice that accumulates from winter storms and cold waves can cause flooding through either rapid melting or ice floes jamming rivers.
- Wildfires could possibly lead to global warming over time as large amounts of greenhouse gases are emitted.[7]

III. Hurricanes

A. Introduction

Hurricanes are products of the tropical ocean and atmosphere. Powered by heat from the sea, they are steered by the easterly trade winds and the temperate westerlies as well as by their own energy. Around their core, winds grow with great velocity, generating violent seas. Moving ashore, they sweep the ocean inward, while spawning tornados and producing torrential rains and floods. Each year on average, ten tropical storms (of which six become hurricanes) develop into hurricanes over the Atlantic Ocean, the Caribbean Sea, and the Gulf of Mexico. Many storms remain at sea and dissipate. Statistically, about five hurricanes make landfall on the U.S. coastline every three years. Of these, two will be major hurricanes (Category 3 or greater).[8] The Saffir-Simpson Hurricane Wind Scale is a 1 to 5 rating based on a hurricane's sustained wind speed. This scale also estimates potential property damage.

Table 5: The Saffir-Simpson Hurricane Wind Scale

Category	Sustained Winds	Types of Damage Due to Hurricane Winds
1	74-95 mph 119-153 km/h	**Very dangerous winds will produce some damage:** Well-constructed frame structures could have damage to roof, shingles, vinyl siding and gutters. Large branches of trees will snap and shallowly rooted trees may be toppled. Extensive damage to power lines and poles likely will result in power outages that could last a few to several days.
2	96-110 mph 154-177 km/h	**Extremely dangerous winds will cause extensive damage:** Well-constructed frame structures could sustain major roof and siding damage. Many shallowly rooted trees will be snapped or uprooted and block numerous roads. Near-total power loss is expected with outages of several days to weeks.
3 (major)	111-129 mph 178-208 km/h	**Devastating damage will occur:** Well-built framed structures may incur major damage or removal of roof decking and gable ends. Many trees will be snapped or uprooted, blocking numerous roads. Electricity and water will be unavailable for several days to weeks after the storm passes.
4 (major)	130-156 mph 209-251 km/h	**Catastrophic damage will occur:** Well-built framed structures can sustain severe damage with loss of most of the roof structure and/or some exterior walls. Most trees will be snapped or uprooted and power poles downed. Fallen trees and power poles will isolate residential areas. Power outages will last weeks to possibly months. Most of the area will be uninhabitable for weeks or months.
5 (major)	157 mph or more 252 km/h or higher	**Catastrophic damage will occur:** A high percentage of framed homes will be destroyed, with total roof failure and wall collapse. Fallen trees and power poles will isolate residential areas. Power outages will last for weeks to possibly months. Most of the area will be uninhabitable for weeks or months.

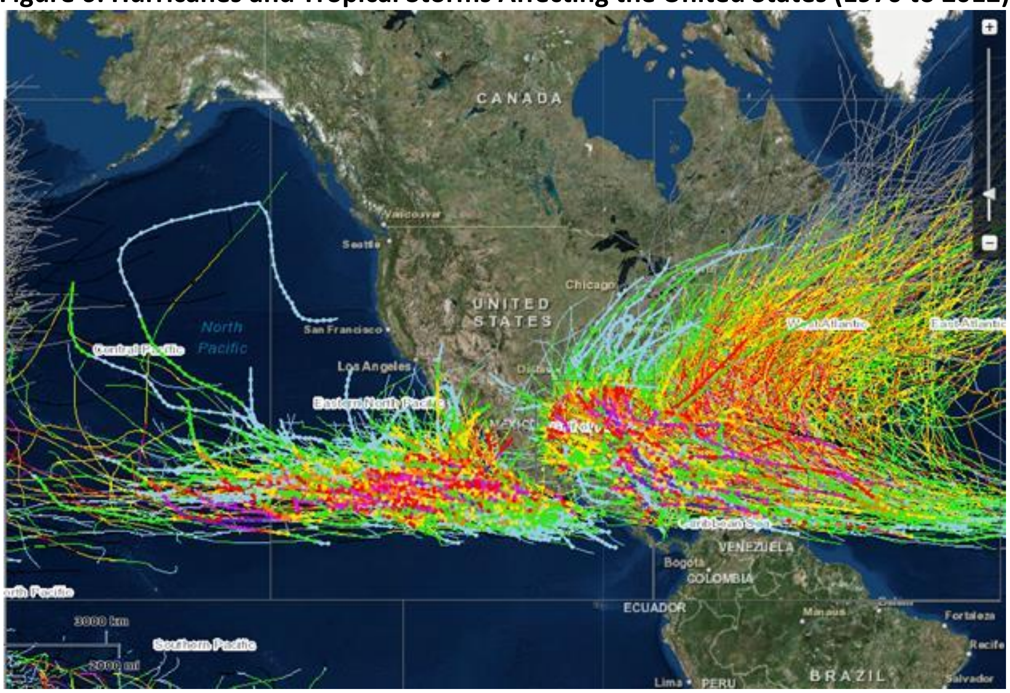
Source: NOAA

Hurricanes reaching Category 3 and higher are considered major hurricanes because of their potential for significant loss of life and damage. Category 1 and 2 storms are less dangerous, but still pose significant risk to infrastructure and require preventative measures. Other important measures of hurricanes include areal extent and storm surge.

As hurricanes require warm water to generate, Atlantic hurricane season generally begins in June and goes through November. Hurricane activity typically peaks in late September and early October. Hurricane climatology also varies throughout the year.[9] Stronger Cape Verde-type hurricanes generally appear between July and September.

B. Hurricanes in the United States

Figure 6: Hurricanes and Tropical Storms Affecting the United States (1970 to 2012)



Source: NOAA, June 2014

The National Oceanographic and Atmospheric Administration (NOAA) of the U.S. Department of Commerce monitors hurricane that affects the United States. Hurricanes that affect or make landfall in the United States generally occur in one of three regions.

- East Coast hurricanes take a northwesterly track following the Gulf Stream, making landfall along the U.S. Atlantic coastline.
- Gulf Coast hurricanes either form in the Caribbean Sea or track in from the Atlantic before moving westward into the Gulf of Mexico and making landfall either in Mexico or along the U.S. Gulf Coast between Brownsville, TX and the west coast of Florida.

- Some storms form off the western coast of Mexico and affect the most southern areas of the west coast of the United States. Only rarely do these storms track as far north as Los Angeles.

Figure 6 shows the paths and intensities of hurricanes and tropical storms affecting the United States since 1970. The most intense storms, (depicted above with thicker lines and darker colors), have been Gulf Coast hurricanes, although a number of very intense East Coast hurricanes have also occurred.

C. Types of Hurricane Impacts on Fuels TS&D Infrastructure

Hurricane effects that can damage fuels TS&D infrastructure can be described in several categories:

Winds: Sustained winds ranging from 74 mph (Category 1) to as high as 157 mph (Category 5) can weaken, shift or topple structures and towers and cause impact damage to structures and towers, above-surface facilities, offshore platforms and drilling rigs, storage tanks, and loading facilities. Hurricane winds can cause severe damage to refineries. Refinery cooling towers are especially prone to wind damage. High winds can cause the fan blades inside a cooling tower to become dislodged and launched from the tower if they are not secured. This renders the cooling tower unusable and creates airborne debris that can cause further damage. During Hurricane Rita in 2005, 50 percent of the cooling towers at Port Arthur, TX refineries were damaged and 54 percent were damaged at Port Neches, according to a National Institute of Standards and Technology reconnaissance report.[10] Wind damage to trees, structures, and control systems can also damage or obstruct roads, bridges, and rail lines that transport crude oil to terminals and refineries, transport alternative fuels (such as biodiesel and ethanol) to distribution terminals, and transport refined products from distribution terminals to end-use distribution points, such as service stations.

Power Loss: Perhaps the most pervasive impacts of hurricanes are caused by power loss. High winds impact electric power transmission lines, knocking out electric power that is essential for control systems, pumps, motors, and other essential operations. Loss of electric power may also curtail the distribution of motor fuels from service stations, until power for pumps and controls can be restored. Power loss also severely impacts communications systems that may be essential for system operations and controls. 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. The high probability of electricity outages after hurricanes has caused refiners to initiate controlled shutdowns in advance of landfalls to avoid “hard shutdowns” that result in refinery damages.

Rain/Flooding: Heavy rains associated with hurricanes can cause significant flooding, which can damage electric motors, pumps, and surface equipment as well as roads, rail lines, and other supporting infrastructure. Flood damage is the most common and costliest type of storm damage to petroleum infrastructure and results in the longest disruption for refineries, pipelines, and terminals. Hurricane rains and flooding can be extremely devastating and costly to petroleum refineries, and normally result in extended refinery recovery times. The Gulf Coast hurricanes of 2005 and 2008 caused extensive water damage to refinery control systems, electrical equipment, and pump motors.

Storm Surge: The winds and pressure created by hurricanes can cause significant storm surge increasing sea level by several feet. A storm surge is an abnormal rise in water levels generated by a storm, over and above the predicted astronomical tides. In addition, storm tides are the abnormal rise in water levels due to a combination of storm surge and the astronomical tide. This rise in water level can cause extreme flooding in coastal areas, particularly when the storm surge coincides with the normal high tide.[11] In addition to the water damage to electric powered infrastructure, the pressure and impact of the storm surge can cause significant structural damage to marine terminals, storage tanks, towers, distillation columns, above ground piping, and surface transport facilities. A 20-foot storm surge in the Gulf Coast region could flood much of the refining infrastructure and jeopardize much of the oil and gas production, processing, and distribution infrastructure. Although most flood walls that currently exist to protect refineries are designed to protect against a 100-year storm surge, they may be inadequate to protect against a direct hit from a Category 4 or 5 hurricane.

Evacuations: High winds, rain, storm surge, downed power lines, and obstructed transportation routes pose major safety issues. Major hurricanes frequently require the evacuation of the population from the affected areas for a period of several days before a storm event to several days or even weeks after the event in the most heavily impacted areas. Consequently, even if physical TS&D infrastructure is not damaged or is quickly reparable, the skilled management and technical workforce that is required for TS&D operations may not be available to resume operations.

D. Threats to the Oil and Gas TS&D

Hurricanes have the potential to affect the entire petroleum production, transportation, storage, and distribution system, both in the hurricane-impacted region as well as other regions interconnected with, and dependent on, the affected region. Interruption of crude oil and natural gas production operations in the Gulf of Mexico, whether due to platform evacuations and or storm damage, reduces the supply of crude oil and natural gas to refining and processing centers. Interruption of supply will cause refining or gas processing operations to cease after on-site stocks have been depleted, unless other sources of supply become available. Similar impacts occur if seaborne crude oil deliveries to refineries are interrupted or by associated damage or obstruction of, shipping channels and marine terminals.

Prolonged interruption of refining operations at Gulf Coast or East Coast refining centers, due to a lack of crude oil supply, power outage, storm damage, or personnel evacuations, will reduce the supply of refined products into pipelines, storage terminals and distribution points. Refining disruptions in the Gulf Coast will impact refined product supplies in the southeastern states (PADD I), as well as PADD III and parts of PADD II. The impacts on refined product supply could extend to all of the northeastern states as well. Disruptions of East Coast refineries, in the Philadelphia and Northern New Jersey areas will affect refined product supplies in the Mid-Atlantic and Northeastern states.

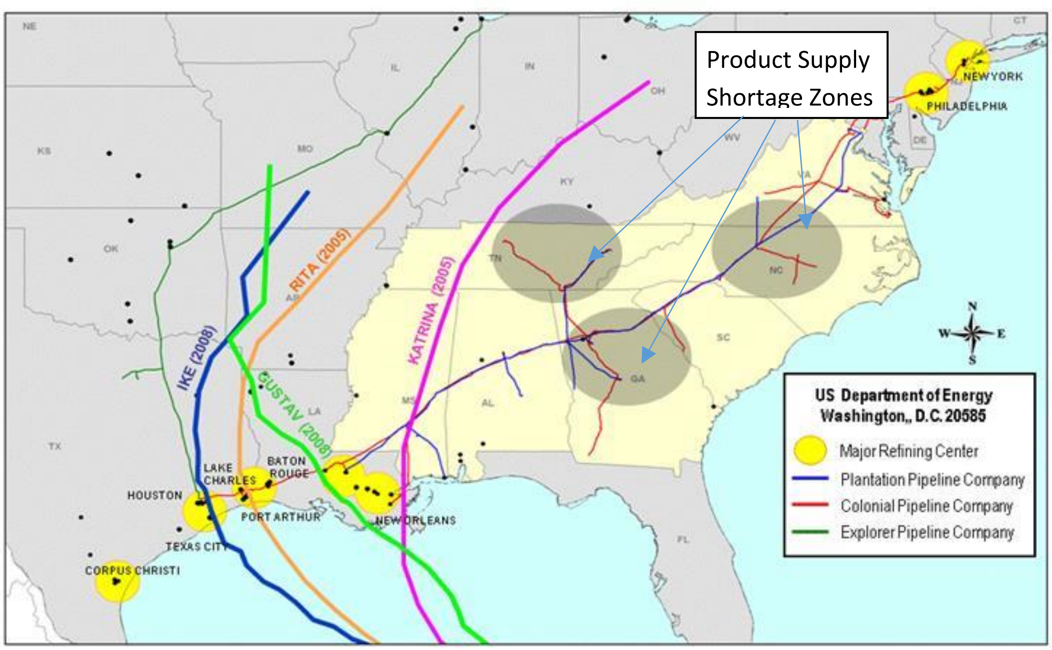
Over the last ten years, hurricanes have caused major storm damage, flooding, and power outages, disrupting the U.S. crude petroleum supplies, refining, product distribution systems. Some of these disruptions have caused shortages of refined products in particular markets and raised regional and national gasoline and diesel fuel prices. The three most significant events in recent memory have been:

- In 2005, Hurricanes Katrina and Rita (Category 3 Hurricanes) severely impacted both Gulf Coast refinery and pipeline distribution operations; 26 refineries were shut down. Refined product distribution via pipelines to the Southeast was terminated and took almost three weeks to recover. Refined product losses were over 180 MMBbl in the Gulf Coast and 43 MMBbl in the Southeast, resulting in major regional gasoline outages and price spikes. Most of the product shortages in the Southeast were due to loss of supply from the Colonial and Plantation pipelines.
- In 2008, Hurricanes Gustav and Ike (Category 2 hurricanes) severely impacted Gulf Coast refinery and pipeline distribution operations. 26 refineries were shut down. Refined product distribution via pipelines to the Southeast was again impacted and took almost two weeks to recover. Refined product losses were over 103 MMBbl in the Gulf Coast and 23 MMBbl in the Southeast, as the Colonial and Plantation pipelines were shut down causing major supply shortages in the Southeast.
- In 2012, Hurricane Sandy (technically a post-tropical cyclone at landfall) severely impacted both East Coast refinery operations and pipeline distribution operations. Two East Coast refineries were severely damaged. Over 40 New York Harbor terminals closed due to electric power losses and water damages. New York area gas stations were without power and fuel for 5 to 30 days, resulting in severe gasoline outages and price spikes.

E. Historical Gulf Coast Hurricanes

The Gulf Coast hurricanes in both 2005 and 2008, caused major storm damage, flooding, and power outages, crippled Gulf Coast refineries and pipeline distribution systems, and created major shortages of refined products in the Southeast and East Coast markets. Figure 7 shows the paths of these major 2005 (Katrina, Rita) and 2008 (Gustav, Ike) hurricanes and the refineries and product pipelines they affected.

Figure 7: Gulf Coast Hurricane Paths in 2005 and 2008



Source: SPR 2013

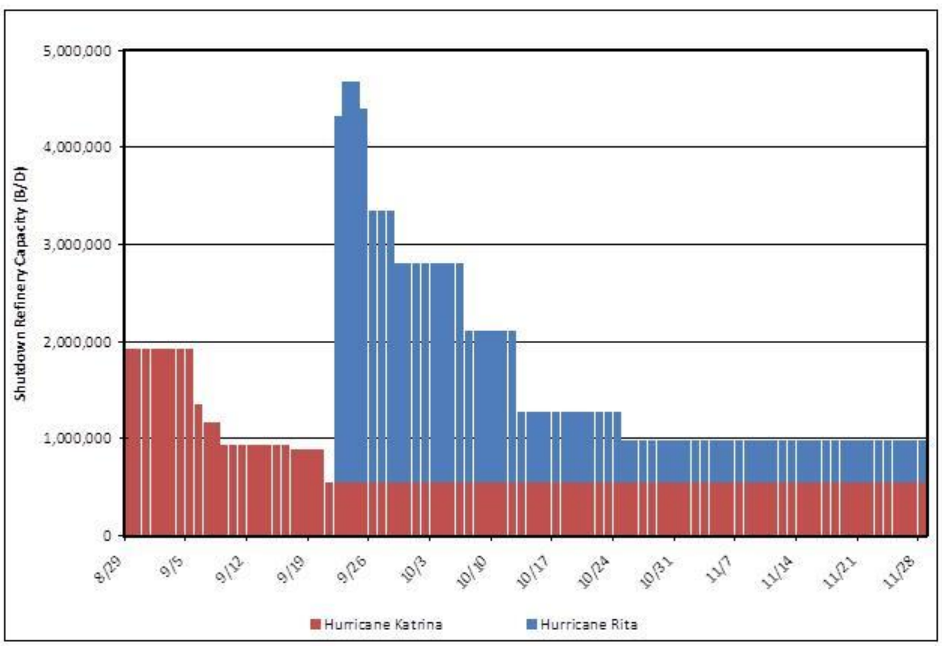
The Gulf Coast has more than 30 refineries, with total refining capacity of over 7.5 MMBbl/d, which is almost 50% of the nation's total refining capacity. These refineries are clustered into five major refining centers, Corpus Christi, Houston/Texas City, Port Arthur/Lake Charles, New Orleans/Baton Rouge, and Pascagoula/Mobile spanning the Gulf Coast. These centers produce and deliver 2.4 MMBbl/d (or one-third of the total Gulf Coast refinery output of refined products) to the Southeast and East Coast via the Colonial and Plantation pipelines. The Gulf Coast hurricanes of 2005 and 2008 caused power outages, flooding, and major storm damage. They crippled Gulf Coast refineries and pipeline distribution systems and created refined products shortages in the Southeast and other East Coast markets.

Hurricane Katrina (Landfall – August 29, 2005)

Hurricane Katrina made landfall on August 29, 2005 and shut down 11 refineries in Louisiana and Mississippi, with a combined capacity of 2.5 MMBbl/d. Less than a month later, Hurricane Rita made landfall farther west along the Gulf Coast, shutting down 4 MMBbl/d of capacity in 16 refineries in Houston, Galveston, Port Arthur, and Lake Charles. Due to severe damage and flooding, more than 2 MMBbl/d of this capacity remained offline two weeks after Rita's landfall, and about 1 MMBbl/d remained offline four weeks after Rita's landfall. A number of other refineries operated at reduced rates for several weeks following the storms. A few refineries remained shut down for periods of over four months (Conoco Phillips' refinery in Belle Chasse, LA; Murphy's refinery in Meraux, LA; and BP's refinery in Texas City, TX.)

In aggregate, Hurricanes Katrina and Rita caused a loss of about 153 MMBbl of refined products (85.8 MMBbl from Katrina and 66.9 MMBbl from Rita) from Gulf Coast refineries and a supply shortage in the Southeast of about 43 MMBbl. Figure 8 shows the refinery capacity loss during the 2005 season.

Figure 8: Impact of Hurricanes Katrina and Rita on U.S. Gulf Coast Refining Capacity during 2005



Source: SPR/RPPR Report 2011

Other impacts of Hurricane Katrina on the TS&D Infrastructure included the following:

Power Outages

- 1.2 million customers were without power in Florida beginning on August 26, 2005, as Florida began to feel the effects of hurricane winds and rain ahead of the eye of the storm making landfall. 90% of Florida customers had power August 30, 2005, the day after Katrina made landfall in Louisiana.
- 2.7 million customers were without electrical power in Louisiana and Mississippi, where Katrina had the greatest impacts. 30 days following the landfall, 500,000 customers were still without power.
- Only 37% of natural gas customers in LA, MS, AR, and AL, had gas service restored by September 22, 2005.

Oil and Gas Production

- 1.5 MMBbl/d of oil production was shut in (99.13%) due to evacuation of offshore platforms. Production was restored to 56% of pre-Katrina levels before the onset of Rita (~September 20, 2005).
- 7.2 Bcf/d of natural gas production was shut in (72% of pre-Katrina production).
- 77% of 819 manned GOM oil and gas production platforms were still evacuated as of September 23, 2005. This evacuation was extended due to Rita.
- 67% of 143 GOM drilling rigs were evacuated prior to the storm and were still evacuated as of September 23, 2005. This evacuation was extended due to Rita.

Refineries

- 11 refineries were shut down due to flooding, power outage, and/or storm damage; 4 of 11 refineries (three in LA and one in MS) were still shut down as of September 22, 2005.
- Refineries that were dependent on sour crude from the Poseidon and Mars deepwater offshore platforms were unable to get oil because the platforms were shut down.

Oil, Gas and Refined Products Pipelines

- The Capline crude oil pipeline (serving Midwest refiners) was shut down due to power outages, but was expected to restart by September 2, 2005, four days after landfall.
- Two of the four lines of the Colonial pipeline supplying the major southeast and northeast markets were shut down due to lack of power. Partial restarts were planned to begin by August 31, 2005. Pumping capacity of the pipeline was severely impacted due to power loss and flooding.
- The Plantation pipeline was shut down due to power outages. A manual restart began within five days.
- The Dixie propane pipeline, supplying the Southeast, was shut down due to power outage.

Hurricane Rita (Landfall – September 24, 2005)

With the Gulf Coast region still struggling to recover from Hurricane Katrina, Hurricane Rita hit Key West, Florida on September 20, 2005 as a Category 2 storm, and then regained strength in the Gulf of Mexico. On September 24, 2005, Hurricane Rita made its second landfall in Sabine Pass, Texas, near the Louisiana border, as a Category 3 hurricane with maximum sustained winds near 120 mph. Hurricane Rita prompted the shutdown of offshore oil and gas production and several refineries and natural gas processing plants in Texas and Louisiana.

Power Outages

- 1.25 million customers were without electric power, mostly in Texas and Louisiana, as of September 26, 2005; restoration was reported to be nearly complete by October 16, 2005, three weeks after the storm made landfall in Texas.

Oil and Gas Production

- Nearly all of the Gulf Coast oil and gas platforms and production were shut down, in anticipation of Rita.
- 1 MMBbl/d of oil production (67%), and 5.6 Bcf/d of gas production (56.5%) remained shut in as of October 16, 2005 three weeks after the storm.
- 30% of manned platforms were still shut down, but 98% of drilling rigs were back in operation October 16, 2005.

Refineries

- 16 Houston and Port Arthur refineries were shut down, a loss of 4 MMBbl/d of capacity.
- Most refineries were either operational or restarting as of October 16, 2005. Four refineries were still shut down due to damage. In January 2006, three major refineries remained shut down. These refineries restarted in mid-March 2006, almost six months after the hurricane's landfall.

Oil, Gas, and Refined Product Pipelines

- Lake Charles and Trunkline LNG pipelines were shut down.
- Seaway crude pipeline was shut down.
- LOOP's onshore operation was operating at 75% of capacity.
- Five of eight major product pipelines were shut down. These pipelines included the Colonial and Plantation pipelines which supply most of the products in the Southeast and Northeast.
- Numerous onshore and offshore gas pipelines were operating with reduced supply.
- By January 26, 2006 product and crude pipelines were operating at or near pre hurricane flows and capacities.

Ports

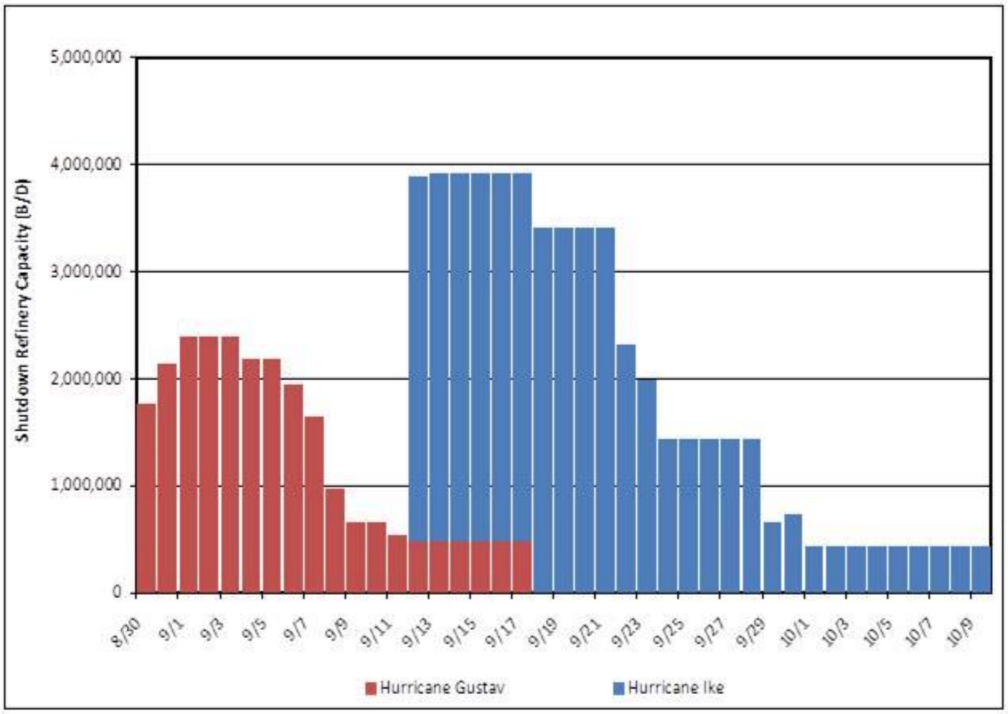
- LOOP, Port of Houston, and Port of Corpus Christi were shut down.

- Partial service was restored at Houston and Corpus Christi several days after the storm, with limitations on the number of vessels and the draft of the vessels that could be served.

Distribution Systems

- On September 23, 2005 there were reports of Houston gasoline stations running out of gas due to terminal shutdowns.

Figure 9: Impact of Hurricanes Gustav and Ike on U.S. Gulf Coast Refining Capacity during 2008



Source: SPR/RPPR Report 2011

Hurricane Gustav (Landfall – September 1, 2008)

Hurricanes Gustav and Ike, both Category 2 storms, made landfall in 2008, but were relatively weaker than the 2005 storms. Figure 9 depicts the refinery capacity loss during shutdown over the 2008 hurricane season. On average, for the 30-day period, 1.5 MMBbl/d of refining capacity was shut down in the Gulf (approximately 20% of the Gulf's capacity). The damage was compounded by Ike's landfall during the recovery from Gustav.

Hurricane Gustav made landfall as a Category 2 Hurricane near Morgan City, Louisiana, at approximately 1:00 PM EDT on Monday, September 1, 2008. The impacts to petroleum, natural gas, and electricity infrastructure in Louisiana and Mississippi were significant.

Power Outages

- 740,000 customers were without electric power, mostly in Louisiana but with some in Mississippi and Arkansas.

- About 90 % of outages had been restored before Hurricane Ike struck the area on September 11, 2008.

Oil and Gas Production

- 334 Gulf Coast oil and gas production platforms and 34 drilling rigs were shut down in anticipation of Gustav.
- 1.2 MMBbl/d of oil production (90.5%) and 6 Bcf/d of gas production (79.8%) were shut down and remained shut in as of September 5, 2008, five days after Gustav made landfall.

Refineries

- Hurricane Gustav primarily affected Louisiana refineries, shutting down 14 with a total capacity of 2.7 MMBbl/d along the Lower Mississippi River and Lake Charles regions. Most of these facilities were shut down out of precaution.
- Five days after landfall, six refineries were still shut down. Ten days after Gustav's landfall, all affected refineries had been completely restored to their pre-hurricane production levels.
- 23 of the 28 natural gas processing plants (18.9 Bcf/d processing capacity) in the path of Gustav shut down operations due to mandatory evacuations or shut in gathering lines.
- Ten gas plants remained shut down five days after the storm, but were ready to resume operations, pending restoration of power or gas flow; another five had resumed full operations and eight were operating at reduced levels.

Oil, Gas, and Refined Product Pipelines

- 19 of 22 natural gas pipelines shut in all operations on their offshore systems; five remained shut in five days after the storm.
- Capline (1.2 MMBbl/d) and LoCap (1.2 MMBbl/d) crude oil pipelines were shut down.
- Centennial product pipeline (210 MBbl/d) was shut down.
- Sabine Gas pipeline was shut down, including all receipt and delivery points for the Henry Hub.

Ports and Waterways

- All waterways were closed in southern Louisiana, including Ports of New Orleans, Baton Rouge, and Fourchon.
- The Gulf Intracoastal Waterway was closed from mile marker 20 to mile marker 44.
- The lower Mississippi River was closed from the Southwest Pass sea buoy to mile marker 303
- The Sabine Ship Channel was closed by the Coast Guard.
- LOOP onshore and offshore operations were suspended.

Hurricane Ike (Landfall – September 13, 2008)

As the Gulf Coast recovered from Hurricane Gustav, Hurricane Ike made landfall near Houston, Texas, at 3:00 AM EDT on September 13, 2008 as a strong Category 2 hurricane. Ike primarily affected Texas refineries, shutting down nearly 4 MMBbl/d of capacity in Houston, Galveston, Port Arthur, and Corpus Christi. As with Gustav, much of this capacity was shut down as a precaution before landfall.

Three weeks later, only two refineries remained idle, one due to complications that occurred during restart. Restoration proceeded more rapidly in 2008, because the on-site damage was less severe. Although some refinery shutdowns lasted from two to three weeks, these outages were primarily caused by a lack of electricity supply rather than on-site hurricane damage.

The aggregate supply effects of Hurricanes Gustav and Ike caused a Gulf Coast shortfall of 103 MMBbl (39.2 MMBbl from Gustav and 63.5 MMBbl from Ike), and a refined-product shortage in the Southeast of about 23 MMBbl.

Power Outages

- 2.6 million customers lost power, mostly in Texas (2.4 million), and some in Louisiana.
- One week after the storm, 50% of outages in Texas and Louisiana had been restored.
- 400,000 customers were still without power two weeks following the storm, but all customers had been restored by October 9, 2008.

Oil and Gas Production

- 596 of 717 (83.2%) of Gulf Coast manned oil and gas production platforms and 101 drilling rigs were shut down, in anticipation of Ike.
- 1.27 MMBbl/d of oil production (97.5%) and 6.9 Bcf/d of gas production (94.4%) were shut in.

Refineries

- Hurricane Ike primarily affected Texas refineries, shutting down 14 with a total operable capacity of 3.8 MMBbl/d primarily in Port Arthur, Houston/Texas City, and Corpus Christi.
- Five days after landfall, only five refineries (656 MBbl/d capacity) were still shut down. Ten days after Gustav's landfall, all refineries were operating at their pre-hurricane production levels.
- 29 of the 39 natural gas processing plants (17.6 Bcf/d processing capacity) in the path of Ike shut down operations, reducing processing capacity by 13.7 Bcf/d).
- Like Gustav, 10 gas plants remained shut down after five days, eight others were operating at reduced levels.

Oil, Gas, and Refined Product Pipelines

- Most crude oil pipelines ceased operations.
- Most petroleum product and natural gas pipelines were shut down or cut back operations.

- Sabine Gas pipeline was shut down once again, including receipt and delivery points for Henry Hub.
- Tanker off-loadings at LOOP were suspended.
- Seven major natural gas pipelines remained shut in two weeks after the storm, four due to lack of supply or problems with interconnects, and three due to ongoing repairs or inspections.

Ports and Waterways

- Ports east of Port Arthur remained open, but Freeport, Texas City, Galveston, Port Arthur, Beaumont, Lake Charles, and Port Lavaca were all closed.
- On September 19, 2008, six days after the storm, 76 ships were waiting in queue to enter ports at Texas City, Houston Beaumont, and Lake Charles, though few were oil tankers.
- Three Mississippi River locks were closed, Calcasieu, River Saltwater Barrier, and Leland Bowman. By September 19, 2008, several of these waterways were partially opened with restrictions on the length and draft of allowed vessels.

The Northeast is also vulnerable to Gulf Coast Hurricanes. Due to recent closures of several Northeast refineries, the Northeast market has been increasing its dependence on refined product supplies via pipeline (700 MBbl/d) and marine (59 MBbl/d) from the Gulf Coast. A major hurricane making landfall in the refining regions of the Gulf Coast would likely cause a disruption to refined product supplies via both marine and interstate pipeline from the Gulf Coast region.

F. Historical East Coast Hurricanes

The Northeast has been struck by six East Coast hurricanes over the last 20 years (Table 6). The paths of these storms are illustrated in Figure 10. These hurricanes caused disruption of refined product supplies from northeast refineries, Gulf Coast pipelines, and waterborne imports.

Table 6: Past Disruptions in Product Supplies During 30 Day Period Following Hurricane Landfall

Year	Northeast Hurricanes & Categories	Refined Product Losses (MBbl)			
		Refineries	Pipeline	Waterborne	Total
2012	Sandy (Cat 1)	13,680	4,770	2,464	20,914
2011	Irene (Cat 1)	6,913	2,760	2,674	12,347
2003	Isabel (Cat 2)	2,535	0	6,913	9,448
1999	Floyd (<Cat 1)	4,940	0	2,153	7,093
1996	Fran (Cat 1)	3,166	0	4,089	7,255
1996	Bertha (Cat 1)	6,623	0	148	6,771

Source: SPR, 2012

Two major hurricanes made landfall on the East Coast in 2011 and 2012, both heavily impacting the region's fuels transportation, supply, and distribution infrastructure (Figure 11).[12]

Hurricane Irene (Landfall – August 27, 2011)

Hurricane Irene, a large, slow-moving storm, made landfall as a Category 3 hurricane in North Carolina on August 27, 2011 (90 mph winds), and then proceeded north up the East Coast, making further landfalls near Atlantic City, New Jersey (80 mph winds), and Coney Island, New York (75 mph winds) in the following days.

Figure 10: Northeast Hurricanes and Affected Refineries (1996-2012)

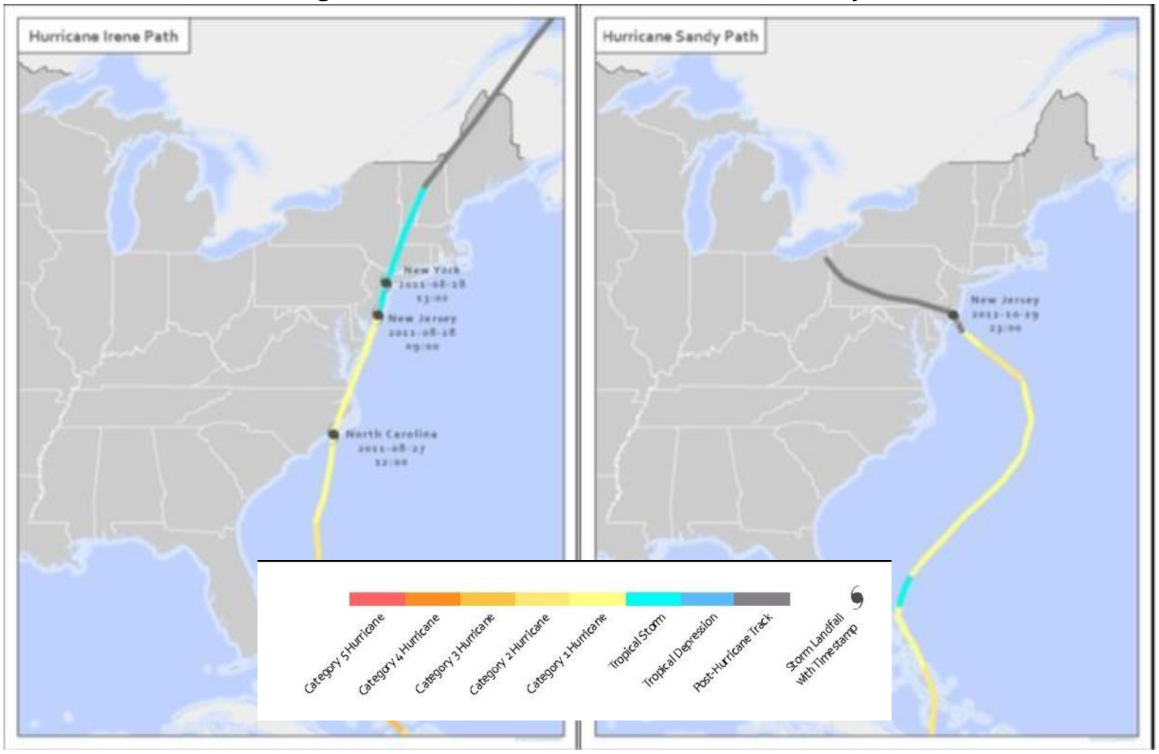
Source: SPR, 2012

Storm force winds affected areas in a 300-mile radius from the center of the storm, affecting communities as far north as Maine. The storm surge caused by Irene resulted in flood waters that rose 9.5 feet above the mean low water level in New York City and 9.9 feet above normal in the Delaware River in Philadelphia.

Property damage exceeded $10 Billion and 45 deaths were attributed to the storm. Flooding caused by the storm was extensive in New York, New Jersey, and Vermont.

Irene caused severe damage to the Northeast petroleum infrastructure and significant disruptions in product supplies.

Figure 11: Paths of Hurricanes Irene and Sandy



Source: Comparison Study, DOE Office of Electricity Delivery and Energy Reliability

Power Outages

- Irene caused extensive damage to the electric transmission and distribution infrastructure in the North East and Mid-Atlantic regions, causing ripple effects to fuels TS&D infrastructure.
- Power was disrupted to 6.69 million customers from South Carolina to Maine. The affected infrastructure included substations, transformers, and transmission lines.
- 95 % of the affected customers had their power restored within five days.

Refineries

- The ConocoPhillips Linden, NJ refinery with a capacity of 238 MBbl/d was shut down for four days.
- Five other refineries in New Jersey, Pennsylvania, and Delaware, with combined capacities exceeding 1 MMBbl/d, operated at reduced throughput rates for one to four days.
- Gross inputs to east coast refineries fell by 416 MBbl/d (31%) during the week of the storm but quickly recovered.

Oil, Gas, and Refined Product Pipelines and Terminals

- Twenty-five New York Harbor oil and refined product terminals were partially or completely closed due to flooding, electric power losses, and water damage to pipelines, pump stations, marine terminals, and storage tanks. Several empty storage tanks were moved off their foundations by floodwaters.

- Segments of three product pipelines and one crude oil pipeline (combined capacity 1.83 MMBbl/d products and 410 MBbl/d crude) were shut down for about 1 week due to Irene.
- Nine days after the storm, refined product deliveries from New York Harbor terminals remained at only 61% of pre-storm outflow levels. Product losses during the 30-day period immediately following the hurricane landfall totaled of over 20 MMBbl.
- Natural gas pipelines remained in operation, but local distribution was suspended in many areas pending safety inspections before service could be restored.
- Transcontinental reported that some of its pumping stations lost power and/or had minor flooding. Iroquois reported that it used backup generators at some of its facilities.

Ports and Waterways

- Eight refined product ports from North Carolina to Boston, including two that also receive crude oil (Delaware Bay and New York Harbor), were closed from one to three days due to flooding and other water and wind impacts.

Retail Gasoline Stations

- Irene had little impact on retail fuel supply or distribution systems or infrastructure.

"Superstorm" Sandy (Landfall – October 29, 2012)

The worse of the two recent East Coast hurricanes was Hurricane Sandy in 2012. Hurricane Sandy was technically a post-tropical cyclone when she made landfall on October 29, 2012 at Atlantic City New Jersey, with sustained winds of 80 mph. Tropical storm force winds extended in a 500-mile radius from the center of the storm, thereby earning the name "Superstorm Sandy."

Sandy brought tropical storm conditions to a large area of the East Coast. Blizzard conditions caused by the storm were felt in the Central and Southern Appalachians. The storm surge caused by Sandy resulted in flood waters that rose 14.1 feet above normal low water mark in New York City and 10.6 feet above low water mark in Philadelphia. Property damage exceeded $20 Billion and 131 deaths were attributed to the storm. Sandy caused severe damage to the Northeast petroleum infrastructure and major disruptions in product supplies.

Power Outages

- 8.66 million customers lost electric power from North Carolina to Maine.
- Ten days after Sandy, approximately 95% customers had their power restored.

Refineries

- Two New Jersey refineries (Phillips 66 Linden and PBF Paulsboro) with combined refining capacity of 308 MBbl/d were shut down for over three weeks.

- Four other refineries in New Jersey, Pennsylvania, and Delaware, with combined capacities of 760 MBbl/d, operated at reduced run rates for up to ten days following the storm.

Oil, Gas, and Refined Product Pipelines and Terminals

- Fifty-seven New York Harbor oil and refined product terminals were partially or completely closed due to flooding, electric power losses, and water damage to pipelines, pump stations, marine terminals, and storage tanks. Several empty storage tanks were moved off their foundations by floodwaters.
- Three major petroleum product pipelines (Buckeye, Plantation, and Colonial) with combined capacity of 3.9 MMBbl/d were shut down or cut back operations on system segments for two to five days.
- Nine days after the storm, refined product deliveries from New York Harbor terminals remained at only 61% of pre-storm outflow levels. (Product losses during the 30-day period immediately following the hurricane landfall totaled of over 20 MMBbl).
- Natural gas pipelines remained in operation, but local distribution was suspended in many areas pending safety inspections before service could be restored.
- Transcontinental reported that some of its pumping stations lost power and/or had minor flooding. Iroquois reported that it used backup generators at some of its facilities.

Ports and Waterways

- Seven refined product ports from Hampton Roads, VA to Boston, MA, including two (Delaware Bay and New York Harbor) that also receive crude oil, were closed from 1 to three days.

Retail Gasoline Stations

Power outages, and disruptions to the fuel supply network, caused widespread fuel outages in the greater New York City area including southeast New York, Long Island, northern New Jersey, and western Connecticut. New York area gas stations were without power or fuel for 5 to 30 days, resulting in regional gasoline shortages and price spikes.

Table 7: Summary of Impacts from Recent Gulf Coast Hurricanes to TS&D Infrastructure

Hurricane	Category	Power Loss	Oil Infrastructure	Gas Infrastructure	Fuels Distribution
Katrina (2005)	• Cat-5 over GOM • Cat-3 at Landfall in LA on 8/29/05	• 1.2 million customers without power in FL. (90% restored by 8/30) • 2.7 million lost power in LA & MS (80% restored 30 post- land fall)	• 44 GOM platforms destroyed, 20 more damaged • 1.5 MMBbl/d of oil production shut in. • 11 refineries shut down; 4 closed 4 weeks or more	• 7.2 Bcf/d of production shut-in. Major gas supply loss to system. • Only 37% of gas customers restored 30 days after landfall.	• 2 Colonial product lines and Plantation shut down 5 days due to power outage • Dixie Propane Pipeline shut down due to power outage.
Rita (2005)	• Cat-2 at landfall in FL 9/20/05 • Cat-3 at landfall at Sabine Pass, TX 9/24/05 • Max sustained winds 120 mph.	• 1.25 million customers in TX and LA without power • Restoration complete late September	• 69 GOM platforms destroyed, 32 damaged • 1 MMBbl/d of oil still shut in on 10/16 • 16 refineries closed (4 MMBbl/d) - 4 for over 3 months. • Ports closed or limited	• Major gas supply loss to system: 5.6 Bcf/d of gas production still shut in after 3 weeks	• Lake Charles Gas Pipeline shut down • Trunkline LNG pipeline shut down • Seaway crude oil pipeline shutdown • 5 of 8 major product pipelines shutdown
Gustav (2008)	• Strong Cat-2 at Landfall in Morgan City, LA • Flooding as far N as Baton Rouge	• 740,000 million customers without power in LA, MS, AR • 90% restored pre-Ike (9/11)	• 334 GOM platforms and 34 rigs shut down • 1.2 MMBbl/d of oil (90.5%) shut in >5 days • 14 LA refineries shut (2.7 MMBbl/d); ~ 10 days. • Ports, waterways, and LOOP closed.	• 6 Bcf/d (79.5%) shut in for > 5 days. • 10 of 25 gas plants shut down >5 days; • 19 offshore gas pipelines shut; five for > 5 days • Sabine Gas line shut	• Henry Hub closed • GOM pipeline damage • Capline and LoCap lines (2.4 MMBD) closed • Centennial pipeline (210 MBbl/d) shut. • 39.2 MMBbl oil shortfall
Ike (2008)	Strong Cat-2 at Landfall near Houston (Baytown) TX	• 2.6 million customers without power in TX (2.4 million), and LA. • 400,000 still without power two weeks later.	• 596 GOM platforms and 101 rigs shutdown • 1.27 MMBbl/d of oil production (97.5%) • 14 TX refineries (3.8 MMBbl/d) closed 5-10 days; 2 still closed 3 weeks later due to power loss. • Major crude P/Ls shutdown.	• 7 Bcf/d (96.9%) shut in • Henry Hub closed • Interconnects on gas pipelines damaged. • 29 gas plants closed (13.7 Bcf/d loss); 10 shut down >5 days. • Sabine Gas pipeline shut down.	• Ports west of Port Arthur closed • Petroleum product pipelines shut down. • Aggregate 63.5 MMBbl oil supply shortfall.

Table 8: Summary of Impacts from Recent East Coast Hurricanes to TS&D Infrastructure

Hurricane	Category	Power Loss	Oil Infrastructure	Gas Infrastructure	Fuels Distribution
Irene (2011)	Cat-3 at landfall in NC 08/27/2011 90 MPH Atlantic City, NJ (80 MPH) Coney Island NY (75 MPH)	• 6.69 million without power from South Carolina to Maine. • 95% restored in 5 days • Extensive damage to the electric T&D infrastructure in the North East and Mid-Atlantic regions	• ConocoPhillips Linden NJ refinery (238 MBbl/d) down 4 days. • 5 NJ, PA, DE refineries (>1 MMBbl/d) at reduced rate 1-4 days. • Refinery inputs fell 416 MBbl/d (31%) for 1 week. • Flooding, power loss, and wind damage to pipe, pumps, terminals, and storage tanks. • Segments of 3product pipelines and 1 oil pipeline (1.83 MMBbl/d products and 410 MBbl/d crude) shut down for ~1 week.	• Natural gas pipelines remained in operation • Local distribution was suspended in many areas, pending safety inspections	• 25 NY Harbor oil and product terminals affected. • Product deliveries from NY Harbor only 61% of pre-storm level 9 days after Irene. • Product losses for 30-day period over 20 million barrels. • 8 East Coast product ports from North Carolina to closed 1-3 days
Superstorm Sandy (2012)	Post-tropical cyclone at landfall on October 29, 2012 at Atlantic City New Jersey, (80 MPH) Tropical storm force winds in a 500 mile radius from center of the storm	• 8.66 million customers lost electric power from North Carolina to Maine. • 10 days after Sandy, approximately 95% customers had their power restored.	• 2 NJ refineries (Phillips 66 Linden / PBF Paulsboro**) (**308 MBbl/d) shut down >3 weeks. • Four other refineries in NJ, PA, DE (760 MBbl/d) operated at reduced runs rates for up to 10 days.	• Natural gas pipelines remained in operation • Local distribution was suspended in many areas pending safety inspections.	• 57 NY Harbor oil and product terminals part- or fully closed. • Storage tanks moved off foundations by flooding. • 3 major product pipelines (Buckeye, Plantation, Colonial) (3.9 MMBbl/d) stop or cut operations 2-5 days. • Product ports from VA to MA, closed 1-3 days. • Gas stations without power or fuel for 5 to 30 days; regional fuel outages and price spikes.

G. Likely Impacts on Infrastructure

Based on the historic Gulf Coast and East Coast hurricanes of 2005, 2008, 2011 and 2012, impacts can range from minimal to major. The key determinants of hurricane impacts on oil and gas infrastructure are the severity, size, speed, duration, and the path of the storm, including the geographic location where the eye makes landfall, relative to the location of vulnerable infrastructure. The effects of a hurricane on oil and gas infrastructure, from most likely to least likely are:

- Widespread power outages that shuts down coastal and inland facilities and operations.
- Flooding from heavy rains and storm surge that damages equipment, piping, and structures and electric motors and pumps.
- Major wind and storm forces that damage production rigs and platforms, pipelines, communication and control systems, gas processing plants and oil refineries, marine ports and terminals, transportation systems, and oil and product storage and distribution facilities.

The size, intensity, speed and path of these storms determine the extent and duration of damages to infrastructure, and consequently, the magnitude of crude oil and refined product losses and market shortages in the Southeast, East Coast, and other markets affected by hurricanes.

Table 9: Summary of Types of TSD Infrastructure Damage from Hurricanes

PADD	Primary Region Affected	Secondary Region Affected	Result of Disaster	Infrastructure Damage	Petroleum or Product Supply Loss (Primary Area)	Petroleum or Product Supply Loss (Secondary Area)
PADD I: East Coast Hurricanes	New England	NA	Power loss Storm Surge Flooding	Bulk Terminals Marine Docks Truck Racks Gas Stations	Loss of products	NA
	Mid-Atlantic including NY/NJ	New England Southeast PADD-II	Power loss Storm Surge Flooding Electrical Infrastructure Damage	Pump Stations Compressor Stations Refineries Bulk Terminals Marine Docks Truck Racks Gas Stations	Loss of products and crude	Loss of Products
	GA, TN, NC, SC, VA	Mid Atlantic New England	None	Short term loss of Colonial or Plantation pipelines.	Loss of products ~2-4 MMBbl/d	Loss of Products
PADD-III: Gulf Coast Hurricanes	Texas, Louisiana, Mississippi, Alabama	PADD-I PADD II	Power loss Storm surge Flooding Wind damage	Oil & Gas Platforms Refineries Shutdown Gas Plant Shutdown Port Closures LOOP Shutdown Product pipelines shut down (Colonial and Plantation)	Crude oil and gas supply. Products to Gulf Coast.	Loss of gas and products to PADD-I (SE, Mid-Atlantic, and NE), and PADD II.

H. Probability and Severity

It is important to analyze hurricane occurrences by intensity category as the potential damage to Gulf Coast refinery production varies significantly based on the severity of the storm. Table 10 shows the probability of damage occurring to various elements of the fuels TS&D infrastructure and the relative severity of potential supply impacts resulting from the infrastructure damage or interruption. Additional information about the probability of the occurrence of hurricanes, their probability of making landfall, and seasonal timings of landfalls was developed through extensive modeling that was conducted for the Department of Energy. This additional information is provided in an appendix of the RPPR report for the Southeast.

Table 10: Probabilty and Severity of Hurricane Damage to Infrastructure

Infrastructure	Tropical Storm (39-73 MPH)		Hurricane Cat 1-2 (74-95 MPH, 96-110 MPH)		Hurricane Cat 3-5 (111-130 MPH, 131-156 MPH, or ->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
Offshore Platforms	Low	Insignificant	Med-High	Major	Med-High	Major
Onshore Wells	Low	Insignificant	Med	Significant	Med-High	Major
Pumping/Compressor Stations	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-Med	Interrupting	Med	Significant
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/NEHOR	Low	Insignificant	Low-Med	Interrupting	Med	Significant

Gulf Coast Hurricane Risk Zones: Table 11 depicts two regional Gulf Coast groupings with the highest probability of a hurricane making landfall: the “Sargent and Galveston, TX” locations and the “Chauvin, LA; Saint Mayo, LA; and Pascagoula, MS” locations.

- The first highlighted region, Sargent and Galveston, TX, together have a probability ranging from 17% to 27% of having a hurricane make landfall.
- The second highlighted region has a 27% to 35% probability of a hurricane making landfall.

These two regions are illustrated in the red areas in Table 11 and are the largest refining centers in the Gulf Coast. Combined, these two high-risk areas contain about 53% of the Gulf Coast's refining capacity.[13] These regions combined account for over half of the Gulf Coast hurricane landfall probability.

Table 11: Conditional Hurricane Probability by Category

Regions (W to E)	Hurricane Category					
	1	2	3	4	5	Overall Average
Armstrong, TX	5.20%	5.60%	6.20%	7.00%	8.60%	6.52%
Corpus Christi,	5.20%	5.60%	6.20%	7.00%	8.60%	6.52%
Port O'Connor,	8.50%	9.30%	9.80%	8.60%	8.50%	8.94%
Sargent, TX	**11.40%**	**11.10%**	**10.70%**	**9.80%**	**8.40%**	**10.28%**
Galveston, TX	**16.00%**	**13.50%**	**11.90%**	**11.10%**	**8.30%**	**12.16%**
Sabine Pass, LA	6.40%	8.10%	8.50%	9.30%	10.50%	8.56%
North Island, LA	6.30%	7.30%	8.10%	8.80%	10.10%	8.12%
Marsh Island,	6.20%	6.50%	7.80%	8.40%	9.60%	7.70%
Chauvin, LA	**8.90%**	**9.40%**	**9.70%**	**9.90%**	**10.60%**	**9.70%**
Saint Mayo, LA	**12.30%**	**11.90%**	**10.90%**	**10.50%**	**9.60%**	**11.04%**
Pascagoula, MS	**13.70%**	**11.60%**	**10.20%**	**9.40%**	**7.30%**	**10.44%**
Total	**100.00%**	**100.00%**	**100.00%**	**100.00%**	**100.00%**	

Source: NOAA Hurricane Risk Model Data as reported in SPR/RPPR 2011

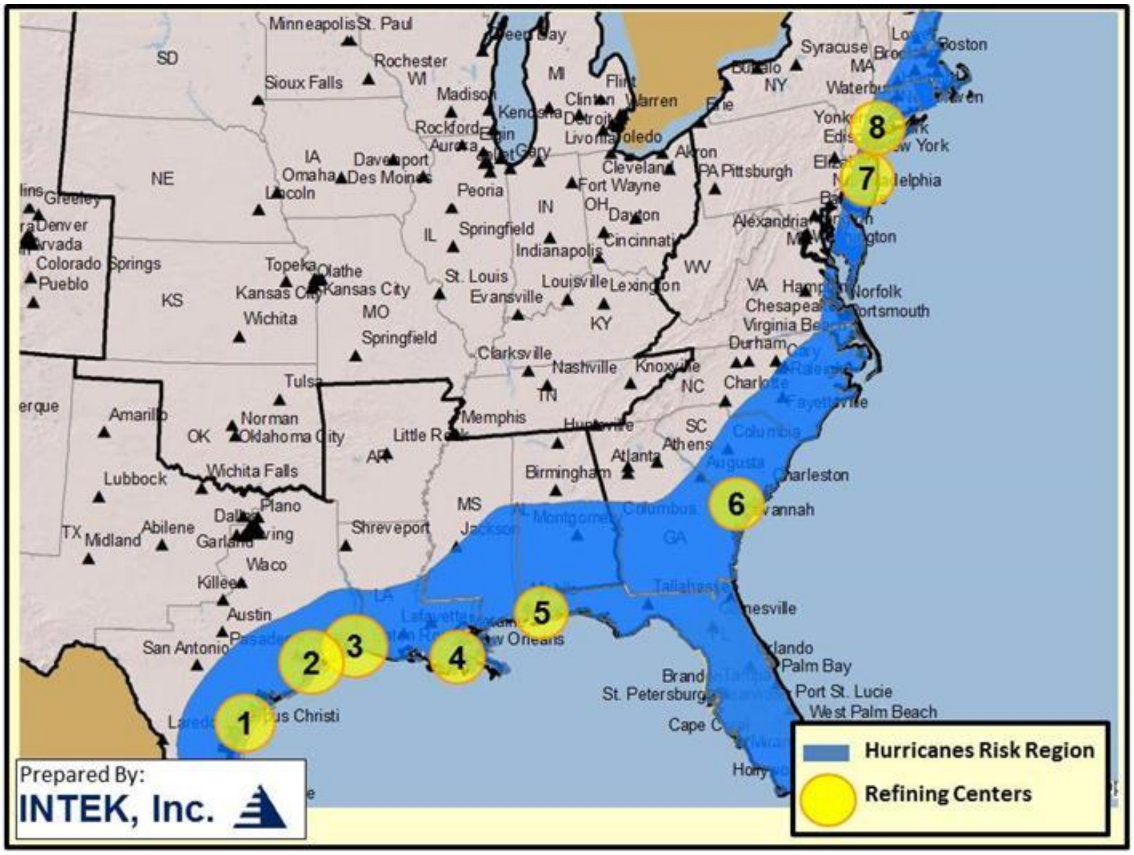
I. Hazard Areas

The major hurricane risk zones in the United States are the Gulf Coast, the East Coast, and to a much lesser extent, the southern part of the West Coast. West Coast hurricanes very rarely extend north of San Diego, CA or threaten the coastal oil and gas infrastructure in the Los Angeles area. Based on historical landfalls, eight hurricane risk zones have been identified by INTEK, as indicated on the map below (Figure 12). These zones were selected based on the probability of occurrences of hurricanes. TS&D infrastructure in their zone which may be compromised by a severe hurricane are listed below. These do not include the vulnerability to human life and the electrical grid.

1. Corpus Christi

- **Refineries:** 3
- **Total refining capacity:** 652 MBbl/d
- **Imported crude:** 244 MBbl/d
- **Petroleum terminals:** 7
- **Product pipelines:** NuStar, Enterprise
- **Port:** Port of Corpus Christi
- **Natural gas plants:** 2
- **Gas pipelines:** NGPL, Transco, Tennessee Gas Pipeline, Florida Gas Transmission, Texas Eastern Transmission
- **LNG Terminals:** 3

Figure 12: Major U.S. Gulf Coast and East Coast Hurricane Risk Zones



2. Houston and Texas City, TX

- **Refineries:** 8
- **Total refining capacity:** 2,091 MBbl/d
- **Imported crude:** 1,101 MBbl/d
- **Petroleum terminals:** 49
- **Product pipelines:** Explorer, Colonial, TEPPCO
- **Port:** Port of Houston
- **Natural gas plants:** 1
- **Underground gas storage:** 3
- **Gas pipelines:** NGPL, Transco, Tennessee Gas Pipeline, Florida Gas Transmission, Texas Eastern Transmission
- **Biodiesel plants:** 5

3. Port Arthur and Lake Charles, LA

- **Refineries:** 7
- **Total refining capacity:** 2,205 MBbl/d
- **Imported crude:** 1,311 MBbl/d

- **Crude pipelines:** Amdel, WTX Gulf, Ho-Ho
- **Petroleum terminals:** 25
- **Product pipelines:** Centennial, Colonial, Plantation
- **Port:** Beaumont, Lake Charles, Port Arthur
- **Natural gas plants:** 7
- **Underground gas storage:** 3
- **Gas pipelines:** NGPL (Louisiana Line), Transco, Tennessee Gas Pipeline, Florida Gas Transmission, Texas Eastern Transmission, Gulf South Pipeline
- **Biodiesel plants:** 2
- **LNG terminals:** 4

4. Baton Rouge and New Orleans, LA

- **Refineries:** 11
- **Total refining capacity:** 2,450 MBbl/d
- **Imported crude:** 817 MBbl/d
- **Crude pipelines:** Capline, ExxonMobil, Ho-Ho
- **Petroleum terminals:** 37
- **Product pipelines:** Colonial, Plantation
- **Port:** Port of New Orleans, Port of Baton Rouge
- **Natural gas plants:** 4
- **Underground gas storage:** 10
- **Gas pipelines:** Florida Gas Transmission, Southern Natural Gas, ANR, Tennessee Gas Pipeline, Columbia Gulf Transmission, Transco, Texas Eastern Transmission, Gulf South Pipeline
- **Biodiesel plants:** 3
- **LNG terminals:** 4

5. Pascagoula, MS

- **Refineries:** 1
- **Total refining capacity:** 330 MBbl/d
- **Imported crude:** 255 MBbl/d
- **Petroleum terminals:** 2
- **Product pipelines:** Plantation
- **Port:** Pascagoula
- **Natural gas plant:** 1
- **Gas pipelines:** Florida Gas Transmission, Gulfstream, Gulf South Pipeline, Destin Pipeline Offshore (Shell), Southeast Supply Header Pipeline
- **LNG terminals:** 1

6. Savannah, GA

- **Refineries:** 1 (Nustar Asphalt)
- **Total refining capacity:** 0 (refinery is idle)
- **Petroleum terminals:** 4
- **Port:** Savannah
- **LNG terminals:** 1
- **Gas pipelines:** Southern Natural Gas

7. Philadelphia, PA and Wilmington, DE

- **Refineries:** 4
- **Total refining capacity:** 932 MBbl/d
- **Imported crude:** 548 MBbl/d
- **Petroleum terminals:** 10
- **Product pipelines:** Colonial, Buckeye, Sunoco
- **Port:** Port of Philadelphia
- **Gas pipelines:** Columbia Gas Transmission, Eastern Shore Natural Gas, Texas Eastern Transmission, Transcontinental Gas

8. New York Harbor Area and Linden, NJ

- **Refineries:** 1
- **Total refining capacity:** 238 MBbl/d
- **Imported crude:** 153 MBbl/d
- **Petroleum terminals:** 48 (Central to the Northeast)
- **Product pipelines:** Colonial, Buckeye, Harbor Pipeline System
- **Port:** Port of New York, New Jersey & New York Channels
- **Gas pipelines:** Algonquin, Columbia, Texas Eastern Transmission, Transcontinental, Brooklyn Union

J. Measures Taken by Industry to Address Vulnerability

Industry has essentially only three alternatives for reducing impacts of natural disasters:

1. Reduction of impacts by hardening
2. Relocation of Infrastructure
3. Positioning of products to provide regional coverage until infrastructure can go back in service

Infrastructure Hardening and Recovery Issues

Past hurricanes in the Gulf Coast and the East Coast have resulted in major storm damages, electrical power outages, and large-scale flooding, which have severely impacted petroleum refining operations and product distribution capabilities. In addition, hurricanes have led to mandatory regional evacuations of both residences and businesses.

In the five years since Hurricanes Katrina and Rita, federal and state governments, public utilities and private industry have taken steps to address these hurricane vulnerabilities through the hardening of infrastructure and by increasing resiliency measures.

In an effort to better understand what actions the energy industry has taken in response to past hurricanes, particularly, the 2005 and 2008 hurricane seasons, the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability (DOE/OE) conducted a study in 2010 to identify specific industry efforts related to storm hardening and resiliency. A summary of their findings is presented below, along with some observations. With past hurricanes, petroleum infrastructure has suffered from:

- Electric power outages
- Storm damages resulting from wind & flooding
- Mandatory evacuations and personnel safety

Though the commercial industry has taken steps to strengthen these areas, infrastructure and personnel safety are still vulnerable to hurricanes, limiting refined product supply reliability.

Electricity Hardening Efforts

Electricity is a critical element of the highly interdependent energy supply and distribution system. A refinery or pipeline pumping station, even if undamaged by a hurricane, will not be able to operate without access to electricity. Hurricane-force winds are the primary cause of damage to electric utility transmission and distribution infrastructure. About 90% of outages occur along distribution systems.

Most utilities have implemented plans to harden their infrastructure against wind and flood damage. All of the utilities interviewed have identified upgrading poles and structures with stronger materials as a primary hardening strategy. For distribution systems, this usually involves upgrading wooden poles to concrete, steel, or a composite material, and installing guys and other structural supports.

Placing utility lines underground eliminates the susceptibility to wind damage that is typically experienced with overhead lines. However, underground utility lines present significant challenges, including additional repair time and much higher installation and repair costs. Perhaps the most important issue for coastal regions is that underground wires are more susceptible to damage from storm surge flooding than overhead wires.

Additional hardening activities reported by utilities to protect against flood damage include elevating substations and relocating facilities to areas less subject to flooding. Utilities report that a number of substations along the Gulf Coast have been elevated as much as 25 feet based on predictions for a Category 3 hurricane. Elevating substations to Category 4 or 5 storm surge levels is not cost effective since storms of that magnitude are relatively rare. Some utilities have also opted to invest in spare equipment to address that risk. To date, the electrical grid remains highly susceptible to damage from hurricane floods and winds.

Refinery Hardening Efforts

One of the biggest vulnerabilities for refineries across the Gulf Coast can be the lack of electricity supply. Without power, refineries cannot continue to operate, and petroleum products cannot be moved through pipelines. The high probability of electricity outages after hurricanes has caused refiners to initiate controlled shutdowns in advance of landfalls to avoid "hard shutdowns" that result in refinery damages.

A number of refineries have invested in portable generators; however, the majority have only established plans for leasing generators in advance of the hurricane. Portable/mobile generators are available in a range of sizes and capacities; from retail scale units (~ 35 kW) to large 2-MW trailer-mounted units, which cost approximately $0.5 million with cables, batteries, fuel tanks and other accessories raising the installed price to over $1 million.[14] However, even the largest 2-MW 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 IT facilities, and the water pumps required to remove storm water from the plant and refinery equipment. Refiners rely on portable generators only to provide critical service until grid power can be restored.

Hurricane winds can cause severe damage to refineries. Refinery cooling towers are especially prone to wind damage. High winds can cause the fan blades inside a cooling tower to become dislodged and launched from the tower if they are not secured. This renders the cooling tower unusable and creates airborne debris that can cause further damage. During Hurricane Rita in 2005, fifty percent of the cooling towers at Port Arthur refineries were damaged and fifty-four percent were damaged at Port Neches, according to a National Institute of Standards and Technology reconnaissance report.[15] Several of the refiners interviewed by DOE/OE reported that they have installed special braces to stop the fan blades from dislodging.

Hurricane rains and flooding can be extremely devastating and costly to petroleum refineries, and normally result in extended refinery recovery times. The Gulf Coast hurricanes of 2005 and 2008 caused extensive water damage to refinery control systems, electrical equipment, and pump motors, and caused storage tanks to move off their foundations. Common flood protection structures such as floodwalls, levees, and berms have been built by either government or industry.

Flood damage is the most common and costliest type of storm damage to petroleum infrastructure, and results in the longest disruption for refineries, pipelines, and terminals. Figure 13 shows the location of key pipelines, refineries, and pumping stations, in relation to areas that would be affected by a hurricane-induced 20-foot Gulf Coast storm surge. Figure 14 shows the coastal areas in the New York area that were affected by flooding and storm surge caused by Hurricane Irene and Superstorm Sandy.

However, most flood walls like those that currently exist to protect refineries have been designed to protect against a 100-year storm surge and are inadequate for a Category 4 or 5 hurricane direct hit.

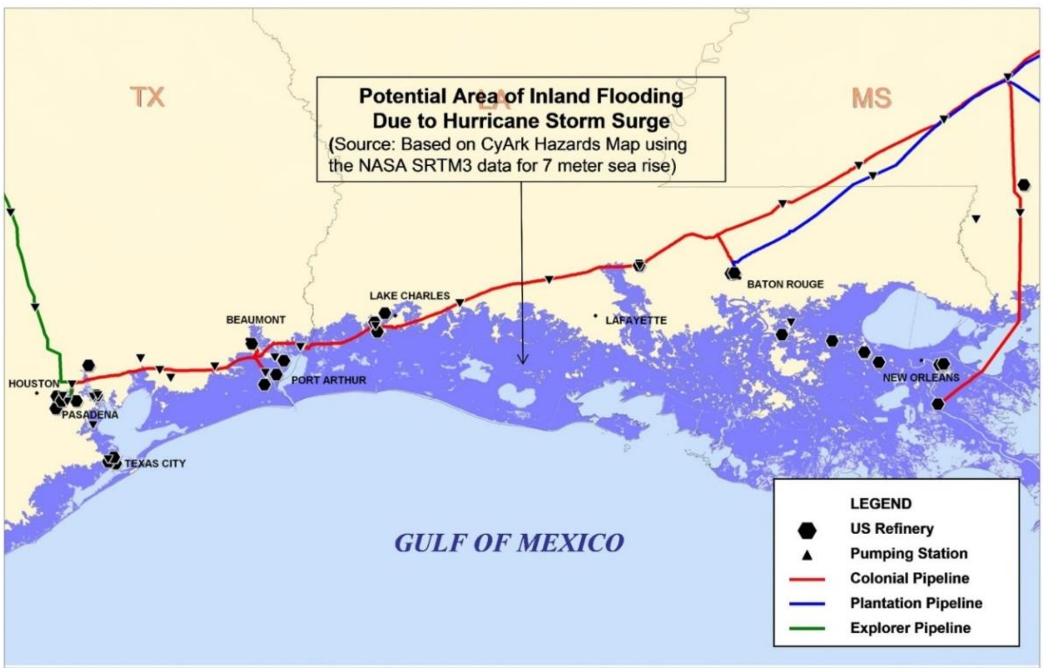
- The 15-foot-high concrete floodwall that protects the BP, Marathon, and Valero refineries at Texas City is considered by some in the industry to be inadequate for recent hurricanes.

- A 5-mile long dike and flood wall that Chevron built to protect its Pascagoula, MS refinery from hurricanes, greatly reduced storm surge damage. The refinery still required six weeks to return to normal production after Katrina, as compared to 3 months after Hurricane Georges in 1998.

In response to extensive water damage, many refineries have elevated substations, control rooms, and pump stations above the likely flood level. In many cases, facilities have been elevated 15-25 feet above ground. Costs for elevating facilities vary depending on the size of the unit, how much power is carried, and how much wind and storm surge the unit is designed to withstand. According to one refiner, elevation costs may range from $500-900 per square foot, based on the project design.

Although, refineries have made some effort to improve their resiliency to hurricanes, refineries remain very susceptible to extensive damages from hurricane winds and flooding, especially for hurricanes of Category 2 or greater strength along with a storm surge.

Figure 13: Impact of 20-Foot Tidal Surge on Gulf Coast Refineries and Product Distribution Infrastructure

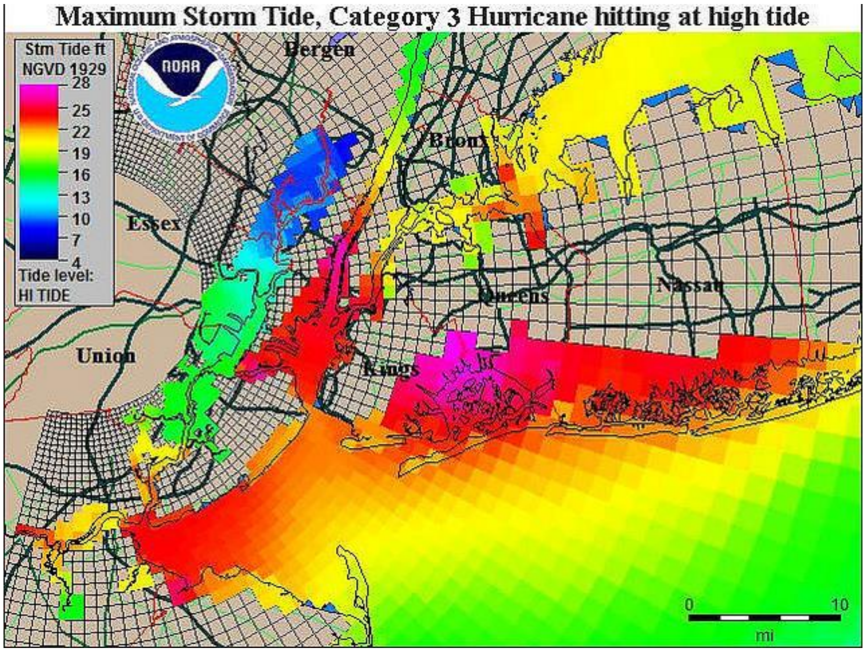


Source: SPR/RPPR 2011

Distribution Terminals and Pipeline Hardening Efforts

The Colonial and Plantation Pipelines, which supply refined products to the Southeast and East Coast, have numerous pipeline injection points and pump stations across the Gulf Coast, and delivery points in the South East which are vulnerable to commercial electrical power system outages. Both pipelines experienced extended operational shutdowns during the 2005 hurricane season due to localized electrical power outages.

Figure 14: New York Harbor Areas Impacted by Storm Surge and Flooding by Sandy, 2012



Source: NOAA

To avoid a recurrence of the experiences during the 2005 hurricane season, the Colonial Pipeline Company purchased 12 trailer-mounted Mitsubishi portable generators, seven transformers, and miles of associated cabling in 2006.[16] These large portable generators are maintained at a site in Mississippi and can be deployed to any of its pump station locations to in order to maintain its pipeline operations. These generators will only be beneficial if there is an uninterrupted supply of products from refineries or terminals.

The Plantation Pipeline has not purchased portable generators but has stated that it has contingency plans for the rental of portable generators in the event of electrical power outages. The Colonial Pipeline has indicated the capability to deploy its generators and return to operations within one week (subject to product supplies).

Although the Colonial and Plantation Pipelines may have been made more resilient to address electrical power losses, the overall system has not been, because the Colonial and Plantation Pipelines are also dependent on the operational capabilities of numerous independent terminals and interconnecting pipelines supplying product. Many of the intermediate pipelines are either owned by the refineries, co-owned with other refineries or terminals using the line, or owned by the major pipeline company accepting delivery. For the most part, these intermediary pipelines' vulnerability directly correlates with the connecting refinery. Thus, if the refinery is out of service, so is the pipeline. For example:

- Port Arthur/Lake Charles area, most product injections for the Colonial pipeline originate from the Port Arthur Product System (PAPS), owned and operated by Shell Pipeline, and Texas Eastern Pipeline Company (TEPPCO).

- Refineries in the Baton Rouge, New Orleans, and Pascagoula areas are connected to the Colonial and Plantation Pipelines through either refinery or independent owned pipeline systems.
- In the Houston area, the majority of product injections for the Colonial Pipeline come from two major terminals: Kinder Morgan terminal and Magellan Midstream Partners terminal. These terminals were previously hardened to the 100-year flood level, which was exceeded by Hurricane Ike. Since 2008, the Magellan Midstream Partners terminal has purchased a crane for the terminal. In the event of a Category 3 storm or greater, they plan to disassemble their motors from the pumps and move them to higher ground for safety.

All terminals and pipelines have updated or implemented new emergency plans. Where reasonable, they have made investments to harden and make their systems more resilient. From the perspective of one operator, an area power outage means that there is no refinery production or stock drawdown to keep the pipeline operational, which makes leasing a portable generator uneconomical.

Mandatory Evacuations and Personnel Safety

Perhaps the biggest issue for recovery is not the hardening of infrastructure, but rather the availability of key personnel. As was the case with past hurricanes, regardless of the damage done to infrastructure, key personnel had been evacuated and were not available to operate the systems. Therefore, despite efforts made to improve recovery time, one aspect of resiliency is the pace in which skilled personnel return to the company facilities.

Personnel may be unavailable due to widespread evacuation and relocation, with their return being precluded by distance of dislocation, lack of resources, roadway closure/compromise, and/or the need to focus on securing their own families and homes. However, DOE/OE found some companies, in particular refiners and pipeline/terminal operators, do keep key personnel in place to ride out the storm.

One company described an approach that establishes a safe haven capable of accommodating 150 people. During mandatory evacuations, personnel from other industries supplying operational-necessary commodities can stay in the haven in return for assuring supply. This arrangement is written into their third-party supply contracts.

Recent discussions with several refiners revealed the actions they have undertaken to enable quicker recovery and resumption of operations. Taking care of personnel is a key focus of companies' hurricane preparedness plans. Some of the specific items mentioned were:

- Obtaining exemptions from evacuation plans (in accordance with local evacuation orders),
- Implementing better systems for keeping track of personnel,
- Arranging a relocation site for key personnel, including food, shelter and gas cards,
- Hiring contractors for personal home repairs so personnel can return to work, and
- Purchasing generators for employees' homes.

Much hardening has been done:

- Facilities have been bermed, flood walls built, and water-sensitive equipment elevated to reduce vulnerability to flooding
- More durable towers and structures have been constructed to reduce wind damage
- Communications systems and controls have been shielded

But major factors such as strength and integrity of the electric power generation, transmission, and distribution infrastructure will remain vulnerable to hurricanes. Further, evacuations of personnel necessitated for safety, cannot be offset by further hardening of vulnerability facilities.

IV. Earthquakes

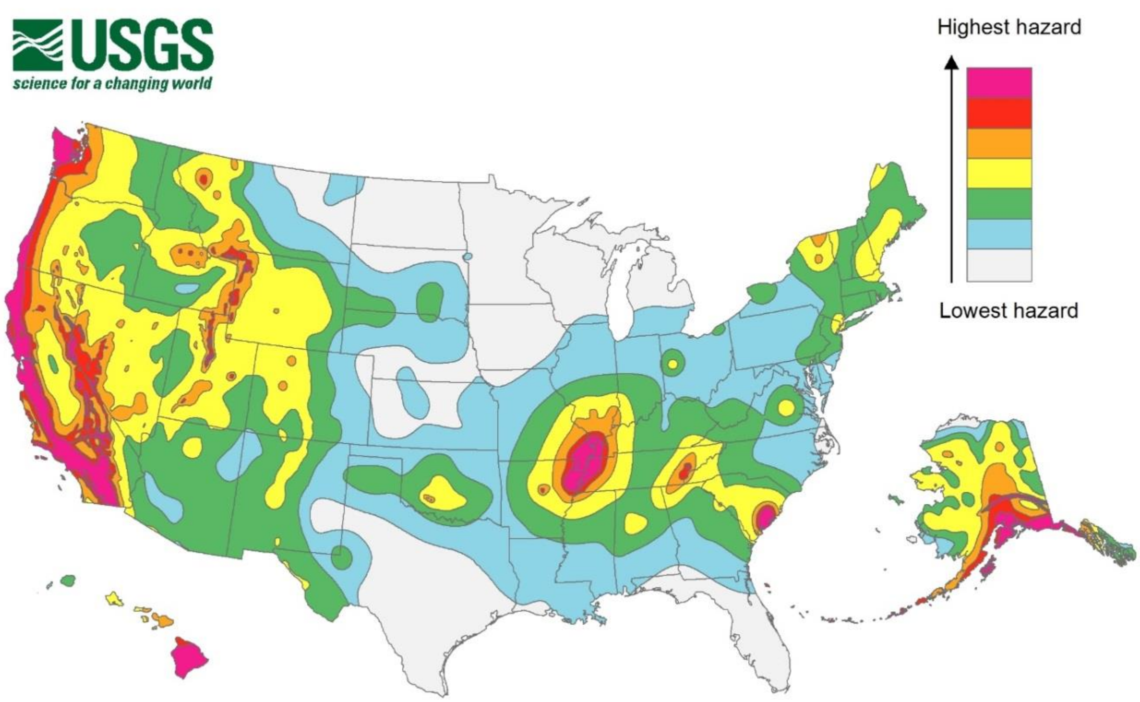
A. Introduction

Earthquakes are usually caused when rock deep underground suddenly breaks or moves along a fault or edge of a tectonic plate. Energy is released in the form of heat, elastic seismic waves, and the cracking of rock. Even though seismic waves are the most apparent sign of an earthquake, only a small portion of the energy is released in the form of seismic waves. The seismic waves radiate outward from the fault and cause vibrations in the surrounding rocks. These vibrations can cause significant damage to natural features and artificial structures on the surface as they pass through.

Most earthquakes occur along the edges of tectonic plates where massive, rigid plates of the Earth's crust move against each other. Where the plate edges are not smooth, and they are unable to move freely past each other, energy and stress are built up until friction and the structures 'locking' the plates in place are suddenly overcome. The result is an earthquake.

All of the United States, except for Hawaii and parts of California, is located in the North American Plate As a result, the majority of significant earthquakes occur in California and Alaska which abut the Juan de Fuca and the Pacific Plate. Part of the edge of the North American Plate is the San Andreas Fault which runs north to south through California.

Figure 15: 2014 U.S. Peak Ground Acceleration Probabilities Map



Source: USGS, 2014

Figure 15 shows the peak ground acceleration (PGA) probabilities in the United States and is used to identify the high risk earthquake zones. PGA measures how hard the ground shakes as a percentage of the Earth's gravity (9.81 m/s^2). Generally speaking, a PGA of 0.1% can be perceived by people, a 2% PGA is strong enough to knock someone off balance, and a PGA of 50% can severely damage a building.[17] As an illustration, the 1994 Northridge, CA earthquake had a magnitude of 6.7 and a PGA of 1.7.[18] The Figure should be interpreted as saying that "the coast of Oregon has an earthquake peak ground acceleration that has a 2% chance of being exceeded in 50 years of 64+ percent of Earth's gravity."

USGS, measuring the peak ground acceleration, identified four high risk areas: the West Coast and Alaska (along the edge of the plate), the Tennessee Valley Zone, and South Carolina.

Earthquakes also occur in the middle of plates at faults. Faults are cracks where plate sections are moving away from each other. There are three types of faults: normal (where one section is sliding down and away from another), reverse (where two sections are sliding towards each other with one above the other), and strike-slip (where two sections are sliding past each other).

B. Measuring an Earthquake

Seismologists commonly use two earthquake measurements scales: the Richter Scale, which measures magnitude, and the Modified Mercalli (MMI), which measures intensity. [19] Magnitude is related to the amount of seismic energy released at the hypocenter of the earthquake and is based on the amplitude registered on calibrated seismographs. The Richter scale is not used to express damage. The intensity is based on the observed effect of ground shaking on people, buildings, infrastructure, and natural surface features. Its measurement, completed after the quake is finished, varies according to the observer's distance to the epicenter of the quake. This scale is assigned by the Geological Survey based on questionnaires sent to postmasters in the disturbed area. The USGS has prepared a comparison of the two scales (Table 10):

- Richter Scale 1 – 3 quakes, which include microearthquakes (Magnitude < 2) correspond with MMI category I. These earthquakes are typically not noticed by people.
- Richter Scale 3 – 3.9 correspond with MMI categories II and III; and are noticed by very few people. Beyond a magnitude of 4.0 earthquakes have a noticeable effect.
- Richter Scale 4.0 – 4.9 earthquakes correspond with MMI of IV and V. In these earthquakes unsecured or fragile objects, such as dishes and windows, may be overturned and broken. Beyond a magnitude of 5.0 the direct correspondence between the Richter scale and MMI breaks down.
- Richter Scale 5.0 – 5.9 corresponds with MMI VI and VII.
- Richter Scale 6.0 – 6.9 corresponds with VII to IX on the MMI scale.
- Richter Scale 7.0 and above correspond with MMI of VIII and higher.

In all of these cases, the earthquake is widely noticed by people and causes damage to structures. The extent of the damage is dependent upon the intensity of the earthquake and the design and construction of the structures. The highest level of the MMI, XII on the scale, is assigned to the areas where the damage is total and the natural lines of sight and level have been distorted. An earthquake of this magnitude is very rare; the average frequency is once every 10 to 50 years worldwide. Table 12 provides a comparison of the Richter and MMI scales, and describes impacts on infrastructure.

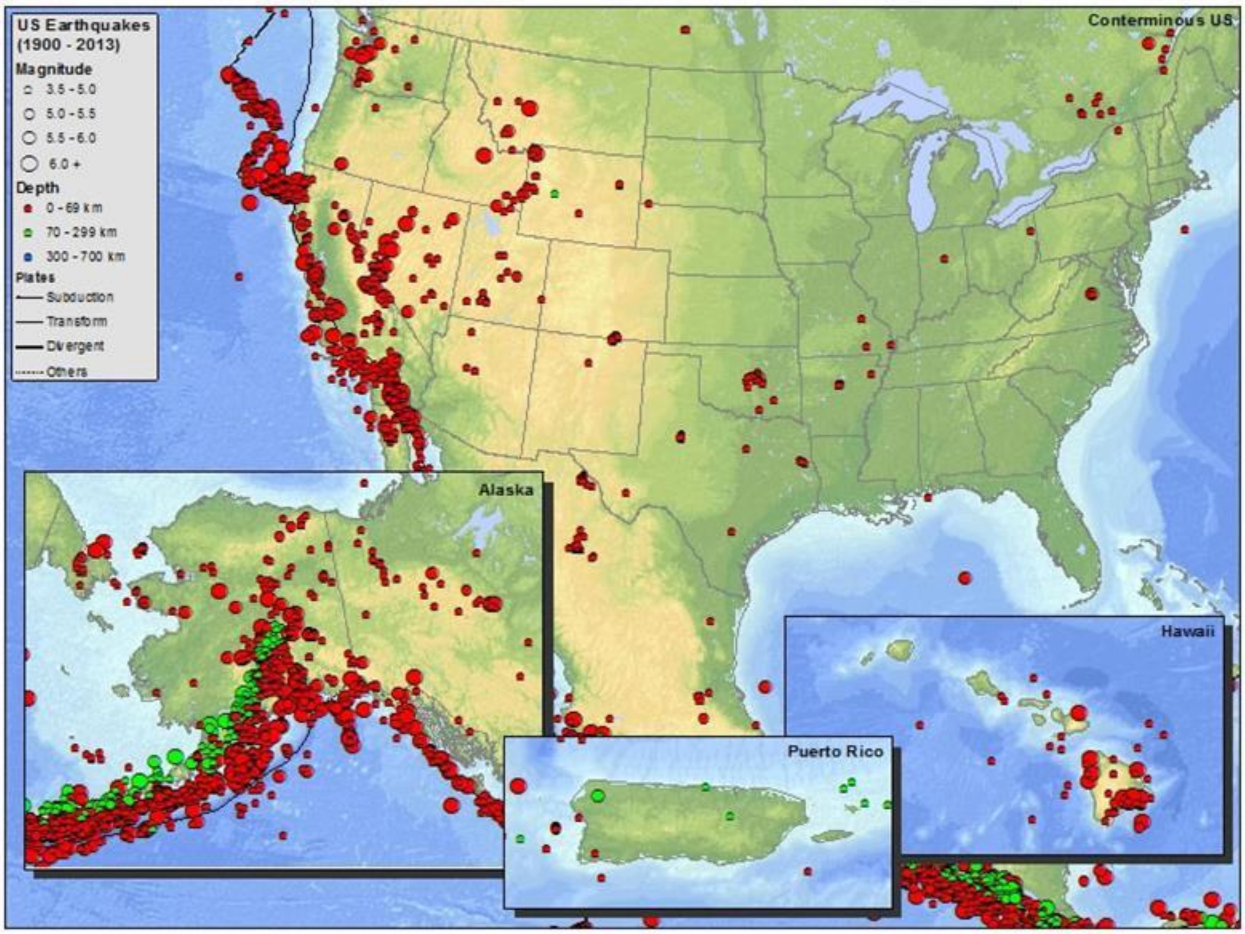
Table 12: Measuring the Severity of an Earthquake

Richter Scale Magnitude	Modified Mercalli Intensity	Description
1.0 – 3.0	I	Not felt except by a very few under especially favorable conditions.
3.0 – 3.9	II	Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing.
	III	Felt quite noticeably by persons indoors, especially on upper floors of buildings. Many people do not recognize it as an earthquake. Standing motor cars may rock slightly. Vibration similar to the passing of a truck. Duration estimated.
4.0 – 4.9	IV	Felt indoors by many, outdoors by few during the day. At night, some awakened. Dishes, windows, doors disturbed; walls make cracking sound. Sensation like heavy truck striking building. Standing motor cars rocked noticeably.
	V	Felt by nearly everyone; many awakened; some dishes, windows broken. Unstable objects overturned. Pendulum clocks may stop.
5.0 – 5.9 (VI – VII)	VI	Felt by all, many frightened. Some heavy furniture moved; a few instances of fallen plaster. Damage slight.
	VII	Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken.
6.0 – 6.9 (VII – IX)	VIII	Damage slight in specially designed structures; considerable damage in ordinary substantial buildings with partial collapse. Damage great in poorly built structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned.
	IX	Damage considerable in specially designed structures; well-designed frame structures thrown out of plumb. Damage great in substantial buildings, with partial collapse. Buildings shifted off foundations.
7.0 – higher (VIII – higher)	X	Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations. Rail bent.
	XI	Few, if any (masonry) structures remain standing. Bridges destroyed. Rails bent greatly.
	XII	Damage total. Lines of sight and level are distorted. Objects thrown into the air.

C. Earthquakes in the United States

The USGS monitors and reports on earthquakes and assesses their impact and hazards. Hundreds of earthquakes with magnitude greater than 3.5 have been recorded in the United States in the last century (Figure 16). The vast majority occurred along the edges of the North American Plate in California and Alaska. Others were located in Nevada, Washington, Oklahoma, Virginia, and the Northern Rockies. Earthquakes in Nevada have measured up to 7.75 on the Richter scale but with little damage to manmade structures. Only one earthquake in Oklahoma, on April 9, 1952, had a magnitude of 5.5 or greater. All of the others shown in Figure 16 had magnitudes less than 5.0. In the past century only one earthquake, in August 2011, has struck Virginia with magnitude greater than 5.0.[20]

Figure 16: The Location of Major U.S. Earthquakes



Source: USGS

D. Types of Damage

Earthquake damage can be described in four categories:[21]

1. **Ground shaking:** buildings and other structures can be damaged by shaking, subsidence, and liquefaction of the ground. Earthquakes can churn the soil to the point that it acts as a liquid.
2. **Ground displacement:** structures can be compressed, bent, or torn apart by ground displacement.
3. **Flooding:** offshore and coastal earthquakes can cause tsunamis. Earthquakes near or under lakes can cause seiches which are like small tsunamis. Damage to dams, levees, and other

structures along rivers can also result in flooding. Vulnerability to tsunamis will be discussed in greater detail in another section of this report.

4. **Fire:** fires can result from damage to natural gas pipelines and power lines.

E. Threats to Oil and Gas TS&D Infrastructure

These types of damage can impact all components of the oil and gas transmission and distribution infrastructure. Depending upon the magnitude and intensity of the earthquake, and the proximity of the infrastructure to the epicenter, the damage can be significant. As shown in past earthquakes, damage to pipelines may disrupt crude supply at refineries, product supply at terminals and fueling stations, and natural gas supply in local distribution systems. Damage to ports, terminals, and refineries may be resolved quickly, as in the case of power loss or minor structural damage, or may result in long disruptions to allow for repairs to storage vessels and towers. Two widespread, and common results of earthquakes, are power loss and interruption of natural gas delivery to consumers. Gas pipelines may be shut down, even if undamaged, to reduce the risk of fire or explosion at other points in the system.

F. Historical Events

Northridge, California (January 17, 1994)

The Northridge earthquake, with a magnitude of 6.8, occurred under the San Fernando Valley on January 17, 1994. It was felt across the entire Los Angeles area. The Northridge earthquake resulted in at least 58 deaths, 1,500 major injuries, up to 120,000 permanently displaced people, and nearly $30 billion in damage. It was the costliest earthquake in U.S. history.[22] While there was significant damage to infrastructure, including highways, bridges, piers, and buildings, relatively little damage was done to energy infrastructure. There were many ruptures in the natural gas pipeline system; more in the distribution lines than the transportation lines. Most ruptures occurred in old, pre-1971, steel pipes.

One distribution pipeline, located along Balboa Boulevard, was the result of compressional ground failure. Two other lines were ruptured by ground contraction. Ground extension ruptured a fourth line and resulted in a fire that destroyed five houses. The result of the ruptures, and people shutting off gas valves to prevent fire or explosion, was widespread gas service outages (about 151,000) in the San Fernando Valley. About 100 fires were attributed to pipeline ruptures. Services were restored to 119,000 by February 7th, 1994. Over 9,100 outages could not be restored because of structural damage.

The Aliso Canyon Gas Storage field was affected by deformation of aboveground pipe supports, displacement of runs of injection and withdrawal lines, and minor structural damage. Service was interrupted for five days.[23]

A crude oil pipeline coming from the San Joaquin Valley to Los Angeles refineries suffered cracks along the welds at several locations and caused a spill along the Santa Clara River. Two other pipelines, constructed after 1950 using improved welding techniques, had no apparent damage.

Power was lost to most of the San Fernando Valley. As a result of the quake, 2 million people were without power. Nearly half of them had power restored within one day. Over 95 percent had power restored by midnight January 18, 1994. Power was completely restored 10 days after the quake.

The Port of Los Angeles suffered insignificant damage. Container terminals at six berths were damaged by soil liquefaction at nearby piers. Crane rails were broken by horizontal shear and lateral movements at wharfs. These damages had very little impact on Port operations. One ship had to be diverted while the originally intended berth was repaired. The Port of LA was fully functional after five days of repairs.

Loma Prieta, California (October 17, 1989)

The Loma Prieta earthquake occurred on October 17, 1989, approximately 60 miles south of San Francisco. The earthquake had a magnitude of 7.2. The earthquake resulted in more than 60 deaths, most of them caused in the collapse of the upper deck of the I-880 Cypress Street viaduct.[24]

The Seaport of Richmond, at the northeast end of San Francisco Bay, the primary regional seaport for petroleum products, suffered very minor damage during the earthquake. A gasoline storage tank was ruptured at the Unocal terminal. Spilled fuel was contained by the surrounding berm. The gasoline leak resulted in power shutoff to avoid the risk of sparks and fire, and a 24 hour delay in unloading cargo. Within 48 hours, normal operations at the entire seaport were restored.

Damages to the natural gas transmission lines were minimal.[25] Two leaks were discovered by Pacific Gas and Electric Company in 12” pipeline constructed in the 1930s and were repaired without interrupting service. However, the damage to the local distribution system was much more severe. Over 1,000 leaks were reported across the system and more than 156,000 consumers were without service. Three sections were so heavily damaged that they were replaced instead of repaired. Service repairs and restorations ranged from three to four weeks.

Product terminals along the San Francisco Bay in Alameda and Contra Costa counties were also damaged. Unanchored tanks were damaged from uplift of tank walls.[26] Uplift displacement between the shells and foundations of some fully loaded tanks were between 6 and 8 inches and resulted in buckling tanks, split walls, punctures by and to connected pipeline, and spills.

Transmission substation damage resulted in electrical power outages for 1.4 million people. Within 7 hours power was restored in most of San Francisco. Within two days all but 12,000 customers had their power restored. Two power plants were also damaged: Moss Landing and Hunter’s Point. Hunter’s Point was restored within days; Moss Landing’s restoration took several weeks.[27]

San Fernando, California (February 9, 1971)

The San Fernando earthquake had a magnitude of 6.6. It occurred at the foothills of the San Gabriel Mountains at the northern edge of the San Fernando Valley. The effects of the earthquake were felt in Sylmar, San Fernando, and other areas north of Los Angeles. At least 58 people were killed by the quake.

The earthquake caused substantial damage to the transportation infrastructure including roadway failure and the collapse of freeway interchanges.

Relatively little damage was done to oil and gas infrastructure. The Newhall asphalt refinery, located about 11 miles from the epicenter of the quake, was temporarily shut down by damage to pipelines and storage tanks. The refinery produced 5,500 Bbl/day of asphalt, road oil, and jet fuel.[28] There were numerous failures in the natural gas pipeline system where there were sharp vertical or lateral ground dislocations or ground failure. The most severe damage was along San Fernando Road. However, the steel pipeline system, as a whole, was undamaged by the earthquake.[29]

In summary, the earthquakes described above caused relatively little damage to the local TS&D infrastructure that resulted in supply disruptions to local, regional, and national markets, as summarized in Table 11. To illustrate the wide-spread damage that an earthquake can cause to TS&D infrastructure, resulting in long-term interruptions to supply, comparative information is provided on the 1999 earthquake which struck Izmit, Turkey.

Table 13: Summary of Damage from Recent Earthquakes to Transmission and Distribution Network

Earthquake	Magnitude	Power Loss	Oil Infrastructure	Gas Infrastructure	Fuel Disruption
Northridge, California	6.8	• 2 million without power. • Restored within 10 days.	• Leaks in crude pipeline. • Insignificant damage at Port of Los Angeles.	• Local distribution system. • 151,000 customers without gas. • Service interruption at Aliso Canyon Gas Storage Field.	• Natural gas disruption
Loma Prieta, California	7.2	• 1.4 million without power. • Restored to all but 12,000 in 2 days.	• Insignificant damage at Richmond Seaport Unocal terminal. • Damage at product terminals along the San Francisco Bay	• Local distribution system. • 156,000 without gas.	• Natural gas disruption
San Fernando, California	6.6	• Unspecified number affected. • Restored in 3 days.	• Newhall Refinery damaged and temporarily closed	• Local distribution system • Up to two weeks to repair.	• None reported
Izmit, Turkey (August 17, 1999)[30],[31]	7.4	• Power loss across the country. • Mostly restored after 2 days.	• Izmit refinery & port severely damaged. • Tank farm burned uncontrollably for three days. • Pipelines damaged and spilling crude.	• Principal port for LPG import and distribution damaged. • LPG spills.	• One third of Turkey's refining capacity (220,000 Bbl/d) closed for three months. • Refinery was "mostly" operational after 13 months.

G. Likely Impacts on Infrastructure

Looking at the historical earthquakes, the impact can range from the hardly noticeable – dishes falling – to the devastating – destruction of large sections of housing, infrastructure and thousands of deaths. Key determining factors are the magnitude of the earthquake and the proximity of the epicenter to a population or infrastructure center. Effects of an earthquake on the oil and gas infrastructure, listed from most likely to least, are provided below:

- Widespread electrical power outages. These may last for a few hours in the least damaged zones to a few weeks in areas most severely affected.
- Interruption of the local natural gas distribution network may last days to weeks. Disruptions will be caused by leaks and other damage to pipelines (those constructed using pre-1950s standards are most vulnerable), customers shutting off gas connections, and risk of fire and explosions.
- Damage to tanks at product and crude storage terminals.
- Damage to ports. The impact could be insignificant – leaks in storage tanks – or significant – the collapse of piers and terminals. Damage to ports can interrupt the supply of crude and products.
- Damage to crude, product, and natural gas pipelines could result in supply interruptions for refineries, gas processing plants, product storage and distribution terminals, and city gates.
- The natural gas loss could be exasperated by damage to underground gas storage sites. Power loss and physical damage will prevent storage sites from responding to local demand.
- Loss of refined products could be caused by power outages at refineries, interruption of crude supply, inability to move products off of refinery grounds, or direct damage to refinery facilities. Interruptions would be resolved as soon as power is restored or pipelines repaired. Onsite damage could, depending upon the extent and severity, result in a partial or complete refinery shut down for weeks or months as components are repaired and replaced.
- A refinery shutdown would result in product loss in the local market and those connected by pipeline. For example, Las Vegas and three military bases in California and Nevada are dependent upon the CALNEV and SFPP southern pipelines for gasoline and jet fuel from refineries in the Los Angeles area.
- An earthquake-caused tsunami could devastate infrastructure located on the coast and cause even greater damage and disruption.

Three factors need to be considered when assessing these impacts: the severity of the earthquake, the probability of the damage and the severity of the damage (Table 14). An earthquake with magnitude less than 5.0 is unlikely to cause significant or widespread damage. The probability of damage describes the likelihood of the occurrence. The severity describes the impact of the occurrence.

Electrical power outages are very likely to occur as a result of a damaging earthquake but they can be restored within a matter of hours or days for the vast majority of consumers. Pipelines, especially those constructed using older specifications and welding practices, are vulnerable to leaks, compression, and breakage. While the transmission lines can be quickly repaired the much wider extent and location of local distribution lines in earthquake damaged areas require lengthier repair periods.

Many railroads receive immediate notification upon an earthquake. Upon notification, they can send out instructions to stop trains and dispatch track and signal inspectors. If no damage is discovered services can be restored within hours. Damaged sections can be replaced and debris cleared quickly. Repairs to critical structures, such as bridges, will take longer.

The most probable damage to refineries and ports are power outages. These can be resolved within a matter of hours. More severe and unlikely events include damage to storage tanks, connected pipelines, and other facilities. Repairs may be lengthy and result in a crude or product interruption.

Table 14: Probabilty and Severity of Earthquake Damage to Infrastructure

Infrastructure	Magnitude < 6.7		Magnitude > 6.7	
	Probability of Damage	Severity of Damage	Probability of Damage	Severity of Damage
Loss of Electrical Power	Med	Significant	High	Catastrophic
Offshore Platforms	Low	Insignificant	Med	Significant
Onshore Wells	Low-Med	Interrupting	Med	Significant
Pumping/Compressor Stations	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	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-Med	Interrupting	High	Catastrophic
Filling Stations	Low	Insignificant	Med	Significant
SPR/NEHOR	Low	Insignificant	Low-Med	Interrupting

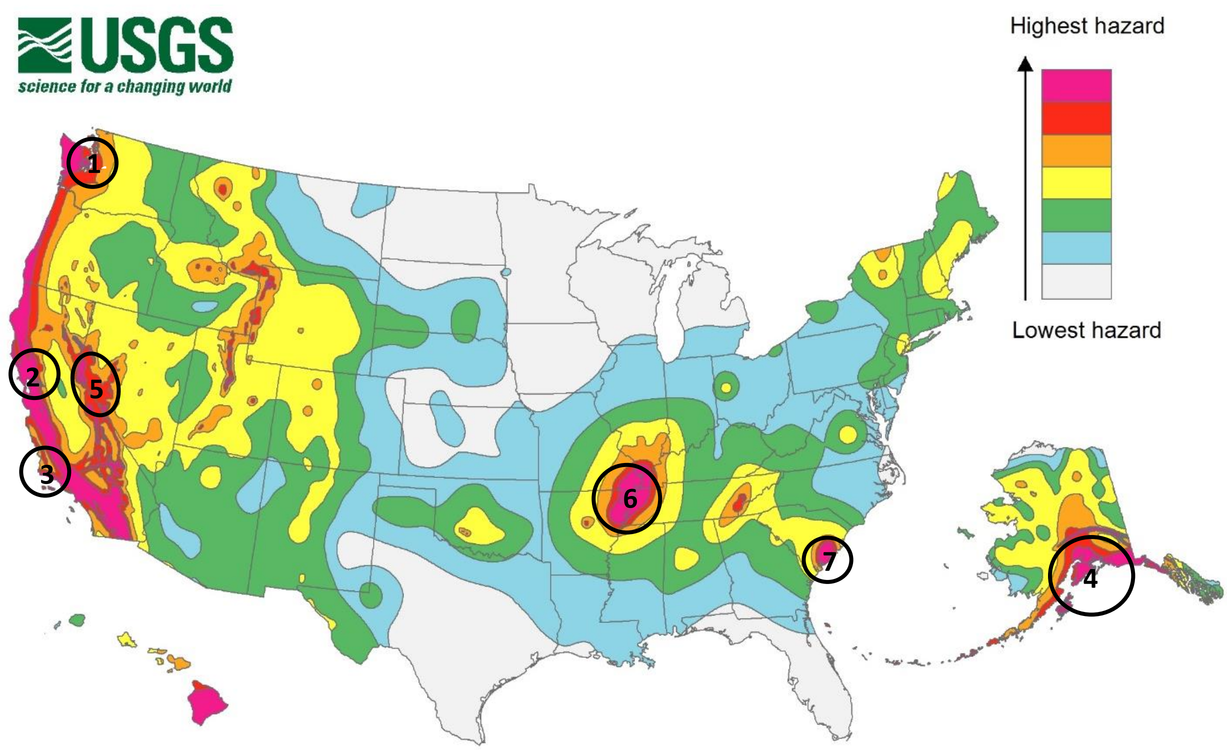
Filling stations could also be directly impacted by quake damage, power loss, and supply disruption. The number and wide distribution of stations reduces the impact to customers of damage to any one particular station.

H. Hazard Areas

The most active earthquake zones in the United States are along the West Coast and Southern coast of Alaska. This region is commonly, because of seismic and volcanic activity, called the “Ring of Fire”. Based on the USGS assessment of regional hazards (Figure 17), seven high risk zones have been identified by

INTEK and indicated upon the map. The following provides a summary of the vulnerable infrastructure in these areas. For more detailed information, please refer to Part I of this analysis. For the purpose of this analysis Hawaii was excluded as there is no TS&D infrastructure. The last refinery in Hawaii was shut down in 2012.

Figure 17: High Earthquake Hazard Zones in the United States



Source: INTEK/USGS 2014

1. Anacortes and Olympia, Washington

- **Refineries:** 4
- **Total refining capacity:** 591 MBbl/d
- **Imported crude:** 221 MBbl/d
- **Petroleum terminals:** 2
- **Crude pipeline:** Kinder Morgan Transmountain
- **Ports:** Anacortes Anchorage
- **Gas pipeline:** Northwest Pipeline

2. Los Angeles, California

- **Refineries:** 9
- **Total refining capacity:** 1,085 MBbl/d
- **Imported crude:** 481 MBbl/d

- **Petroleum terminals:** 27
- **Crude pipelines:** Plains All American, ExxonMobil West
- **Ports:** Port of Los Angeles
- **Product pipelines:** Kinder Morgan SFPP Southern and CALNEV
- **Natural gas plants:** 6
- **Gas processing capacity:** 13 MMcf/d
- **Underground gas storage:** 3 sites
- **Gas pipeline:** SoCal Gas

3. San Francisco, California

- **Refineries:** 5
- **Total refining capacity:** 820 MBbl/d
- **Imported crude:** 385 MBbl/d
- **Petroleum Terminals:** 12
- **Crude pipeline:** Phillips 66
- **Ports:** Port of Oakland
- **Product pipelines:** Kinder Morgan SFPP Northern and Phillips 66 Richmond
- **Underground gas storage:** 1 site
- **Gas pipeline:** California Gas Transmission

4. Southern Coast of Alaska

- **Refineries:** 2
- **Total refining capacity:** 110 MBbl/d
- **Imported crude:** none
- **Petroleum terminals:** 15
- **Crude pipeline:** Trans-Alaska Pipeline
- **Ports:** Port of Anchorage
- **Natural gas pipeline:** Kenai Kachamale gas pipeline
- **Underground gas storage:** 5 sites
- **LNG Terminal:** Kenai LNG Export terminal

5. Sierra Nevada (California and Nevada)

- **Refineries:** none
- **Petroleum terminals:** 5
- **Natural gas pipelines:** Tuscarora pipeline and Paiute pipeline

6. Tennessee Valley Zone

- **Refineries:** 2
- **Total refining capacity:** 207 MBbl/d

- **Imported crude:** none
- **Petroleum terminals:** 28
- **Crude pipelines:** Capline, Midvalley, and Pegasus
- **Ports:** 5 inland ports
- **Product pipelines:** TEPPCO, Explorer, and Centennial pipelines
- **Natural gas pipelines:** Texas Eastern Transmission, ANR Pipeline, NGPL, Tennessee Gas Pipeline
- **Underground gas storage:** 10 sites

7. Charleston, South Carolina

- **Refineries:** none
- **Petroleum terminals:** 4
- **Ports:** Charleston
- **Gas pipeline:** Carolina Gas Transmission

I. Measures Taken by Industry to Address Vulnerability

Given recent history, the location of major faults, and the concentration of infrastructure, the West Coast is the most vulnerable to earthquake damage to oil and gas facilities. As seen in previous quakes, most of this damage can be repaired within a few hours or days. These damages can include power outages, leaks in major transmission pipelines, damage at petroleum terminals, and insignificant damage at ports. Lengthier repair times are required for the natural gas distribution system and facilities at refineries.

It is possible that, along the crude oil supply chain, the refineries are the last component to be repaired. Depending upon the location of the earthquake between five and nine refineries, with combined capacity from 820 MBbl/d to 1,085 MBbl/d, can be shut-in for weeks or months. This loss of production will lead to supply interruptions in the local and connected markets.

Supply loss mitigation, immediately after the quake, can be achieved through the storage and use of products at key terminals away from the immediate hazard zone and connected to major product pipelines supplying the local and connected markets. This storage should contain volumes of gasoline and distillate sufficient to meet 8 to 10 days of reduced demand[32] while additional supplies are brought in from other U.S. regions. Additional analyses are required to identify potential storage sites, determine appropriate supply levels, and estimate the costs and benefits.

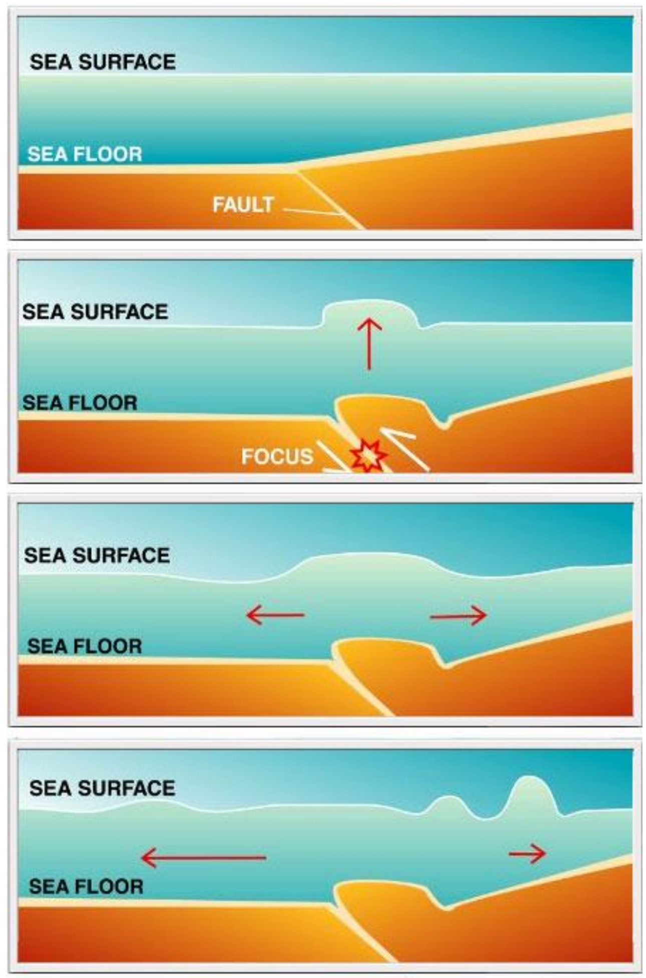
Industry has since improved pipeline standards and welding techniques to account for shock.

V. Tsunamis

A. Introduction

A tsunami, which means "harbor wave" in Japanese, is a series of ocean waves generated by sudden displacement in the sea floor, landslides, or volcanic activity.[33] A large disturbance, near a coastline, can create a tsunami strong enough to devastate coastal communities and propagate other tsunamis thousands of miles away.

Figure 18: Causes of Tsunami



Source: UNESCO 2006

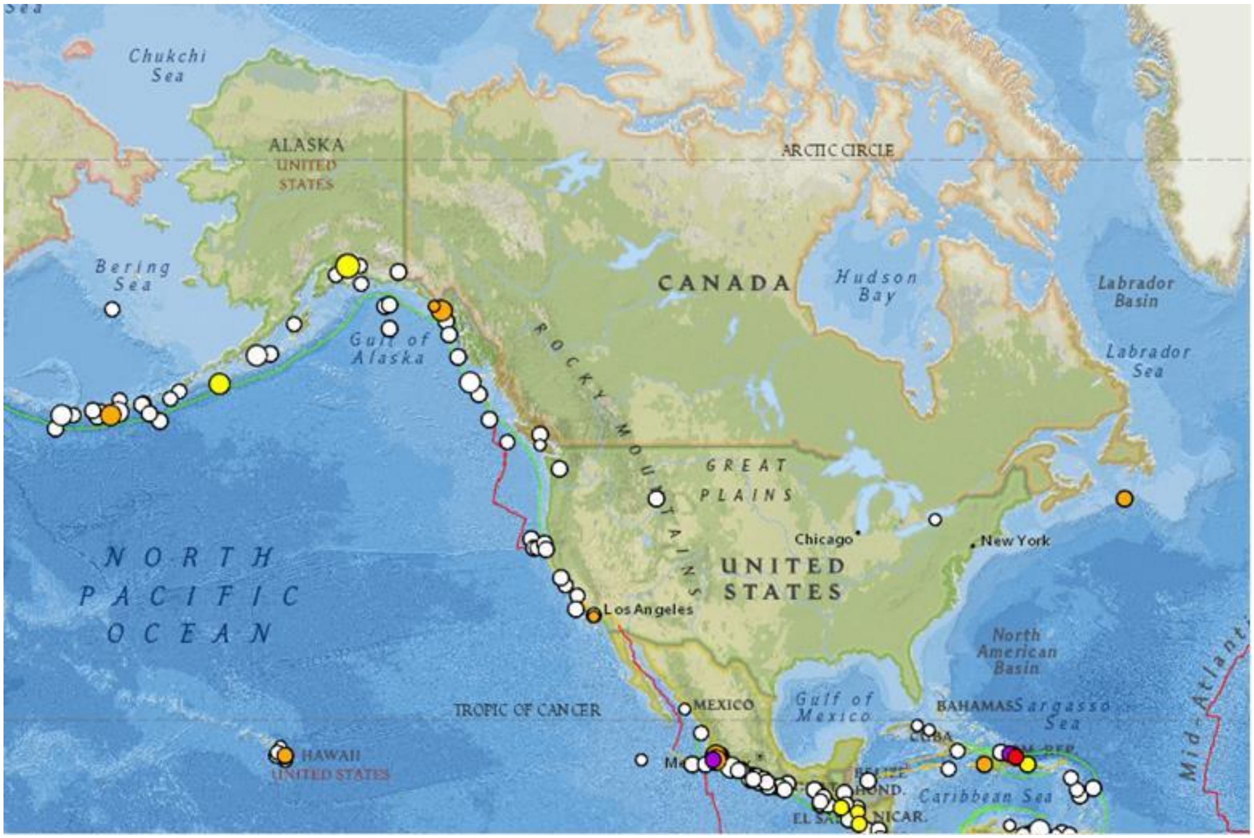
Tsunamis are most commonly created by large (magnitude 7.0 or greater), shallow (less than 30 km depth) earthquakes associated with the movement of oceanic and continental plates (Figure 18).[34] They occur frequently in the Pacific. When the plates fracture, an enormous amount of energy is released into the surrounding seawater. This energy propels the seawater and creates a tsunami.

In the open ocean, a tsunami may be a few centimeters high with energy extending from the surface to the ocean floor. As the tsunami reaches the coastline, wave energy compresses during shoaling and pushes the water into large, destructive waves.

Tsunamis can also be caused by underwater landslides. In 1998, a large underwater landslide, caused by a nearby earthquake, created three waves more than seven meters tall which devastated the northwestern coast of Papua New Guinea. A similar event caused the 1958 Lituya Bay mega-tsunami which struck Alaska.

Several scales have been proposed for measuring the intensity and the magnitude of tsunamis. The Soloviev-Imamura scale, used by the National Oceanic and Atmospheric Administration (NOAA), uses the average height of the waves striking the coast to measure the total tsunami energy released from the source.[35] Although tsunamis have been recorded along the East Coast of North America, they mostly occur along the West Coast (Figure 19).[36] Tsunami reports are indicated in the figure by the circles. The only significant recorded tsunami to hit the East Coast was in Newfoundland, Canada, in 1929. Tsunamis along the West Coast are relatively common because of the seismic and volcanic activity in the "Ring of Fire" along the edge of the North American plate.

Figure 19: Historical Tsunamis in the United States (Since 1900)



Source: NOAA

B. Types of Damages

Tsunami damage can be described under four categories:[37]

1. Impact damage from the wave or carried debris.
2. Flooding.
3. Destruction of infrastructure.
4. Fire from ruptured tanks and gas lines.

A single tsunami may include multiple waves.

C. Threats to Oil and Gas TS&D

These types of damage can impact all components of the ocean coastal oil and gas transmission and distribution infrastructure. Depending upon the intensity of the tsunami and the proximity of the infrastructure to the coastline, damage can be severe. As shown in past tsunamis, damage to tanks and other industrial structures can be caused by the waves, by impact with debris, and by flooding.

Alaska (March 27, 1964) “Good Friday Earthquake and Tsunami”

The March 27, 1964 Alaska earthquake (magnitude 9.2) was, at that time, the largest recorded in North America and the second largest in the world. It struck the West Coast of Alaska, did considerable damage to Anchorage, Valdez, Seward, and other villages, towns, and cities across the state, and created several tsunamis. The tsunami waves hit Valdez, Seward, Whittier, and Kachemak Bay in Alaska, and extended as far south as the coasts of Washington, Oregon, California, and British Columbia. The effects of the tsunamis were detected as far away as Hawaii.[38]

The damage casued in this disaster was from both the earthquake and the tsunamis they spawned. The Valdez waterfront was devastated by the tsunami. Standard Oil of California and Union Oil’s tanks farms, located on the waterfront, exploded and burned for two weeks.[39] Ships were damaged and slammed into the bottom of the harbor, and the entire dock area was swept away.[40] The tsunami also essentially dredged the harbor, increasing the water depth at the dock from 35 feet to 110 feet.

The City of Seward, and the oil infrastructure contained within, suffered considerable damage as well. Fuel storage tanks ruptured, ignited, and spread burning fuel into the water along half a mile of waterfront. Other sections of the waterfront containing storage tanks, warehouses, and docks owned by Standard Oil, slid into the bay. The tsunami inundated the bay and did extensive damage to the homes, boats, docks, and other structures. Other oil and gas infrastructure was also damaged at Nikiski but caused no important delays in production. A few wells in the Swanson River oil field and the Kenai gas field were damaged and some pipeline leaks and breaks occurred.

Lituya Bay, Alaska (July 9, 1958)

The highest recorded tsunami, at Lituya Bay, occurred on July 9, 1958 as a result of a magnitude 8.3 earthquake on the Fairweather fault.[41] The earthquake triggered a massive landside into the bay; the displacement of water created a 524 meter wave. The wave stripped all vegetation from the point opposite the landslide, inundated 5 square miles along the shore, and sent water as far as 3,600 feet inland. Five people were killed. In this remote location, no oil and gas infrastructure was impacted.

Table 15: Summary of Recent West Coast Tsunamis

Date	Location	Source	Maximum Water Height (m)
June 15, 2005	Off the coast of Eureka, CA	Magnitude 7.2 earthquake	0.1
September 1, 1994	Off the coast of Eureka, CA	Magnitude 7 earthquake	0.07
January 17, 1994	West Coast, CA	Northridge earthquake (6.8)	0.1
April 25, 1992	Cape Mendocino, CA	Magnitude 7.2 earthquake	1.8
October 10, 1989	Monterey Bay, CA	Magnitude 6.9 earthquake	1.0

California (1989 to 2005)

NOAA has recorded several small earthquake generated tsunamis in California in the past two decades (Table 15).[42] The waves generated were between 0.1 and 1.8 meters in maximum height. None of them significantly damaged the local infrastructure.

Table 16: Summary of Damage from Recent Tsunamis to Transmission and Distribution Network

Tsunami	Earthquake Magnitude	Oil Infrastructure	Gas Infrastructure	Fuel Disruption
Alaska, 4/27/64	9.2	• Storage tanks damaged • Ports damaged • Insignificant refinery damage	• Pipeline leaks	• Widespread devastation and destruction
Alaska, 7/9/58	8.3	• None	• None	• None
West Coast	6.8 – 7.2	• None	• None	• None

D. Likely Impacts on Infrastructure

Looking at the historical U.S. tsunamis, the impact can range from the very minor – flood damage to houses along the coast – to the devastating – destruction of large sections of housing, infrastructure, and hundreds of deaths (Table 16 above). However, assessing direct damage from tsunamis can be complicated as tsunamis often occur alongside earthquakes. Key determining factors are the height of the waves, the proximity of the infrastructure to the coast, and the elevation of the infrastructure. Impacts of the tsunami on oil and gas infrastructure, from most likely to least likely are provided below:

- Flooding.
- Widespread electrical power outages. These may last for a few hours in the least damaged zones to a few weeks in areas most severely affected.
- Damage to docks, associated fuel storage tanks, and other related infrastructure.
- Damage to pipelines either from flooding of compression/pumping stations or debris impact damage.
- Damage to railroads from washed away track and bridges, spills, damaged signals, and overturned cars.
- Damage to refineries either from flooding or debris impact damage.

The probability of a significant tsunami is low, but the threat they pose to infrastructure, communities, and population is significant (Table 17). Both the probability and severity of damage from tsunamis are higher for infrastructure located on the West Coast.

Filling stations could also be directly impacted by flood damage, power loss, and supply disruption. The number and wide distribution of stations reduces the impact of damage to any one particular station.

Table 17: Probabilty and Severity of Tsunami Damage to Infrastructure

Infrastructure	Probability of Damage	Severity of Damage
Loss of Electrical Power	Med	Significant
Offshore Platforms	Low	Insignificant
Onshore Wells	Med	Significant
Pumping/Compressor Stations	Low	Insignificant
Pipelines	Low	Insignificant
Rail	Low-Med	Interrupting
Ports	High	Catastrophic
Crude Tank Farm	Med	Significant
Refineries	Med	Significant
Natural Gas Plants	Med	Significant
Product Storage	Med	Significant
Propane Tanks	Low	Insignificant
Underground Storage	Low	Insignificant
LNG Terminals	Med-High	Major
Local Natural Gas Distribution	Low	Insignificant
Filling Stations	Low	Insignificant
SPR/NEHOR	Low	Insignificant

E. Hazard Areas

The NOAA and USGS conducted a qualitative assessment of tsunami hazard for coastal and island regions of the United States. Three metrics were used: the run-up (maximum height of the wave), the frequency, and the probability of local earthquakes (Table 18).[43]

Table 18: Qualitative Hazard Assessment for Regions in the U.S.

Region	Hazard based on Run-ups	Hazards based on Frequency	Hazards based on Local Earthquakes
U.S. Atlantic Coast	Very low to low*	Very low	Very low to low
U.S. Gulf Coast	Very low	Very low	Very low
Puerto Rico and the Virgin Islands	High	High	High
U.S. West Coast	High	High	High
Alaska	Very high	Very high	High
Hawaii	Very high	Very high	High
U.S. Pacific Island Territories	Moderate	High	High

* The last occurrence of an Atlantic Coast tsunami was November 18, 1929.

The largest Tsunami hazards are along the West Coast and the southern coast of Alaska. This region is commonly called the "Ring of Fire" because of seismic and volcanic activity. Hawaii experiences tsunamis from local earthquakes and those generated in the Pacific. The following provides a summary of the infrastructure in these three areas. For more detailed information, please refer to Part I of this analysis.

1. Anacortes and Olympia, Washington

- **Refineries:** 4
- **Total refining capacity:** 591 MBbl/d
- **Imported crude:** 221 MBbl/d
- **Petroleum terminals:** 2
- **Crude pipeline:** Kinder Morgan Transmountain
- **Ports:** Anacortes Anchorage
- **Gas pipeline:** Northwest Pipeline

2. Los Angeles, California

- **Refineries:** 9
- **Total refining capacity:** 1,085 MBbl/d
- **Imported crude:** 481 MBbl/d
- **Petroleum terminals:** 27
- **Crude pipelines:** Plains All American, ExxonMobil West
- **Ports:** Port of Los Angeles
- **Product pipelines:** Kinder Morgan SFPP Southern and CALNEV
- **Natural gas plants:** 6
- **Gas processing capacity:** 13 MMcf/d
- **Underground gas storage:** 3 sites
- **Gas pipeline:** SoCal Gas

3. San Francisco, California

- **Refineries:** 5
- **Total refining capacity:** 820 MBbl/d
- **Imported crude:** 385 MBbl/d
- **Petroleum Terminals:** 12
- **Crude pipeline:** Phillips 66
- **Ports:** Port of Oakland
- **Product pipelines:** Kinder Morgan SFPP Northern and Phillips 66 Richmond
- **Underground gas storage:** 1 site
- **Gas pipeline:** California Gas Transmission

4. Southern Coast of Alaska

- **Refineries:** 2
- **Total refining capacity:** 110 MBbl/d
- **Imported crude:** none
- **Petroleum terminals:** 15
- **Crude pipeline:** Trans-Alaska Pipeline
- **Ports:** Port of Anchorage
- **Natural gas pipeline:** Kenai Kachamale gas pipeline
- **Underground gas storage:** 5 sites
- **LNG Terminal:** Kenai LNG Export terminal

5. Hawaii

- **Refineries:** 2
- **Total refining capacity:** 147.5 MBbl/d
- **Imported crude:** 83.4
- **Petroleum terminals:** 25
- **Ports:** Ports on Maui, Kauai, and Honolulu

F. Measures Taken by Industry to Address Vulnerability

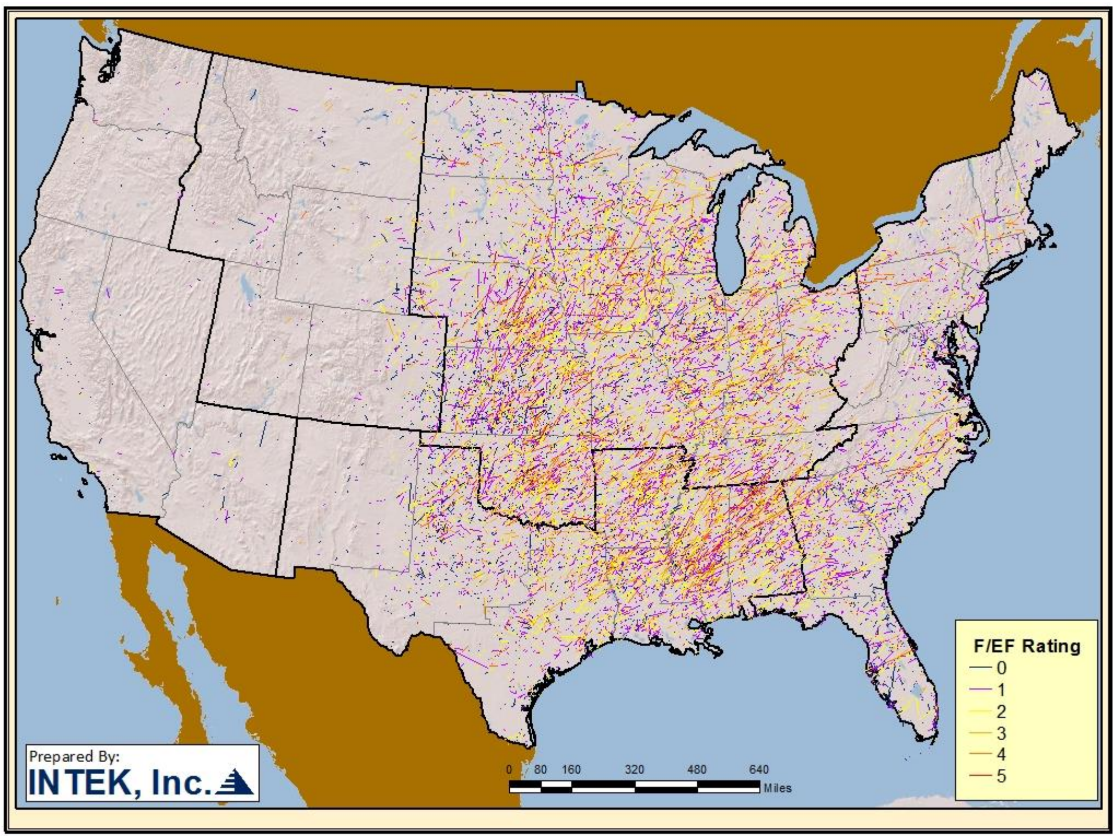
While the damage from a tsunami can be significant, the likelihood of one is very low. Any potential solutions need to take this into account. Another consideration is that the areas at greatest risk to tsunamis, California and the southern coast of Alaska, are also at great risk of earthquakes. Any remedies taken for earthquakes will also help effects from tsunamis.

VI. Tornadoes

A. Introduction

The American Meteorological Society defines a tornado as “a rotating column of air pendant from a cumuliform cloud and, often visible as a funnel cloud.”[44] Tornadoes generally, but not necessarily, originate from thunderstorms when a horizontal air speed differential causes a swirl and is tilted vertically by a storm’s updraft. More intense tornadoes form from more intense thunderstorms called supercells (high-energy thunderstorms with large rotating updrafts). Tornadoes may also be caused by hurricanes which have similar characteristics to thunderstorms, and occasionally by wildfires, where rising heat combines with swirling air.

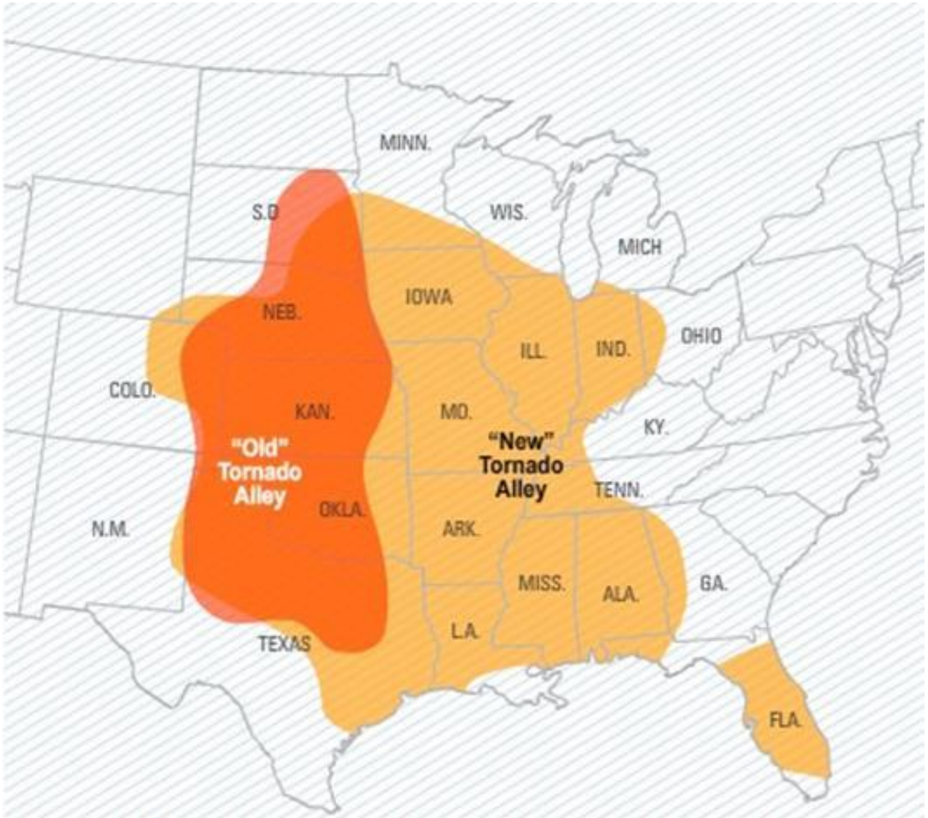
Figure 20: Historical Tornado Paths 1950-2006



Source: NOAA/NWS

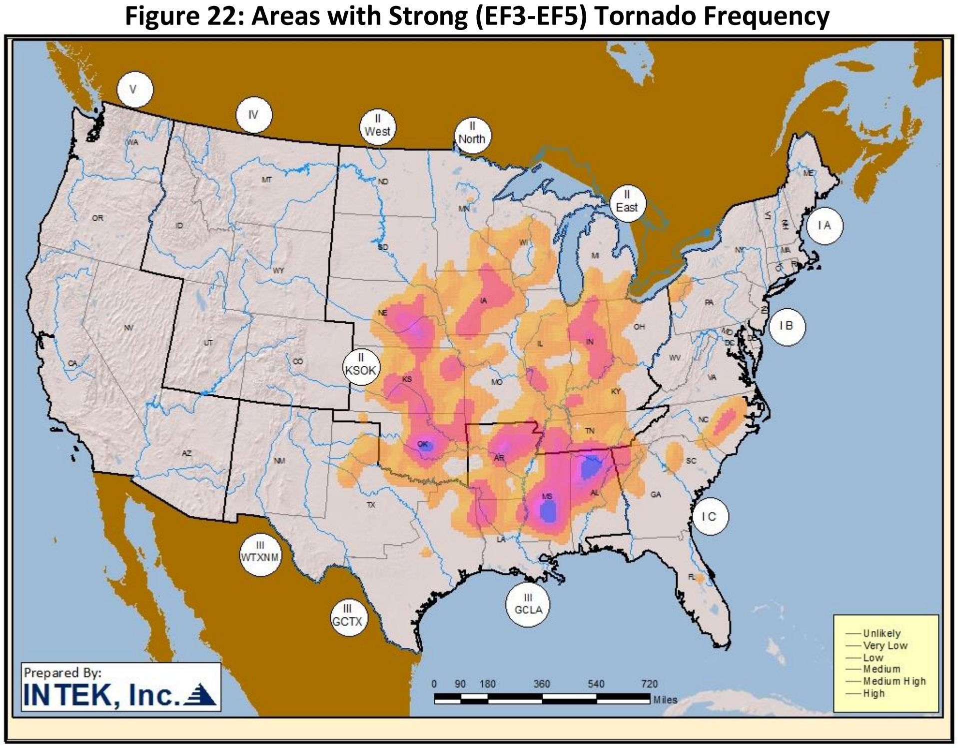
While the phenomenon occurs all over the world, tornadoes are most numerous in the United States, which averages around 1,000 per year. Since the mid-20th century, the central region comprising Nebraska, Kansas, Oklahoma, and Texas, has been most associated with frequent tornadoes, earning it the nickname “Tornado Alley.” However, this designation downplays the tornado risk in other parts of the country. Recent studies and surveys show that while tornadoes are common in the plains, they are also common in the Southeast, in parts of Florida, and in the Ohio Valley, leading some to call for a “New” Tornado Alley which covers a much larger area (Figure 21).

Figure 21: "New" Tornado Alley



Source: CoreLogic; Storm Prediction Center via USA TODAY

Figure 22: Areas with Strong (EF3-EF5) Tornado Frequency



Source: NOAA/NWS

Citing differences in tornado characteristics, other meteorologists prefer to keep the regions separate and call the Southeast region with high tornado frequency “Dixie Alley.” Tornadoes in this area often form from high-precipitation supercells, are fast moving, and often visibly-obscured by rain. Tornadoes in the central region are seasonal and more diversified in strength as the region sees a much larger amount of weaker tornadoes than the Southeast does (Figure 22).[45]

Tornadoes may occur singularly or in an “outbreak”. There must be at least six separate tornadoes to count as an outbreak, but the number may be much higher. A record-setting tornado outbreak in April 2011 produced 358 tornadoes over six states.

B. Measuring a Tornado

Table 19: Enhanced Fujita Classification

EF Rating	Wind Speeds	Expected Damage	
EF-0	65-85 mph	'Minor' damage: shingles blown off or parts of a roof peeled off, damage to gutters/siding, branches broken off trees, shallow rooted trees toppled.	
EF-1	86-110 mph	'Moderate' damage: more significant roof damage, windows broken, exterior doors damaged or lost, mobile homes overturned or badly damaged.	
EF-2	111-135 mph	'Considerable' damage: roofs torn off well constructed homes, homes shifted off their foundation, mobile homes completely destroyed, large trees snapped or uprooted, cars can be tossed.	
EF-3	136-165 mph	'Severe' damage: entire stories of well constructed homes destroyed, significant damage done to large buildings, homes with weak foundations can be blown away, trees begin to lose their bark.	
EF-4	166-200 mph	'Extreme' damage: Well constructed homes are leveled, cars are thrown significant distances, top story exterior walls of masonry buildings would likely collapse.	
EF-5	> 200 mph	'Massive/incredible' damage: Well constructed homes are swept away, steel-reinforced concrete structures are critically damaged, high-rise buildings sustain severe structural damage, trees are usually completely debarked, stripped of branches and snapped.	

Source: NWS, NOAA

Tornadoes vary considerably in intensity, duration, width, path, and speed, often making them hard to predict. Meteorologists rank their strength using the Enhanced Fujita Scale of EF0 through EF5 with increasing numbers denoting increasing intensity. This scale replaced the Fujita-Pearson scale (F0-F5) in

2007, after the earlier designations were found to be inaccurate. Table 19 shows the modern criteria used to rank a tornado by wind speed.

Tornadoes are classified retrospectively by surveyors assessing the amount of damage caused and correlating the damage to wind speed. Depending on the intensity of the tornado, damage caused may range from light to catastrophic. An EF0 tornado might tear some shingles off the roof of a house while an EF2 tornado could remove the roof and an EF4 tornado can completely level a house. EF5 tornadoes are capable of removing a house from its foundation, disintegrating it, and scattering the debris over a considerable distance. These high-intensity tornadoes are also capable of “throwing” heavy objects like trucks up to half a mile.

C. Threats to Oil and Gas TS&D Infrastructure

Given the extreme damage tornadoes can cause to firmly rooted infrastructure, they pose a significant threat to most oil and gas infrastructure in their paths. Tornadoes can destroy nearly anything above ground including oil and gas wells, pumping stations, terminals, tank farms, transportation infrastructure, refineries, processing plants, and pipeline manifolds. However, while tornadoes are capable of causing serious damage, their threat is mitigated by their relatively short duration and localization compared to other disasters. Hurricanes might affect an area hundreds of miles in diameter for days, yet tornadoes generally last for minutes to hours and only affect an area of a couple square miles. Even when tornadoes have a sizeable width and travel long distances, the area damaged is miniscule compared to other natural disasters.

When tornadoes do hit oil infrastructure directly, it is often not enough to affect national supplies or major disruptions. Tornadoes regularly destroy wells and rigs in the Great Plains region, causing extensive site damage and spills, yet the effects are isolated to those sites. Tornadoes pose a more dangerous threat to refineries and tank farms which contain more significant production and commodity capacity. Extensive damage to one refinery could reduce overall operable capacity for months. A powerful tornado hitting the tank farms and pipelines at Cushing could have long-term consequences and create significant supply problems.

Cushing is not unaware of its vulnerability. In May of 2013, a coordinated response drill was held with representatives from different companies with stakes in the storage and transport hub. The drill posed a scenario where an EF5 took a path directly through the Cushing tank farms. While the drill focused heavily on the response, highlighting the chaos and confusion an event like that could bring, it also implicitly conceded that serious structural damage would be inevitable. Coordinators concluded that a powerful tornado hitting the hub would seriously interrupt operations for at least three days.

Tornadoes also pose a serious threat to the Bakken play and other emerging areas. As North Dakota oil production has moved more quickly than housing construction, workers commonly reside in trailers. In late May 2014, a tornado destroyed an oil workers trailer camp, injuring nine. Trailers are especially susceptible because of their relatively lighter weight and lack of firm anchoring which makes them vulnerable to the less intense and more frequent EF0-EF1 tornadoes. At least one company has made investments to anchor their rig change houses to withstand an EF5 tornado.

D. Historical Events

As mentioned above, tornadoes are unlikely to seriously impact the overall petroleum supply due to their localization. A severe EF5 tornado would have to hit Cushing or a "refinery row" to significantly impact production and supplies throughout the country. During a tornado outbreak these threats are multiplied, yet as each individual probability is rather low, the cumulative probability also remains rather low.

Historical events may help shed light on some of the possible impacts tornadoes may have on oil and natural gas TS&D infrastructure, yet the unique nature of each event ultimately dictates the scope of impact. Future risk and vulnerability assessment must consider past events in their own context and not mark them as typical occurrences.

One notable and record-breaking outbreak occurred in April 2011 and will be discussed further. However, due to the unique nature of each outbreak, some recent selective examples can highlight what damage future tornadoes may cause.

- A 1998 tornado spawned by Hurricane Georges destroyed a refinery's cooling tower along the Mississippi Gulf Coast.
- A rare 2002 tornado in Corpus Christi, TX struck refinery row causing "significant damage" to the Citgo refinery. It was an F2.
- A 2008 tornado caused a major explosion at a natural gas pumping plant in Tennessee.
- A May 2011 tornado damaged a 200 MMcf/d gas processing plant in Oklahoma, causing it to go idle for 3 months.
- A 2013 EF5 tornado destroyed five oil wells and damaged an additional three in Oklahoma.
- A 2014 EF1 tornado destroyed a cooling tower and knocked out a crude unit at a Marathon refinery in Garyville, LA.

April 25-28 2011 Tornado Outbreak

In late April 2011 a line of severe thunderstorms moving through the Southeast caused a four-day tornado outbreak consisting of 358 tornadoes, 207 of which occurred within a 24-hr period, setting a record for the most tornadoes spawned in a single day. The total outbreak caused 316 deaths, 2,400 injuries, and over $4.2 billion in damages. The 358 tornadoes were made up of 129 EF0s, 143 EF1s, 49 EF2s, 22 EF3s, 11 EF4s, and 4 EF5s, the majority of which touched down in Alabama.

The most direct impact the tornadoes had on the fuel supply infrastructure was in electricity outages. The tornadoes and accompanying thunderstorm destroyed over 300 power transmission towers, knocking out power to at least 270,000 customers and one refinery in Alabama. The tornadoes also created significant fuel shortages by disrupting power and by destroying several gas stations in northern Alabama.[46] Power was not restored to many places until a week later.

However, despite the record-setting number of tornadoes and intensive damage to communities and businesses, oil and gas infrastructure was relatively unaffected. Some pipeline pumping stations shut down temporarily and one tornado came close to a refinery but no capacity was significantly impacted nor supply lost. One of the worst tornado outbreaks in recent history follows the typical infrastructure-roulette characteristic in tornadoes.

The impact of these tornadoes, on oil and gas infrastructure, is summarized in Table 20 below.

Table 20: Summary of Damage from Recent Tornadoes to Transmission and Distribution Network

Tornado	#	Intensity	Power Loss	Oil Infrastructure	Gas Infrastructure	Fuel Disruption
2014 Garyville, LA	1	EF1	• Hundreds without power. • Restored within several hours.	• Refinery cooling tower damaged and one crude unit lost. • Running at reduced capacity for several months.	• None reported	• None reported
2013 El Reno, Kansas Outbreak	1	EF3-EF5	• 100,000 with-out power due to tornado and accompanyin g storm.	• Five oil wells destroyed, another three damaged	• None reported	• None reported
May 2011 Oklahoma Outbreak	242	EF0-EF5	• Unspecified number affected. • Restored in 3 days.	• None	• 200 MMcf/d Natural gas plant damaged and idled for 3 months	• None reported
April 25-28, 2011 Outbreak	358	EF0-EF5	• 270,000 lost power. • All restored within a week.	• One refinery experienced a brief power loss.	• None reported	• Local supply disruption immediatel y after event

E. Likely Impacts on Infrastructure

Tornadoes are capable of having a range of impacts on oil and gas infrastructure, yet the probability of any single event happening is quite low. At the same time, the area where tornadoes may spawn is expansive and contains a large amount of oil and gas infrastructure. Nearly 70% of refining capacity and

50% of natural gas processing are located in areas prone to tornado outbreaks. Additionally, the crucial chokepoint and storage hub at Cushing, OK sits in the heart of “Tornado Alley.” Therefore, while each piece of infrastructure on its own faces a minute risk of damage, it is virtually guaranteed that tornadoes will impact infrastructure somewhere on almost a yearly basis.

Any disruption a tornado or tornado outbreak will have on infrastructure largely depends on the intensity of the tornado and the type of infrastructure. A relatively weak tornado can do serious damage against vulnerable infrastructure while an EF4 or EF5 tornado can damage some of the most structurally hardened infrastructure. Effects of a tornado outbreak on the oil and gas infrastructure, listed from most likely to least, are provided below. The more numerous a type of infrastructure, the more likely any single piece is likely to be impacted by a tornado.

- Widespread electrical power outages. These may last for a few hours in the case of a downed line, or up to a week if power transmission towers are destroyed. Power outages also coincide with tornadoes because of supercell thunderstorms.
- Damage to rail lines, truck racks, and fueling stations can present insignificant distribution problems and cause brief local supply shortages.
- Damage to pumping and compressor stations can cause temporary pipeline disruptions.
- Damages to refineries, natural gas processing plants, and biofuels plants could cause insignificant product disruptions or major product loss depending on the size of the facility and the damage done.
- Damage to above-ground sections of crude, product, and natural gas pipelines could result in supply interruptions for refineries, gas processing plants, product storage and distribution terminals, and city gates.
- Damage to multiple refineries in the same area or on a refinery row could shut down significant capacity for weeks to months.
- Destruction of the tanks and pipelines at Cushing could cause significant disruptions and chaos for refineries, storage companies, and pipeline operators lasting weeks.

Table 21 summarizes the probability and severity of the damage for different types of infrastructure given an EF1 strength tornado or an EF4-5 strength tornado.

Probability for these events is also augmented by the intensity of the tornadoes. EF0 and EF1 tornadoes are far more numerous than stronger ones, especially in the traditional “Tornado Alley” area. Therefore, any infrastructure is far more likely to be hit by a “weak” tornado than a strong one.

The increased probability of damage to wells, platforms, and pumps/compressors stations from EF1 tornadoes reflects the significantly higher frequency of these cyclones when compared to EF5 tornadoes. The biggest threat to oil and gas infrastructure from a tornado is loss of electrical power which could take days or weeks to get repaired.

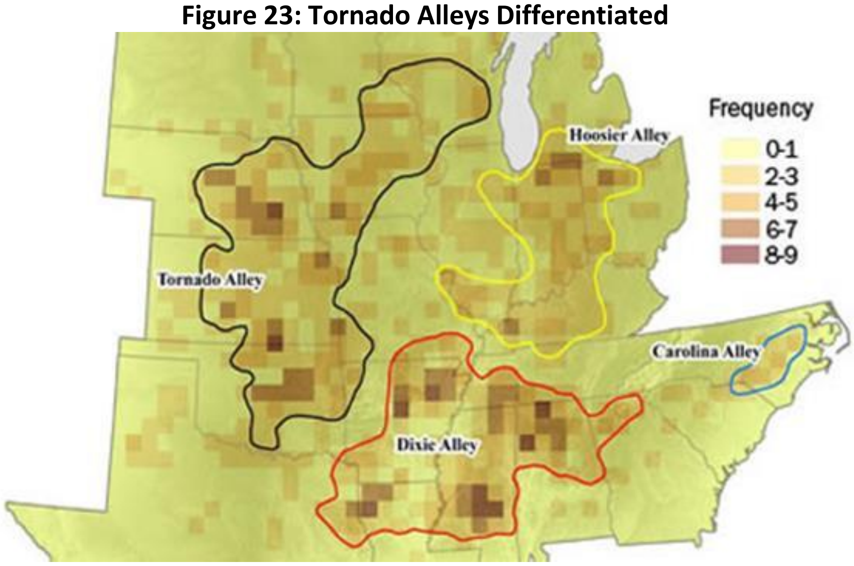
Table 21: Probability and Severity of Tornado Damage to Infrastructure

Infrastructure	EF1 Tornado		EF2-3 Tornado		EF4-5 Tornado	
	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
Offshore Platforms	Low	Insignificant	Low	Insignificant	Low	Insignificant
Onshore Wells	Low	Insignificant	Low-Med	Interrupting	Med-High	Major
Pumping/Compressor Stations	Low	Insignificant	Low-Med	Interrupting	Med	Significant
Pipelines	Low	Insignificant	Low-Med	Interrupting	Med	Significant
Rail	Low	Insignificant	Low-Med	Interrupting	Low-Med	Interrupting
Ports	Low	Insignificant	Low	Insignificant	Low	Insignificant
Crude Tank Farm	Low	Insignificant	Low-Med	Interrupting	Med	Significant
Refineries	Low	Insignificant	Med	Significant	Med	Significant
Natural Gas Plants	Low	Insignificant	Med	Significant	Med	Significant
Product Storage	Low	Insignificant	Med	Significant	Med	Significant
Propane Tanks	Low	Insignificant	Low-Med	Interrupting	Low-Med	Interrupting
Underground Storage	Low	Insignificant	Low	Insignificant	Med	Significant
LNG Terminals	Low	Insignificant	Low	Insignificant	Low	Insignificant
Local Natural Gas Distribution	Low	Insignificant	Low-Med	Interrupting	Med	Significant
Filling Stations	Low	Insignificant	Low-Med	Interrupting	Med	Significant
SPR/NEHOR	Low	Insignificant	Low	Insignificant	Med	Significant

F. Hazard Areas

Tornadoes can potentially affect nearly the entire eastern half of the Unites States. Even areas that are not known for tornadoes may experience a relatively strong tornado as frequently as once every decade (Figure 23). However, given the purpose of this study, only three high incidence areas will be discussed – Tornado Alley, Dixie Alley, and the slightly-less-intense but still-relevant Hoosier Alley.

Figure 23: Tornado Alleys Differentiated



Source: Sciencenews.org via Washington Post

While these are high risk areas, the infrastructure within each does not represent the total possible risk from an event as it might with a hurricane or an earthquake. Rather it is meant to show how much, and what key components of infrastructure could be singularly affected by any one tornado. Furthermore, as these areas are often poorly defined the infrastructure characterizations of each region should be seen as approximations.

1. Tornado Alley (KS, OK, NE, IA)

- **Refineries:** 9
- **Total refining capacity:** 860 MBbl/d
- **Petroleum terminals:** ~100
- **Major crude pipelines:** Keystone, Basin, Occidental, Spearhead, Plains Oklahoma, Whitecliff, Seaway
- **Major product pipelines:** Magellan, NuStar East, Explorer
- **Major gas pipeline:** NGPL, Colorado Interstate Gas, ANR, Northern Natural Gas, Panhandle Eastern Pipeline
- **Major Tank Farm:** Cushing

2. Dixie Alley (LA, AR, MS, AL)

- **Refineries:** 26
- **Total refining capacity:** 3,848 MBbl/d
- **Petroleum terminals:** ~125
- **Major crude pipelines:** Ho-Ho, Capline
- **Major product pipelines:** Centennial, Colonial, Plantation, TEPPCO
- **Major gas pipeline:** Texas Eastern Transmission, ANR, Transco, Tennessee Gas Pipeline, NGPL, Columbia Gulf Transmission, Florida Gas Transmission, Southern Natural Gas
- **Major Tank Farms:** LOOP and SPR sites

3. Hoosier Alley (IN, IL, OH, KY)

- **Refineries:** 11
- **Total refining capacity:** 2,073 MBbl/d
- **Petroleum terminals:** ~165
- **Major crude pipelines:** Spearhead, Ozark, Mid-Valley, Flanagan, Capline, Pegasus, Chicap, Mustang, Lakehead
- **Major product pipelines:** Centennial, Marathon, Explorer, TEPPCO
- **Major gas pipeline:** NGPL, ANR, Texas Eastern Transmission, Panhandle Eastern Pipeline

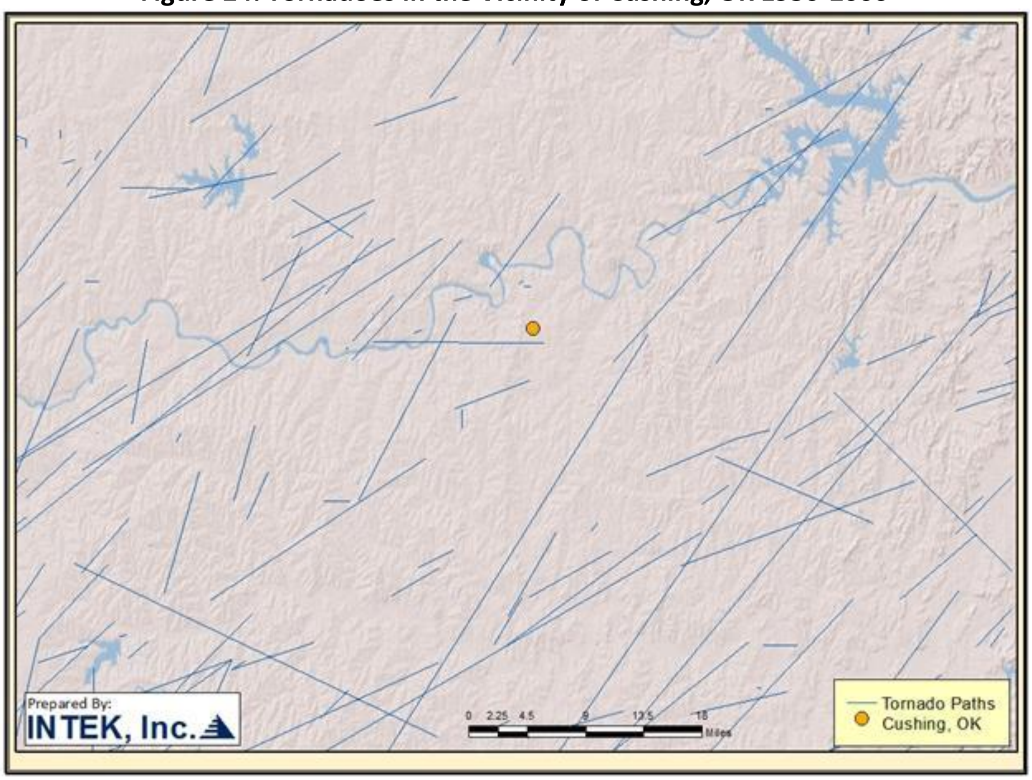
G. Measures Taken by Industry to Address Vulnerability

As tornadoes generally only affect one piece of infrastructure at a time, there is little value in implementing a sweeping strategy to mitigate tornado damages and shift resources. Refineries, gas processing plants, and other large infrastructure in tornado-prone areas should have protocols and emergency plans, be aware of the risks, and take all necessary precautions if under threat. The NWS issues tornado watches for areas that contain conditions ripe for tornado formation and issues tornado warnings for areas if those conditions materialize. Owners and managers should monitor threats and take necessary steps to minimize damage and loss should the worst happen. Infrastructure could also be hardened against weaker EF0 and EF1 tornadoes by reinforcing structures and anchoring any loose equipment. However, as these changes may be costly, it's up to the infrastructure owner to determine whether the risk and probability of damages outweighs the cost to implement the changes. As tornadoes occur in tandem with other severe weather such as derechos and hurricanes, any infrastructure changes may also respond to tornadoes as a secondary threat.

Tornadoes vary considerably in intensity and size during their lifetime – one may shift from EF3 one block to EF5 the next, lightly damaging a house on one street while leveling an entire row on the next. Therefore risk mitigation for all infrastructure should also focus on cooperation and building relations with neighboring infrastructure. Refineries clustered in tornado-prone regions could draw contracts to pool or lend resources as a form of tornado insurance.

Cushing, OK Tank Farm

Figure 24: Tornadoes in the Vicinity of Cushing, OK 1950-2006



Source: NOAA/NWS

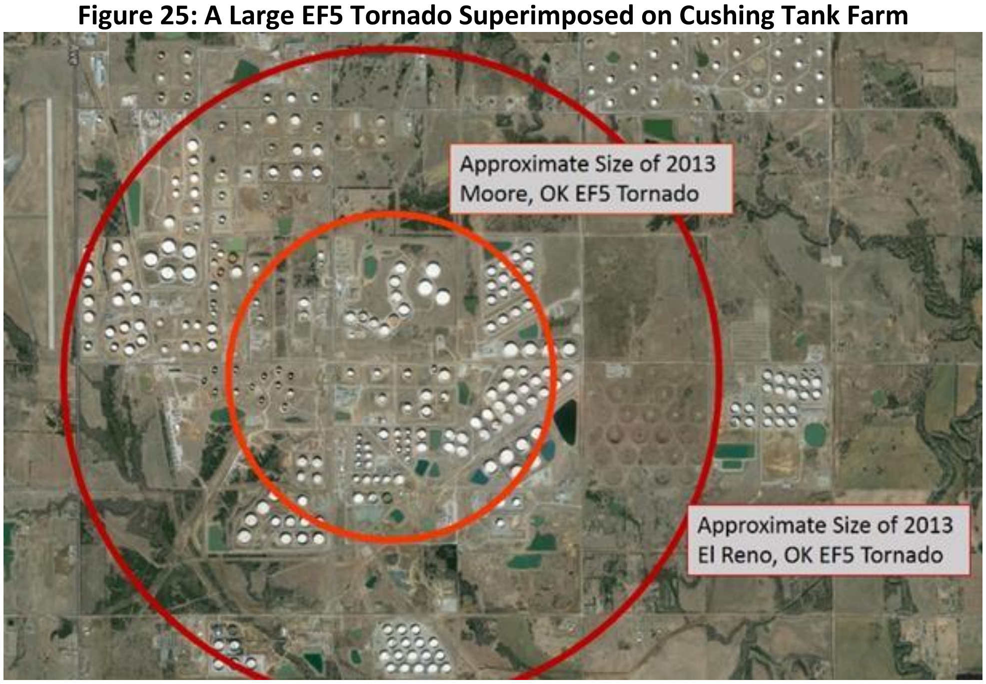
The real threat tornadoes pose to oil infrastructure is to the tank farms and pipeline junctions at Cushing, OK. As a major market hub, pipeline junction, storage center, and chokepoint, severe damage to Cushing could significantly disrupt crude supply to refineries and cause rippling effects throughout the supply chain. The hub is directly connected to eleven refineries having operable capacity of 1,150

MBbl/d. It connects over 20 pipeline systems and has working storage capacity of 66 MMBbl. Figure 24 shows the path of EF3 or stronger tornadoes that have passed within 25 miles of Cushing.

Cushing is also in a highly vulnerable area and has seen a number of tornadoes brush by the area in recent years, including a deadly EF5 that stuck the nearby town of Moore, OK in 2013. The Moore tornado had a width of 1.3 miles. Another large tornado also struck close to Cushing at El Reno, OK in May 2013 and currently holds the record for widest tornado at 2.6 miles. Figure 25 shows the size of both tornadoes relative to the tank farms at Cushing.

In 2013, the Safety Alliance of Cushing (SAC) staged a tornado drill for the first time. SAC is composed of a group of midstream companies with stakes in Cushing like pipeline operators, refiners, and oil traders. Press reports of the event cited attendees who called it “chaos,” yet SAC noted that there were several lessons learned. Given Cushing’s vulnerability and the severe impact it could have on supplies and the industry, the SAC or other groups could stage annual drills to enhance preparedness and work out any communication and collaboration issues. A quick coordinated response can save days, if not weeks, of supply and minimize impacts that would be felt farther along the supply chain.

Figure 25: A Large EF5 Tornado Superimposed on Cushing Tank Farm



Source: INTEK/Google Earth 2014

Tornadoes may also present a unique environmental challenge for Cushing in the event of a massive tornado strike. While berms are in place to catch any oil spilled, tornadoes have been known to suck up liquids into the atmosphere and deposit them further along their path rendering berms obsolete. More research should be done to determine the environmental impact of such phenomenon and what solutions might be appropriate.

VII. Heat Waves and Drought

A. Introduction

While heat waves are not defined in any rigidly scientific manner, they are universally understood as times when temperatures in a given area are higher than they usually are for an extended period, generally several days to a couple weeks. Heat waves normally occur when high pressure aloft traps warm air beneath it and causes it to sink to the ground, essentially creating a dome within the atmosphere. In the United States the phenomenon occurs during the summer months as the northern jet stream "follows the sun" and creates high pressure regions to the south, covering the East Coast and Midwest.[47]

Heat waves and droughts are often inextricably linked when hot and dry weather overtakes a region for a prolonged time period. However, droughts can also occur separately. Droughts are primarily caused by lack of rain, yet in places like California, droughts also may arise from a lack of snowmelt if snow accumulation during the winter months was lighter than normal. Drought conditions may also have human origins if water use is ill-managed, agriculture is overextended and leads to erosion, or water is diverted from one area to another.

Drought risk is routinely reported by the USDA and NOAA which produces the "U.S. Drought Monitor," a weekly publication examining current risks across the country. The NOAA also publishes a "Seasonal Drought Outlook" that predicts whether droughts in areas will get worse, stay about the same, or get better throughout the season. Droughts in the United States have occurred nearly everywhere, yet in recent years California and Texas have been hardest hit.

While linked, for the purposes of this section droughts and heat waves will be discussed separately in terms of their impacts as they affect different parts of the infrastructure. Both effects will then be combined to present an overall risk assessment in the case of a severe heat wave and accompanying drought.

B. Measuring Droughts

Measuring and categorizing drought raises challenges because of its varying implications, regions, and timeframes. For instance, farmers might have a different need to classify drought than a city official working in water management, or a lock operator three hundred miles from an area with low precipitation. Similarly, there might be a long period without precipitation lasting several months punctuated by a brief period of heavy rainfall or simply just below average rainfall for a region used to an abundance of rain.

Because of this difficulty there are several ways to measure a drought. First, the Standardized Precipitation Index measures how dry or wet a region is based on past precipitation. It sets 0 as the median precipitation and measures deviations with negative values denoting dryness and positive ones denoting wetness. Second, the Crop Moisture Index measures a much shorter weekly timescale to assess how much water is available to crops. A third scale, the Palmer Drought Index, gives a cumulative measurement that takes levels in reservoirs and other supply systems into account. It only measures dryness and uses negative numbers to denote the level of drought. The USDA and NOAA use the Palmer Drought Index and Standardized Precipitation Index, among others, to create categories D0-D4 which ascend with intensifying droughts (Table 22). At lower levels, a drought has minimal impacts, consisting mostly of limited water shortages and some possible crop loss, but at higher levels government intervention is necessary to maintain water levels and crop loss begins to affect national and global markets. It is also important to note that unlike other disasters where an event is singularly rated on a scale of intensity, a drought will progress up the scale as it gets worse.

Table 22: USDA/NOAA Drought Scales

Category	Description	Possible Impacts	Palmer Drought Index	Standardized Precipitation Index (SPI)
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered	-1.0 to -1.9	-0.5 to -0.7
D1	Moderate Drought	Some damage to crops, pastures; streams, reservoirs, or wells low, some water shortages developing or imminent; voluntary water-use restrictions requested	-2.0 to -2.9	-0.8 to -1.2
D2	Severe Drought	Crop or pasture losses likely; water shortages common; water restrictions imposed	-3.0 to -3.9	-1.3 to -1.5
D3	Extreme Drought	Major crop/pasture losses; widespread water shortages or restrictions	-4.0 to -4.9	-1.6 to -1.9
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; shortages of water in reservoirs, streams, and wells creating water emergencies	-5.0 or less	-2.0 or less

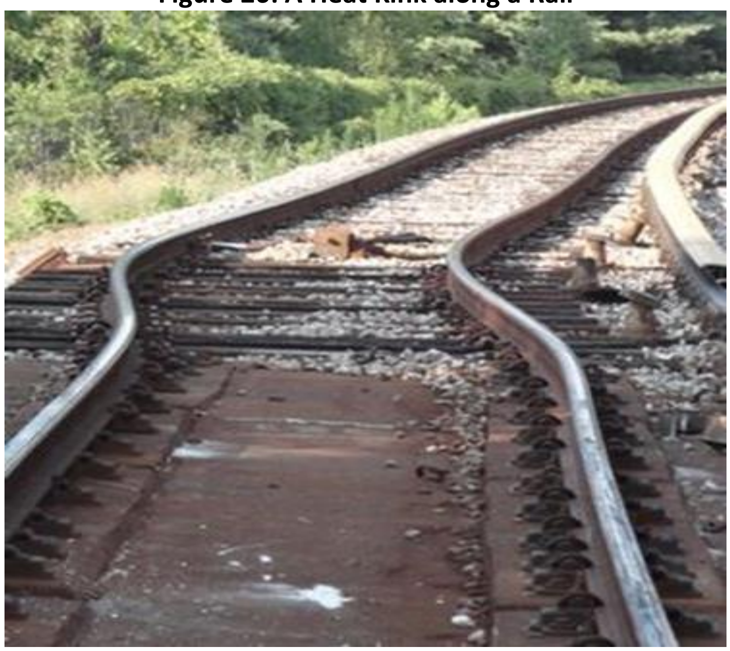
Source: United States Drought Monitor, USDA, NOAA

C. Threats to Oil and Gas TS&D Infrastructure

Heat waves generally affect fuel supply infrastructure through power loss. During extremely high temperatures people use more electricity to stay cool which puts stress on the power grid, particularly on transmission lines and generating facilities. This increased demand can lead to brownouts which occur as a power company lower voltage to avoid blackouts by overloading their system. In addition, hotter temperatures also decrease the capacity of power lines and cause them to sag, increasing their vulnerability.[48]

Hot temperatures can also interfere with transportation. Extreme heat causes materials to expand, leading highways and roads to buckle and rails to kink (Figure 26). A 1,800 foot section of rail can expand an extra foot with an 80 degree temperature change. 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. Rail becomes more vulnerable to kinks as they approach cities which act as heat islands due to their lack of vegetation.

Figure 26: A Heat Kink along a Rail



Source: Washington Metro Area Transit Authority

Historically, drought has had little impact on fuel supply infrastructure, yet a changing fuels landscape has increased reliance on water, thereby creating several key vulnerabilities previously non-existent. First, with the creation of the RFS in 2005, ethanol has played a large role in the gasoline supply chain. As ethanol is refined from crops, droughts can take a severe toll on the ethanol feedstock and reduce production. Ethanol plants also require large volumes or process water. Second, hydraulic fracturing, while responsible for the recent oil and gas boom, also uses a large amount of water, about 5.6 million gallons per well in the Marcellus shale play.[49] Many wells are in drought-stricken areas and fracking may exacerbate the drought and, in turn, cut into production as water becomes less available and prohibitively expensive. Third, the re-emergence of barge transport for crude means greater reliance on the waterway network for transportation.

During droughts, river water levels drop and may not be able to sustain traffic. Sections of major river routes may have to be closed, or barges may be forced to carry less oil to lessen their draft. If a river's water level drops an inch, it could reduce the amount a barge may tow by as much as 255 tons.

While these newer developments have presented new problems from drought, lack of water can have other effects on infrastructure. Refineries and gas processing plants also require large amounts of water to produce their fuels while hydroelectric plants rely on sustained water levels to generate electricity. Nuclear power plants also rely on normal water levels to intake water to cool their cores. Table 23 shows how oil and gas infrastructure relies on water availability.

Table 23: Oil and Gas Industry Water Needs

Activity	Water Needs
Oil and Gas E&P	Needed for drilling, completion, fracturing, and enhanced oil and gas recovery
Oil Refining and Gas Processing	Required for refining processes
Oil and Gas Storage	Required for slurry mining of caverns
Oil and Gas Pipeline Transport	Needed for hydrostatic testing of pipelines
Oil Barge Transport	Adequate river flows are required
Biofuel Production	Needed for feedstock production and processing
Electricity Production	Needed for hydropower generation and for steam turbine cooling

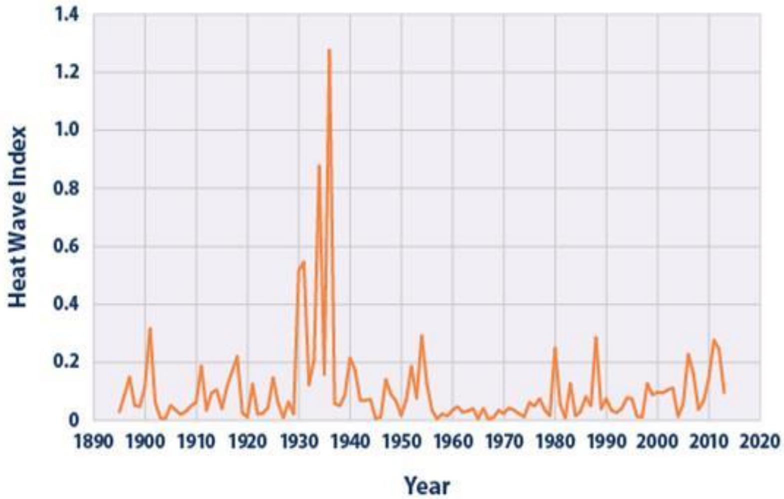
Source: United States Dept. of Energy

D. Historical Events

Thus far, few heat waves or droughts have had widespread detrimental effects across the oil and gas supply chain, yet many have had disruptive effects on individual parts of the infrastructure. The most major and widespread drought and heat wave in the United States was in 1936, too far in the past for relevant analysis on oil and gas infrastructure (Figure 27). The past decade has had the second most extreme heat waves on record. The 2012 drought and heat wave was the largest heat wave geographically and had some damaging consequences for oil and gas production. Recent droughts and heat waves were not as statistically severe as the 1936 drought. A similar event occurring in the coming years would likely affect large parts of the infrastructure. Past droughts and heat waves have caused the following damage:

- A 1980 heat wave caused hundreds of miles of highways to buckle and closed bridges over the Mississippi River.
- The 2003 blackout which affected 55 million people was indirectly caused by high temperatures.
- In 2006, power transformers failed due to a heat wave, causing blackouts in Missouri and New York.
- In 2007, power plants in the southeast had to reduce production due to low water levels.
- In 2011, a heat wave caused brownouts across New York City.

Figure 27: Historical Heat Waves in the United States

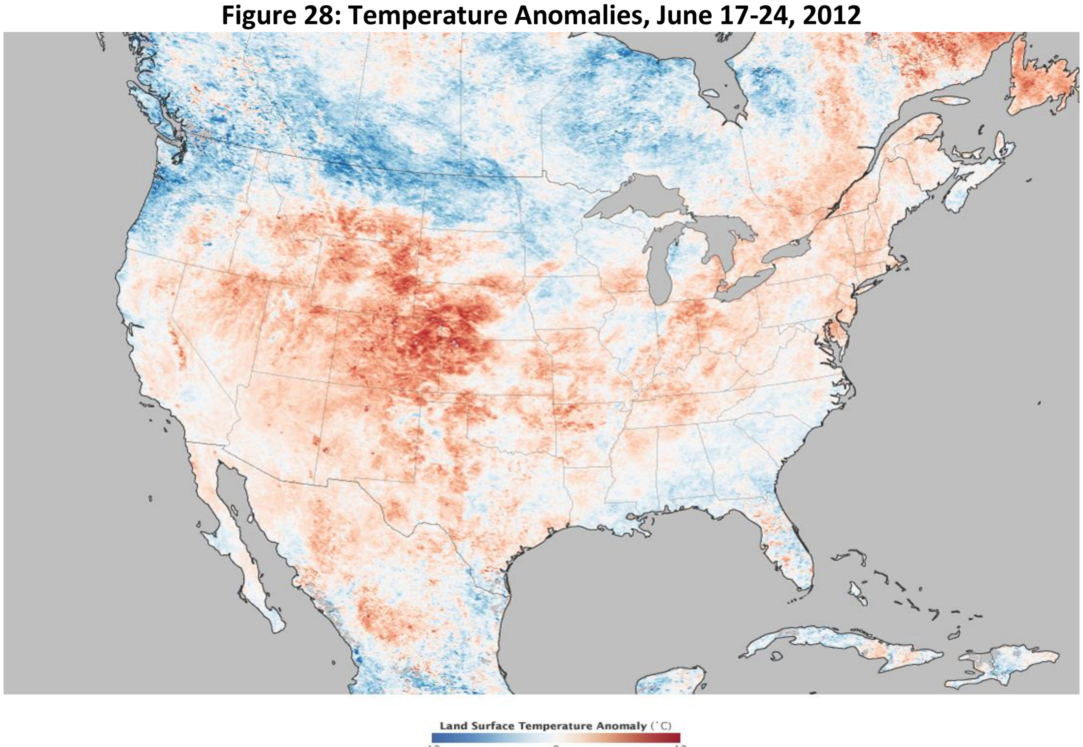


Source: EPA

Summer 2012 Heat Wave and Drought

2012 was the warmest year on record in the United States and July was the hottest recorded month (Figure 28). The previous record July temperature occurred during the 1936 heat wave.[50] The summer heat resulted in a greater number of wildfires and an exceptionally strong derecho that ravaged the Ohio Valley and the Mid-Atlantic.

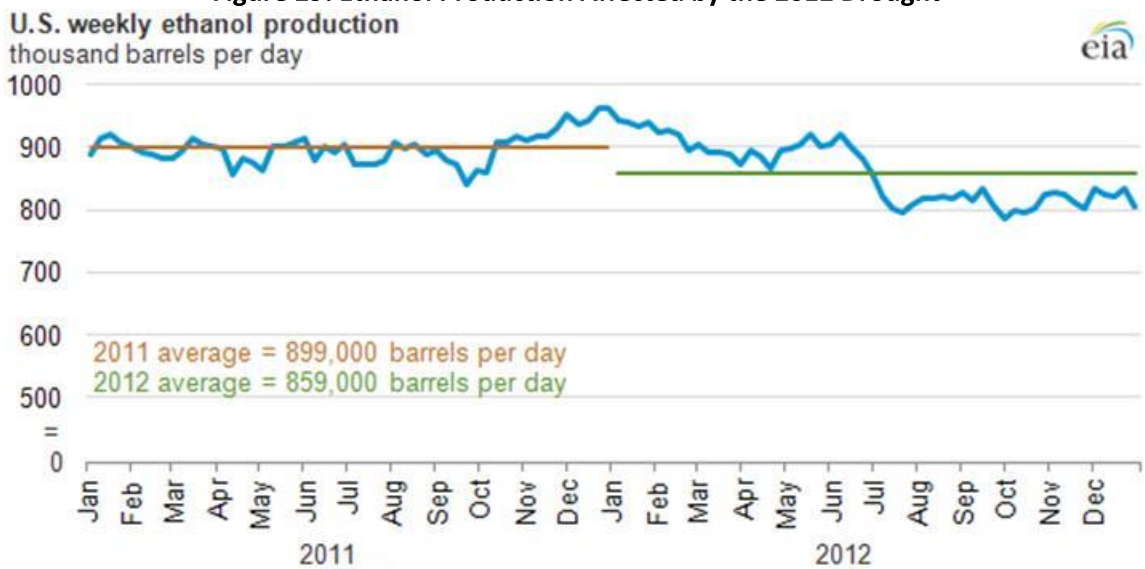
Figure 28: Temperature Anomalies, June 17-24, 2012



Source: NASA

During the year, more than 60% of the country also experienced drought leading to a number of impacts on the oil and gas supply chain. The drought severely affected crop production, particularly corn, which is used as an ethanol feedstock. Nearly 85% of all corn production was located within a drought-affected area with almost half of the crop in areas under D3-D4 conditions (extreme and exceptional droughts). As a result, ethanol producers began scaling back production, reducing output by about 90 MBbl/d on average compared to 2011.[51] Figure 29 shows the rapid drop in production beginning in June 2012.

Figure 29: Ethanol Production Affected by the 2012 Drought



Source: EIA

Production was also hit at the oil and gas wells. During the drought, some counties in Pennsylvania stopped issuing permits for fracking companies to draw water from the rivers, delaying new well operations. The heat wave and drought also reduced transportation capabilities. Besides causing highways to buckle and rails to kink, the drought also closed off sections of the Mississippi River to barge traffic after it hit near-record-low levels.

E. Likely Impacts on Infrastructure

Heat waves and droughts differ from other natural disasters examined in this report as they do not necessarily cause physical damage to the oil and gas infrastructure. Instead, their effects tend to disrupt normal operations by reducing feedstock, interrupting the flow of throughputs, or cutting off power and other resources. Because of this, effects from a drought are sometimes not immediately felt or apparent in the oil and gas industry. For instance, the drought throughout 2012 did not severely affect the water levels on the Mississippi River until late in the year and early 2013. Water loss in aquifers and reservoirs might not have an impact for current fracking, but will create a threshold for future wells.

As effects from droughts are delayed, those effects also become more uncertain. A months-long drought with little precipitation might lead to low river levels, or a tropical storm might pass over the area and relieve those conditions. The following list presents drought and heat wave effects from most likely to least likely while taking those delayed effects with their uncertainties into account.

- Transportation disruptions in the form of temporarily closed highways and railroad tracks due to buckling effects.
- Brownouts due to high electricity usage.
- Power loss due to sagging lines and blown transformers.
- Insignificant ethanol feedstock crop loss.
- Reduced extraction and refining productivity due to worker breaks.
- Halt in local fracking activity due to drop in water levels.
- Restricted river transportation.
- Major ethanol feedstock crop loss.
- Improperly stored propane could cause explosions.
- Compounding other natural disasters due to extreme heat (derechos, wildfires).
- Reduced refinery runs due to water restrictions.

These impacts are summarized in Table 24 and reflect both the probability and severity of damage as well as the probability and severity of disruption of normal operations for any piece of infrastructure.

Table 24: Probability and Severity of Drought and Heat Wave Damage to Infrastructure

Infrastructure	Heat Wave		D3-D4 Drought	
	Probability of Damage	Severity of Damage	Probability of Damage	Severity of Damage
Loss of Electrical Power	Low-Med	Interrupting	Low-Med	Interrupting
Offshore Platforms	Low	Insignificant	Low	Insignificant
Onshore Wells	Low	Insignificant	Low-Med	Interrupting
Pumping/Compressor Stations	Low	Insignificant	Low	Insignificant
Pipelines	Low	Insignificant	Low	Insignificant
Rail	Low-Med	Interrupting	Low	Insignificant
Ports	Low	Insignificant	Low-Med	Interrupting
Crude Tank Farm	Low	Insignificant	Low	Insignificant
Refineries	Low	Insignificant	Low-Med	Interrupting
Natural Gas Plants	Low	Insignificant	Low-Med	Interrupting
Product Storage	Low	Insignificant	Low	Insignificant
Propane Tanks	Low	Insignificant	Low	Insignificant
Underground Storage	Low	Insignificant	Low	Insignificant
LNG Terminals	Low	Insignificant	Low	Insignificant
Local Natural Gas Distribution	Low	Insignificant	Low	Insignificant
Filling Stations	Low	Insignificant	Low	Insignificant
SPR/NEHOR	Low	Insignificant	Low	Insignificant

It does not take into account any affect from other disasters associated with heat waves such as derechos or wildfires. Those events are discussed in their own separate sections. Furthermore, as the effects from drought levels D0-D2 will have minimal impacts on oil and gas infrastructure, only extreme and exceptional droughts (D3-D4) will be examined and distinguished from the effects of a heat wave.

F. Hazard Areas

Heat waves and droughts affect the entire country, yet there are some areas where they have become more frequent and worse in recent decades, and some areas where they have greater impacts. For instance, the effects of droughts in California are more severe because the state has a high population, a large and diverse agricultural sector, and is prone to dangerous wildfires. California also relies on snowpack accumulated in the mountains during the winter months as well as river flows from the Colorado River to provide water, making drought alleviations less likely once they begin. Droughts which occur outside of California frequently impact California's water supply.

Over the past 40 years drought conditions have become more common in the southern half of the country and less common throughout most of the north. Groundwater levels have also declined in the Great Plains, California Central Valley, the Chicago-Milwaukee area, west-central Florida, and the desert Southwest, being depleted faster than they are refreshed. These depletions may have compounding effects on oil and gas extraction during periods of drought as they are often the go-to water resources in absence of rivers.

While California stands out as an exception, it is more difficult to pinpoint other regions facing severe infrastructure risks due to droughts and heat waves. Both weather effects are perhaps the geographically largest in this analysis and therefore generate substantial effects by covering large swaths of land. Most of a drought's affects also transcend the regions in which they occur. Losses in crop production will have national price affects and droughts in an area upstream could affect water levels in a non-drought area downstream.

G. Rising Temperatures

Looming over all discussions of abnormally hot temperatures is the threat of climate change. Heat waves and droughts are also inextricably tied to this phenomenon which has seen average global temperatures rise by 1.4 degrees Fahrenheit in the last century. Rising temperatures have already had impacts on fuel supply infrastructure.

For instance, Alaska's drilling season has been shortened due to the permafrost thawing earlier in the spring. Thawing permafrost has also disrupted transportation networks and there are concerns that it will affect the Trans-Alaska Pipeline. Much infrastructure in Alaska relies on a frozen ground to support the weight of the structure, and the region, which has now warmed twice as fast as the rest of the planet, is facing new challenges and more unpredictable weather.

Furthermore, climate change is expected to have even larger impacts on infrastructure as temperatures continue to rise. Extreme weather events could become more common. Melting sea ice and the ice sheets in Greenland and Antarctica could cause sea levels to rise causing greater problems with flooding and storm surges. The water risks posed to oil and gas infrastructure are especially problematic due to the location of refineries along major rivers and the large amount of extraction in the Gulf of Mexico. A further risk is posed by old and aging infrastructure built and designed for a different climate. Such infrastructure is more vulnerable to increased risks than their newer counterparts.

H. Measures Taken by Industry to Address Vulnerability

Because of rising global temperatures, heat waves and droughts are expected to get worse in the coming decades. Hardening efforts may be useful to update some key parts of the infrastructure to guard against more damaging weather events, yet may have little impact regarding supply interruptions created by drought conditions. Nonetheless, the public and private sectors could take some large steps to improve fuel resiliency in the face of exceptional and devastating droughts.

One of the main concerns over droughts is that the oil and gas industry is often directly competing with agriculture for resources. Ethanol uses a large amount of the corn produced in the country and fracking competes with agriculture and town authorities for water. One large measure would be to reduce the reliance on corn-based ethanol either by switching to a feedstock not also used as food, such as switchgrass.

Water issues at the well site and refineries can also be mitigated through cooperation with local officials and better water management policies. Some refiners have already taken steps to ensure a steady water supply. A BP refinery in California has contracted a local water agency to send the plant their sewage water, which is then treated at the refinery. Fracking firms could pursue similar relationships. There are also other possible avenues to make water use in fracking more sustainable. Some fracking companies recycle the used water for later injections, and others have begun experimenting with using carbon dioxide.

VIII. Derechos

A. Introduction

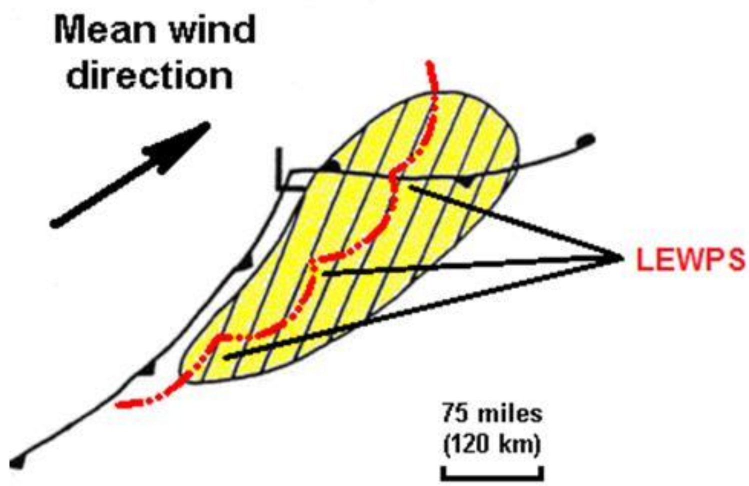
A derecho is defined as a long-lived and "widespread convectively-induced straight-line windstorm." More specifically, if the storm has a length of at least 240 miles and wind speeds of at least 58 mph then it is classified as a derecho. Often the storms are much wider with much stronger winds occasionally topping 100 mph. These characteristics have given derecho the nickname "land hurricanes." However, unlike hurricane derecho is not ranked by intensity outside of wind speeds measured along a derecho's path. Instead, derecho is considered a particularly intense thunderstorm with some unique characteristics.

The high winds that characterize a derecho, come from downbursts which form when upper wet air in the storm contacts dry air and evaporates, cooling the air and forcing it downward. The air descends until it hits the ground and pushes outward creating high winds. These downbursts often contain smaller microbursts of about 2.5 miles in length and those microbursts can contain burst swaths of 50-150 yards. As the packets of air get smaller and more localized they can reach velocities capable of causing tornado-like damage. Besides strong winds, derecho also have bow echoes as a key characteristic. Bow echoes are a line of thunderstorms that resemble a bow or bent shape caused by an updraft flowing in front of the formation and a rear-inflow jet pushing from behind.

There are two main types of derechos, serial and progressive. Serial derechos have multiple bow echoes, can be many hundreds of miles wide, and are typically associated with a migrating low-pressure system (Figure 30). These storms are far less common and form mainly in the late winter and early spring. Progressive derechos are much narrower but also considered more intense and dangerous as they form with less warning. They account for about 85% of all derechos and occur primarily in the summer, driven by heat waves. The storms form along a stationary front where hot air form the south meets cooler northern air, conditions often found in the Great Lakes and Midwest region.

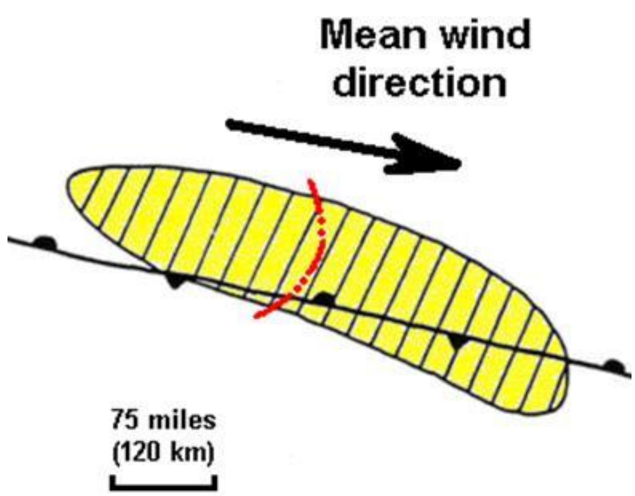
Meteorologists still know little about how or why derechos form. Nonetheless, for serial derechos, they are often able to forecast a storm's emergence based on atmospheric conditions, like changes in jet stream. Progressive derechos are much more difficult to predict as nearly identical atmospheric conditions may produce a derecho one time and not the next (Figure 31). The storm's unpredictability and rapid movement make them especially dangerous as preparations can't be made in anticipation of damage.

Figure 30: Serial Derechos



Source: NOAA

Figure 31: Progressive Derechos



Source: NOAA

B. Threats to Oil and Gas TS&D Infrastructure

Oil and gas infrastructure is primarily affected by derechos through access to power supply. Fast-moving violent thunderstorms characteristic of derechos often cause massive power outages over large areas. These outages can last for days to weeks and are exacerbated by lack of forewarning and subsequent heat waves that slow recovery. In this respect, derechos are similar to hurricanes which also leave large areas without power in the wake of the storm that require coordination with unaffected regions to bring in work crews temporarily.

Like hurricanes, most power outages are caused by high winds. Strong microbursts and burst swaths can produce winds up to 140 mph in some places, easily felling large trees and capable of inflicting structural damage on transmission towers. As power restoration is often prioritized to key parts of infrastructure (airports, pipelines) and industry, the main effects of power loss will most likely be on fueling stations in affected areas.

Flooding is also a concern, and given the speed and amounts of rainfall produced in a short time, flash floods pose serious threats to people caught unawares. However, the storms ultimately pose little flood risk to infrastructure not located in flood zones and don't pose any of the larger flooding threats like storm surges.

One thing that solidly separates derechos from other disasters is the added threat of lightning. Lightning is a common occurrence while rarely damaging infrastructure, yet it does pose unique challenges to the TS&D infrastructure. Over the years lightning strikes have been known to start fires at tank farms and pipelines, and have caused explosions in propane tanks.[52] These are typically rare and localized events, but must be considered as part of total impact that derechos present.

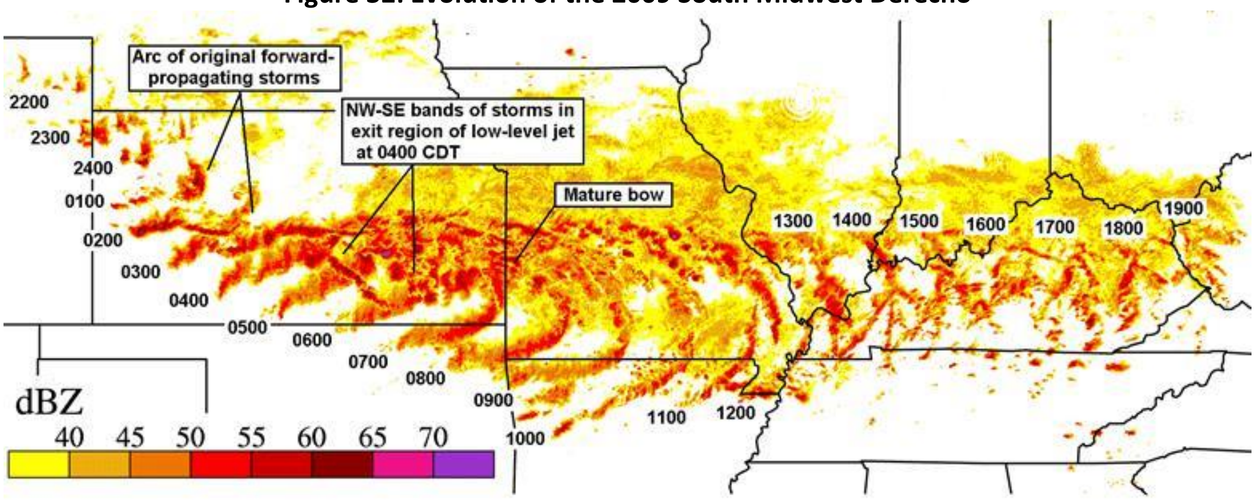
C. Historical Events

Despite being little understood by meteorologists and relatively unknown by the public, there were several high-profile derecho events in recent years.

May 2009 "Super Derecho"

The May 2009 derecho is considered amongst, if not the strongest, derecho ever recorded. It moved from Kansas to western Virginia and North Carolina - over 1000 miles, in about 24 hours (Figure 32).

Figure 32: Evolution of the 2009 South Midwest Derecho



Source: NOAA

The storm, while beginning as a progressive derecho, also evolved into a mesoscale convective vortex, giving it an unusual circulation that resembled the shape of a hurricane. As the storm moved over Missouri, the vortex produced sustained winds between 70 and 90 mph, with some gusts topping 100 mph. The storm also produced 39 confirmed tornadoes within it, including two EF3s.

Overall, the storm killed six people and damaged hundreds of homes and businesses totaling around hundreds of millions in damages. Flash floods through Kansas and Missouri caused multiple road closures, and thousands were left without power due to downed power lines. In addition, a TV tower in Joplin, MO was toppled by strong winds.

However, despite the storm's severity, the most detrimental impact on oil and gas infrastructure came from power loss and local access to gasoline. One refinery near El Dorado, KS had a dented storage tank due to high winds, but that was the extent of the damage.[53] Despite being one of the strongest derechos in memory, the affected areas were sparsely populated and contained relatively little infrastructure.

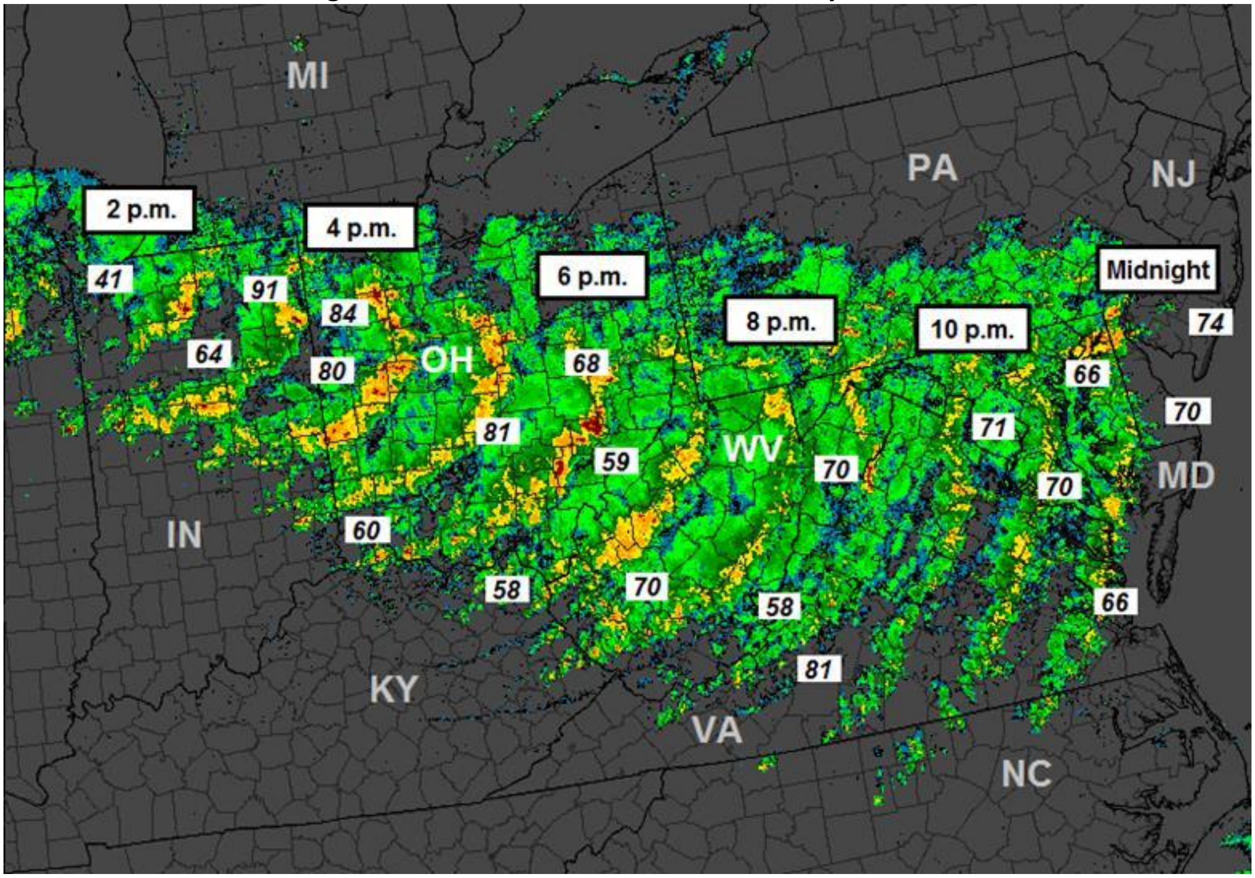
June 2012 Midwest and Mid-Atlantic Derecho

While not nearly the strongest or most severe derecho, the June 2012 derecho caused widespread damage and cost numerous lives when it hit the densely populated mid-Atlantic region. The derecho also coincided with a heat wave which aggravated the effects of power loss. Also a progressive derecho, the storm moved rapidly, covering approximately 700 miles in twelve hours (Figure 33).

Overall, some five million people lost power, many for prolonged periods. A week after the storm hit nearly half a million customers were still without power in six states.[54] Several states saw record percentages of their population without power for a non-hurricane event. West Virginia was hit hardest as 62% of its population was without electricity after the storm hit and 20% remained powerless a week later. Power restoration was further hampered by record-setting heat; workers needed constant breaks to hydrate, rest, and avoid heat exhaustion.

Impacts of the oil and gas infrastructure were again mostly isolated to power loss and local petroleum disruptions. While many gas stations had fuel supplies, widespread power outages left pumps inoperable and unable to deliver fuel to consumers. The derecho also knocked out power to a key communications station in the Washington D.C. area interrupting emergency, telephone, internet, and other communications for several days. This problem exposed a severe vulnerability in an industry interdependent on the oil and gas infrastructure and led to an FCC report examining what went wrong.[55]

Figure 33: Evolution of the 2012 Ohio Valley Derecho



Source: NOAA

D. Likely Impacts on Infrastructure

Effects of a derecho on the oil and gas infrastructure, listed from most likely to least, are provided below.

- Widespread electrical power outages. These may last for a few hours in the case of a downed line, days, if a transmission tower is damaged or large trees need to be removed, or up to a week depending on the extent of the storm and available resources.
- Access cut to terminals, fueling stations, and possible rail obstruction due to fallen trees and debris.
- Fuel shortages caused by power outages can lead to massive distribution disruption.
- Light to moderate damage to refineries, storage tanks, and other exposed infrastructure due to high winds.
- Lightning strikes, causing severe fires that may damage pipelines, refineries, or other key infrastructure.
- Accompanying tornado outbreaks, causing significant damage to nearly all infrastructure if hit.

Because derechos affect large areas, probability of damage will be relatively high. However, variance in derechos, outside of being either serial or progressive, occurs within the storm in terms of microbursts and burst swaths. Therefore, while a derecho may cover a large amount of territory, these events are localized and the probability of damage done by high wind bursts will be extremely low even if the severity may be relatively high. Table 25 summarizes the probability and severity of the damage for different types of infrastructure during a derecho event.

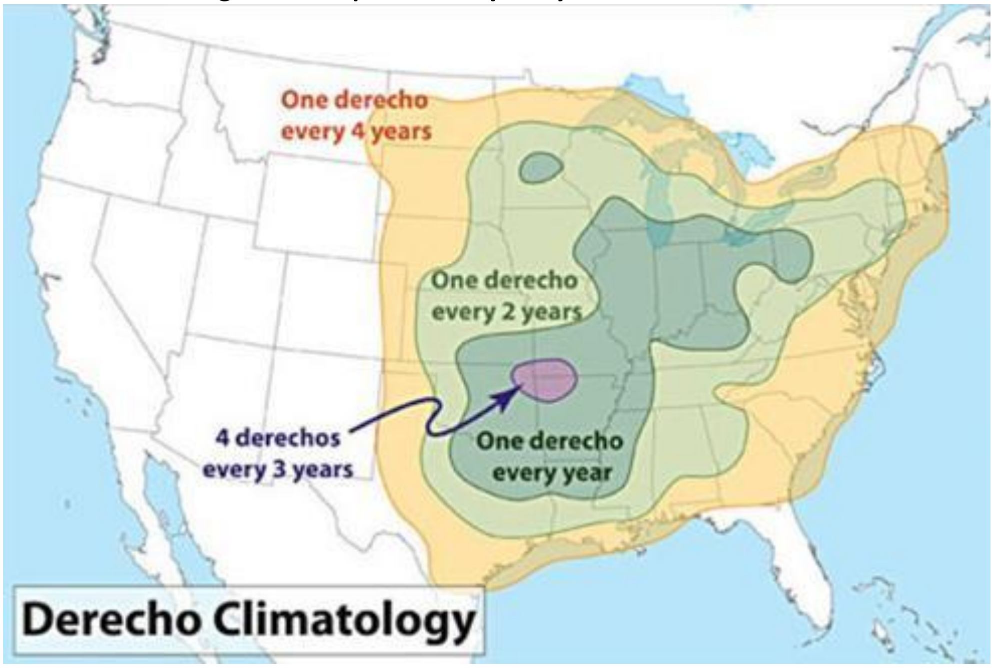
Table 25: Probability and Severity of Derecho Damage to Infrastructure

Infrastructure	Probability of Damage	Severity of Damage
Loss of Electrical Power	High	Catastrophic
Offshore Platforms	Low-Med	Interrupting
Onshore Wells	Low-Med	Interrupting
Pumping/Compressor Stations	Low-Med	Interrupting
Pipelines	Low-Med	Interrupting
Rail	Low-Med	Interrupting
Ports	Low-Med	Interrupting
Crude Tank Farm	Low-Med	Interrupting
Refineries	Low-Med	Interrupting
Natural Gas Plants	Low-Med	Interrupting
Product Storage	Low-Med	Interrupting
Propane Tanks	Low-Med	Interrupting
Underground Storage	Low-Med	Interrupting
LNG Terminals	Low-Med	Interrupting
Local Natural Gas Distribution	Low-Med	Interrupting
Filling Stations	Med	Significant
SPR/NEHOR	Low-Med	Interrupting

E. Hazard Areas

Derechos occur throughout the world, yet they appear to be more frequent in the United States. However, as the phenomena is little understood and only gained recognition relatively recently, meteorologists are still debating where derechos are most frequent and whether past weather events were simply mis-categorized as severe thunderstorms. From data available, derechos affect the south Midwest and Ohio Valley regions once a year, while the entire eastern half of the United States is expected to experience a derecho at least once every four years (Figure 34).

Figure 34: Expected Frequency of Derecho Events



Source: NOAA

While derechoes might occur more frequently in some areas, they are common enough that all areas should be considered. However, for the purposes of this study only areas that are expected to experience one derecho every year will be considered. This region includes the Midwest, the Southern plains, parts of the Southeast, and the Ohio Valley.

F. Measures Taken by Industry to Address Vulnerability

One of the biggest challenges derechos pose is the difficulty in forecasting. Once they appear they generally move in a straight path (derecho means "straight" in Spanish), yet often too quickly to allow for serious preparations. While they can generate hurricane-like effects, bringing wind and rain, they lack the arguably most devastating hurricane attribute of storm surges. Therefore, while derechos are serious threats to lives and property, their impacts on fuel supply will ultimately be minimal and mostly constrained to the distribution end.

However, because they are capable of generating winds inland typically stronger than hurricanes and bring lightning, derechos are a significant threat to the power grid. Any discussion of fuel resiliency under threats from derechos must be centered on hardening the electric power system or implementing plans for coordinated responses to restore power to vital industries.

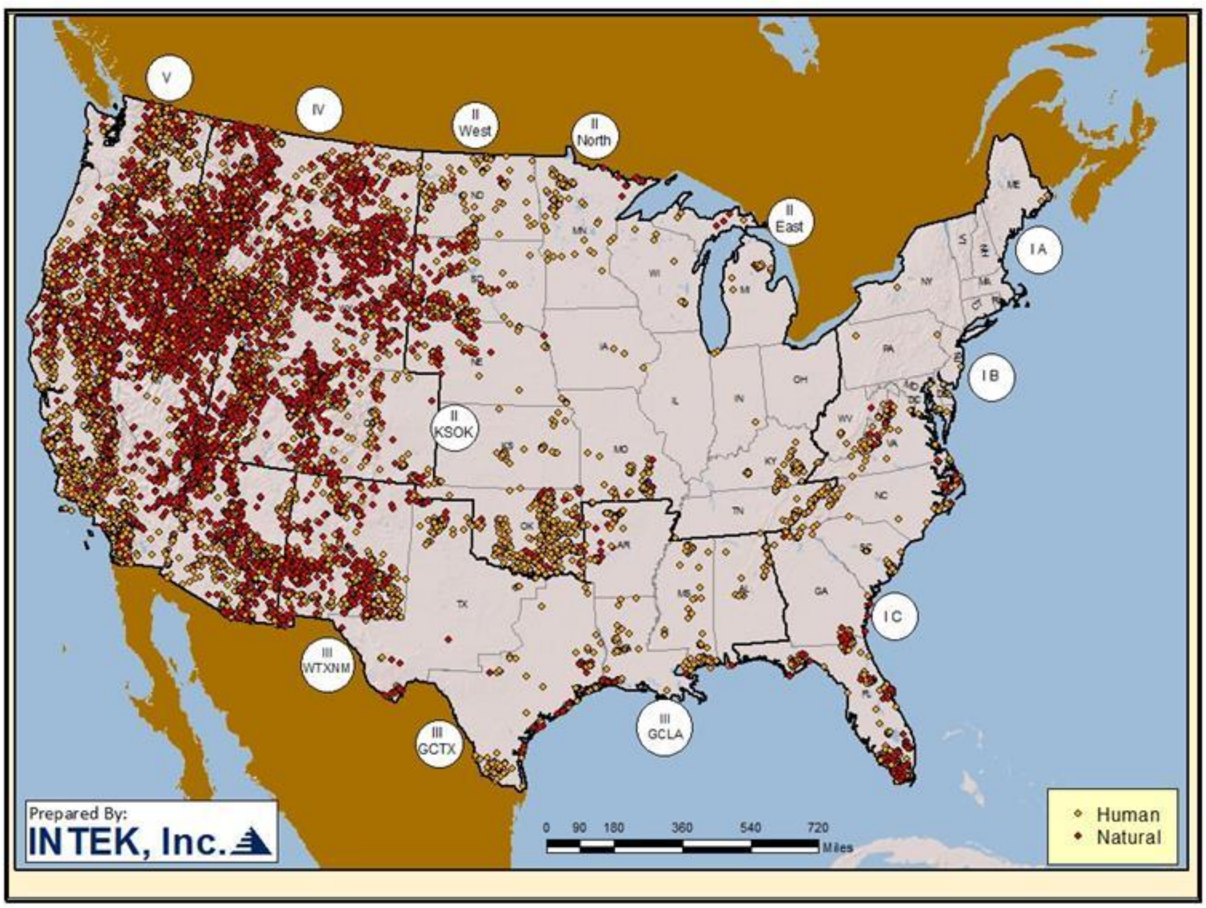
IX. Wildfires

A. Introduction

Wildfires, also called forest fires or bush fires, are uncontrolled fires that spread among vegetation in the wild. They can start either through accident (leaving coals unattended), malevolence (arson), or natural causes (lightning), yet are most likely to start under prolonged dry spells and droughts. Since 1980, 8,200 major wildfires (over 500 acres in size) were caused by humans and 9,591 were natural (Figure 35). Wildfires are a common occurrence and sometimes necessary to rejuvenate forests that have become overgrown.

There are many factors which influence the spread and severity of a wildfire. Region, geography, species of vegetation, rainfall, and temperature all determine how quickly a fire will spread and how much damage it will cause to the forest and surrounding areas. Some forest fires will just burn brush and undergrowth, leaving most of the trees still standing, albeit a little crisp, while others will turn entire acres to ash.

Figure 35: Wildfires Larger than 500 Acres 1980-2012



Source: USGS

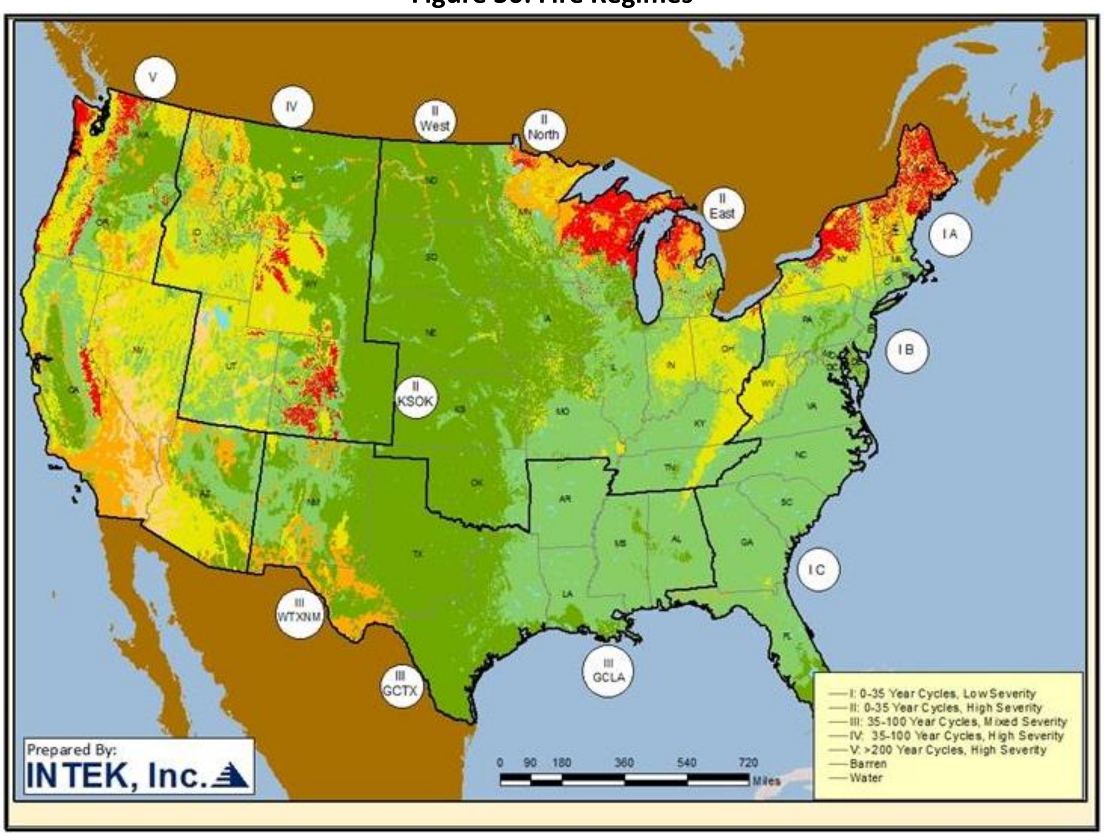
Wildfires can occur nearly anywhere with vegetation, yet in the United States they are mostly concentrated in the west where arid conditions increase the chance of a fire starting or spreading. The eastern forests also experience fires yet they are generally not as severe because of differences in the climate. The east receives rainfall throughout the year whereas the west relies on snowpack gained in the mountainous areas and forests during the winter and saturate forest soils to stave off droughts. With little snowpack the forests become dry by early summer, leaving areas vulnerable to wildfires. This trend is highly visible in the 2014 fire season in California.

These causal factors allow the US Forest Service to predict the dangerousness of the fire season for the year. During 2014, California is expected to have its worst drought in a century with an extremely high risk for wildfires.

B. Measuring Fire Risk

The USDA Forest Service rates an area's fire risk by condition class system (Figure 36). The system assesses risk based on two metrics: an area's condition class (1-3) and an area's fire regime (I-V). The condition class refers to how much an area deviates from its historical wildfire profile. Condition Class 1 means that an area has about the same burn risk and frequency as in the past while Condition Class 3 means an area has drastically departed from its historical frequency and its vegetation contains a high risk to the ecosystem either due to fire suppression or other factors.

Figure 36: Fire Regimes



Source: Fire Sciences Laboratory, Rocky Mountain Research Station, USDA Forest Service

An area's fire regime denotes what's likely to happen during a fire based on how frequent fires occur, what kind of vegetation (fuel) grows there, and what the climate conditions are like. Fire Regimes I and II mean that fires occur frequently, about every 35 years or less, with I signifying a lower severity and II signifying a higher severity. Fire Regimes III and IV denote a 35-100 year cycle with III signifying a mixed severity and IV a higher severity. Fire Regime V denotes sections of forest that experience fires on a 200 or more year cycle and are all high severity.

The eastern half of the country generally falls into Fire Regimes I and II with some exceptions in Appalachia and the Northeast. The western half of the country primarily has Fire Regimes III, IV, and V, leading to larger and more severe fires. The USDA Forest Service uses Condition Classes and Fire Regimes to allocate resources to high-risk areas and develop management plans.

C. Threats to Oil and Gas TS&D

Uncontrolled wildfires can cause serious damage to all structures and pose a special risk to oil and gas infrastructure because they necessarily contain highly flammable substances. Refineries have experienced fires in the past which have caused severe injuries and damage. Outside of the clear risks associated with fire, wildfires can also cause power outages, affect local natural gas distribution, create road and rail obstruction, and can cause areas to be unsafe for humans through smoke and ash deposits.

While wildfires could wreak havoc at refineries, petroleum terminals, and other key infrastructures, they are generally slow moving and start far enough away from key areas to cause too much concern. Unlike other natural disasters, wildfires can also be controlled if not stopped altogether. Therefore, if any wildfire begins to threaten a refinery or other key infrastructure, firefighters can take steps to delay the spread or direct it elsewhere. However, due to the severe nature of the threat, personnel may be evacuated and the refinery may be temporarily shut. Pipelines are also rarely threatened by wildfires as nearly all are mostly underground. The exception is the Trans-Alaska pipeline which has been threatened by wildfires a couple times and has emerged unscathed.

Wildfires have occasionally disrupted oil and gas production if they encroach on areas with wells. In 2013, wildfires in Colorado caused the temporary shutdown of over 500 gas wells and the evacuation of a gas processing plant. The fire was contained, the sites undamaged, and production resumed to near full capacity several days later. In 2011, a wildfire also disrupted well operations in the Permian Basin in West Texas shutting 60 wells temporarily and destroying 120,000 feet of poly flow lines that transport crude oil from the wells to the storage tanks. Workers at the site and firefighters were able to take necessary precautions to avoid damage to wells or control equipment.

D. Historical Events

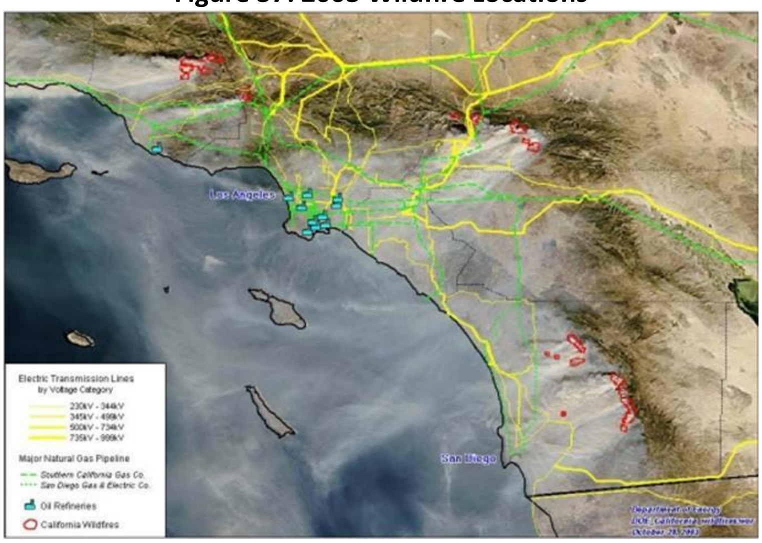
While wildfires have the ability to affect oil and gas supply if they're in a producing region, the extent to which they can impact the overall market is highly limited. They are relatively slow-moving and even the largest ones are localized and most likely in rural areas lacking in key infrastructure. These relatively insignificant impacts are illustrated by the limited effects of some of the largest wildfires have had in recent decades (Table 26).

The 2003 California Wildfire Outbreak

2003 was a record-setting year for California fires. Fifteen fires burned in southern California. The Cedar Fire in San Diego County was the largest fire on record with more than 280,000 acres burned. The Cedar Fire alone caused 15 fatalities, over 100 injuries, and nearly $30 million in damages. All the fires caused substantial power losses, leaving 58,700 customers without electricity for several days and 40,000 more with brief, daily losses.

Despite being one of the worst wildfires in history, the 2003 outbreaks did little damage to the oil and gas infrastructure. While many people lost electricity, only 1,000 customers lost natural gas service for about a week and there were insignificant product disruptions due to closed highways. No refineries were close enough to the fires to warrant evacuations and product pipelines were unaffected. (Figure 37)[56]

Figure 37: 2003 Wildfire Locations



Source: Office of Electricity Delivery and Energy Reliability, United States Department of Energy

The 2007 California Wildfire Outbreak

In 2007, California again experienced a major wildfire outbreak that caused a state of emergency. About thirty wildfires started from a variety of sources, burned nearly 1 million acres, and were contained after 19 days.

The fires were hard to contain due to high winds reaching up to 70 mph, yet at the height of the emergency, only 40,000 customers had lost power. As the fire burned through various power transmission centers, crews moved in quickly, assessed the damage, and were able to restore power to most within a couple days. Around 1,600 customers also lost natural gas service as distribution lines were shut as a precaution.

Like the 2003 wildfires, the 2007 event proved to have minimal impacts on oil and gas infrastructure, if any.

Table 26: Summary of Damage from Recent Wildfires to Transmission and Distribution Network

Wildfire	#	Total Acreage Burned	Power Loss	Oil Infrastructure	Gas Infrastructure	Fuel Disruption
2003 California Wildfires	15	800,000	• ~100,000 without power • 40,000 restored within hours, the rest restored within a week.	• None reported	• None reported	• 1,000 customers lost natural gas service • Insignificant disruptions due to highway closures
2007 California Wildfires	30	971,000	• 44,000 without power • Most restored within several days	• None reported	• None reported	• 1,600 customers lost natural gas service
2013 Colorado Wildfires	~12	~150,000	• Hundreds	• None reported	• 500 gas wells (~12.2 MMcf/d) shut for several days • 1 small gas processing plant shut	• None reported

E. Likely Impacts on Infrastructure

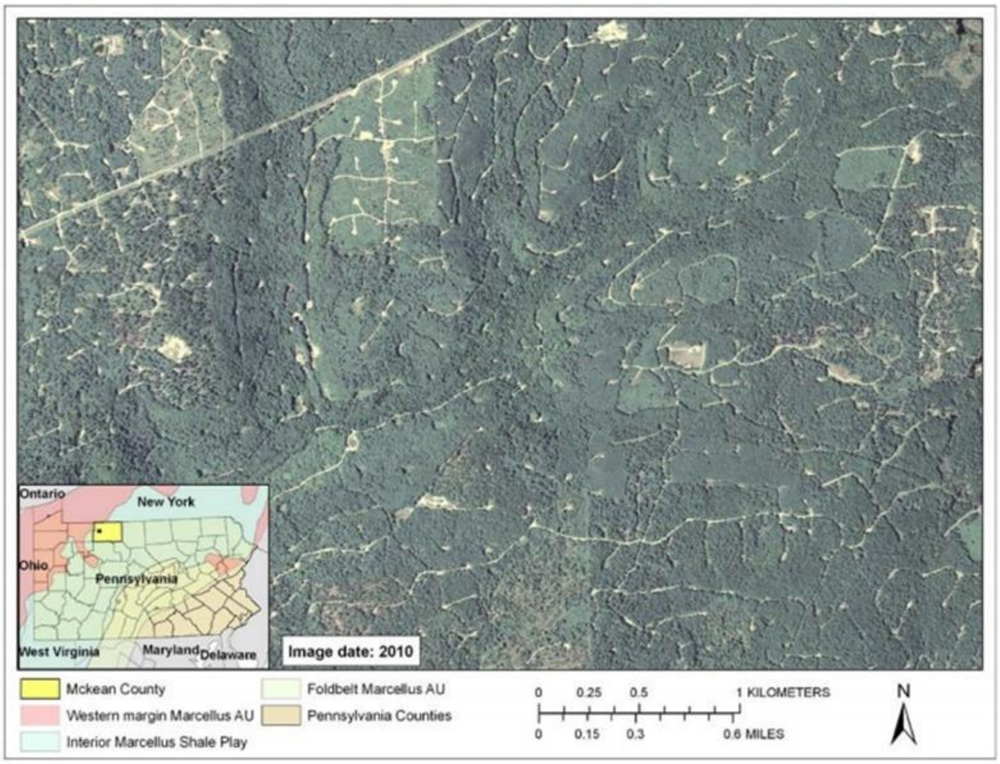
Wildfires occur in nearly every part of the country, yet by definition, almost always originate away from key infrastructures. Because of their origin in the wilderness, the ease to identify them, and their slow, possibly containable spread, wildfires pose little risk to oil and gas infrastructure. When infrastructure is in the area of a large wildfire, firefighters and the US Forest Service have a variety of time-tested tools to stop the fire from reaching equipment or storage that could exacerbate the situation.

However, there remain some concerns. First, there are a large number of gas wells located within forests as new areas of exploration open up previously forested areas, such as northern Pennsylvania and upstate New York (Figure 38). If wildfires start in these areas and consume a large number of wells, it would still be unlikely to have much of an impact as long as precautions are taken to shut down the wells. The 2013 Colorado wildfires threatened 500 wells, yet only the flow lines were lost to the flames while the wells were shut-in for several days.

Second, while fires can be contained or diverted with proper resources, there have been times recently when that support has been stretched thin. In 2008, California was forced to enlist its National Guard to help combat fires that had sprung up in several parts of the state.[57]

Third, wildfires sometimes exist at the intersection of natural and man-made disasters. Wildfires caused by lightning strikes have no intended targets and burn randomly, yet arsonists could start fires to target particular infrastructure. While it does not present as nearly a direct threat as more conventional methods of sabotage or terrorism, it does pose some risk to infrastructure.

Figure 38: Gas Well Infrastructure in Northern Pennsylvania



Source: USGS

The possible effects of a wildfire on oil and gas infrastructure, listed from most likely to least likely are:

- Large but localized electrical outages due to fire overtaking power lines and substations.
- Localized natural gas service disruptions due to lines being temporarily shut over safety concerns.
- Minimal distribution interruptions due to prolonged closure of roads and highways.
- Loss of remote-area filling stations.
- Loss of well platforms and gathering lines with proper shutdown precautions taken.
- Evacuations of refineries and natural gas processing plants for several days.
- Loss of compressor stations, and pumping stations in remote areas.

- Severe damage to refineries or natural gas plants in the event of an uncontrolled conflagration.

These probabilities may differ slightly with different fire regimes. Frequent, low-severity regimes will be unlikely to generate the heat or momentum needed to destroy some smaller trees and undergrowth whereas higher regime levels can take weeks to contain and may turn into firestorms which generate strong winds and possibly tornadoes. Table 27 shows the probabilities and severities of fires developing under either extreme of the regime. As wildfires are mostly local events not covering large areas, any probability for damage will be relatively low.

Table 27: Probability and Severity of Wildfire Damage to Infrastructure

Infrastructure	Fire Regime I Wildfire		Fire Regime V Wildfire	
	Probability of Damage	Severity of Damage	Probability of Damage	Severity of Damage
Loss of Electrical Power	Low-Med	Interrupting	Med	Significant
Offshore Platforms	Low	Insignificant	Low	Insignificant
Onshore Wells	Low	Insignificant	Low-Med	Interrupting
Pumping/Compressor Stations	Low	Insignificant	Low-Med	Interrupting
Pipelines	Low	Insignificant	Low-Med	Interrupting
Rail	Low	Insignificant	Low-Med	Interrupting
Ports	Low	Insignificant	Low-Med	Interrupting
Crude Tank Farm	Low	Insignificant	Low-Med	Interrupting
Refineries	Low	Insignificant	Low-Med	Interrupting
Natural Gas Plants	Low	Insignificant	Low-Med	Interrupting
Product Storage	Low	Insignificant	Low-Med	Interrupting
Propane Tanks	Low	Insignificant	Low-Med	Interrupting
Underground Storage	Low	Insignificant	Low-Med	Interrupting
LNG Terminals	Low	Insignificant	Low-Med	Interrupting
Local Natural Gas Distribution	Low	Insignificant	Low-Med	Interrupting
Filling Stations	Low	Insignificant	Low-Med	Interrupting
SPR/NEHOR	Low	Insignificant	Low-Med	Interrupting

Probability of each of the above events is also largely based on where the wildfire occurs. Some fires consume thousands of acres of wilderness and go virtually unnoticed. Others, particularly those in southern California attract widespread media attention because of their proximity to large population centers and heavy industry.

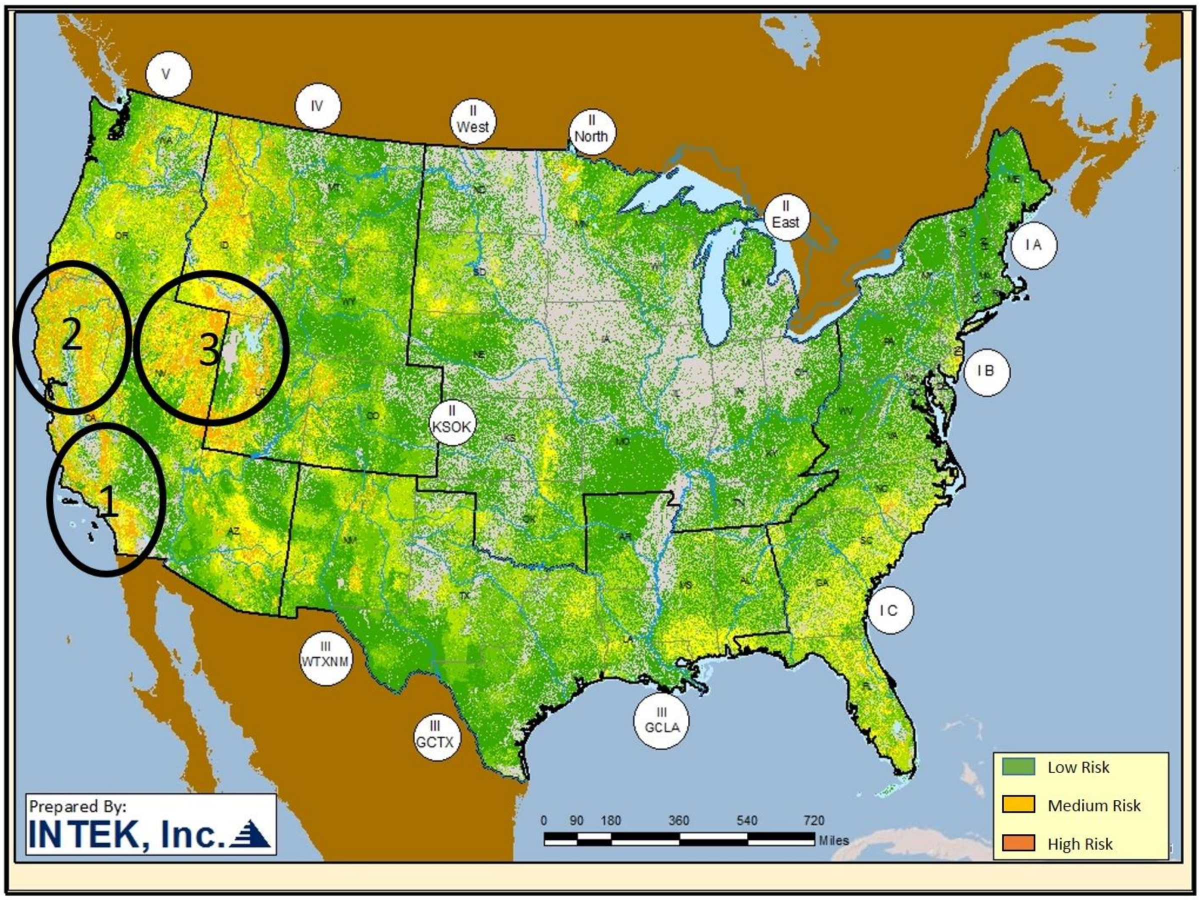
F. Hazard Areas

Wildfires can occur nearly anywhere in the country yet are most prolific in the arid parts of the West. For the purposes of this report, three regions of key importance and high fire frequency will be examined (Figure 39).

1. Southern California

- **Refineries:** 9
- **Total refining capacity:** 1,085 MBbl/d
- **Petroleum terminals:** 27
- **Crude pipelines:** Plains All American, ExxonMobil West
- **Product pipelines:** Kinder Morgan, SFPP Southern, and CALNEV
- **Natural gas plants:** 6
- **Gas processing capacity:** 13 MMcf/d
- **Gas pipelines:** SoCal Gas, California Gas Transmission

Figure 39: Key Vulnerable Wildfire Regions



Source: Rocky Mountain Research Station

2. Northern California

- **Refineries:** 5
- **Total refining capacity:** 820 MBbl/d
- **Petroleum Terminals:** 12
- **Crude pipelines:** Phillips 66

- **Product pipelines:** Kinder Morgan, SFPP Northern, and Phillips 66 Richmond
- **Gas pipelines**: California Gas Transmission

3. Great Basin

- **Refineries:** 6
- **Total refining capacity:** 172.8 MBbl/d
- **Imported crude:** 8.4 MBbl/d
- **Petroleum terminals:** 7
- **Natural gas plants:** 3
- **Gas pipelines:** Paiute, Ruby, Questar, Northwest, Kern River Gas Transmission.

G. Measures Taken by Industry to Address Vulnerability

Wildfires are unique amongst the other natural disasters in that they can be controlled. Human intervention will not be able to stop the emergence of wildfires, yet the U.S. Forest Service and state and local officials have long-term experience mitigating wildfires, understand when their appearance is more likely, and have a large number of tools at their disposal to deal with the potential threats.

Larger conflagrations will require more resources to prevent life loss and property damage, yet given the commodities involved in the hydrocarbon industries, threats to refineries, pipelines, and storage facilities will always be prioritized if for no reason more than to prevent a greater disaster and by literally adding fuel to the fire.

With rising temperatures and more droughts, wildfires will continue to be a major problem for many areas of the country, yet in terms of fuel resiliency they will remain a manageable one.

X. Flooding

A. Introduction

A flood is an inundation of water over usually dry land. Floods can occur in all regions of the United States and all parts of the year. Three-fourths of presidential disaster declarations are a due to flooding.

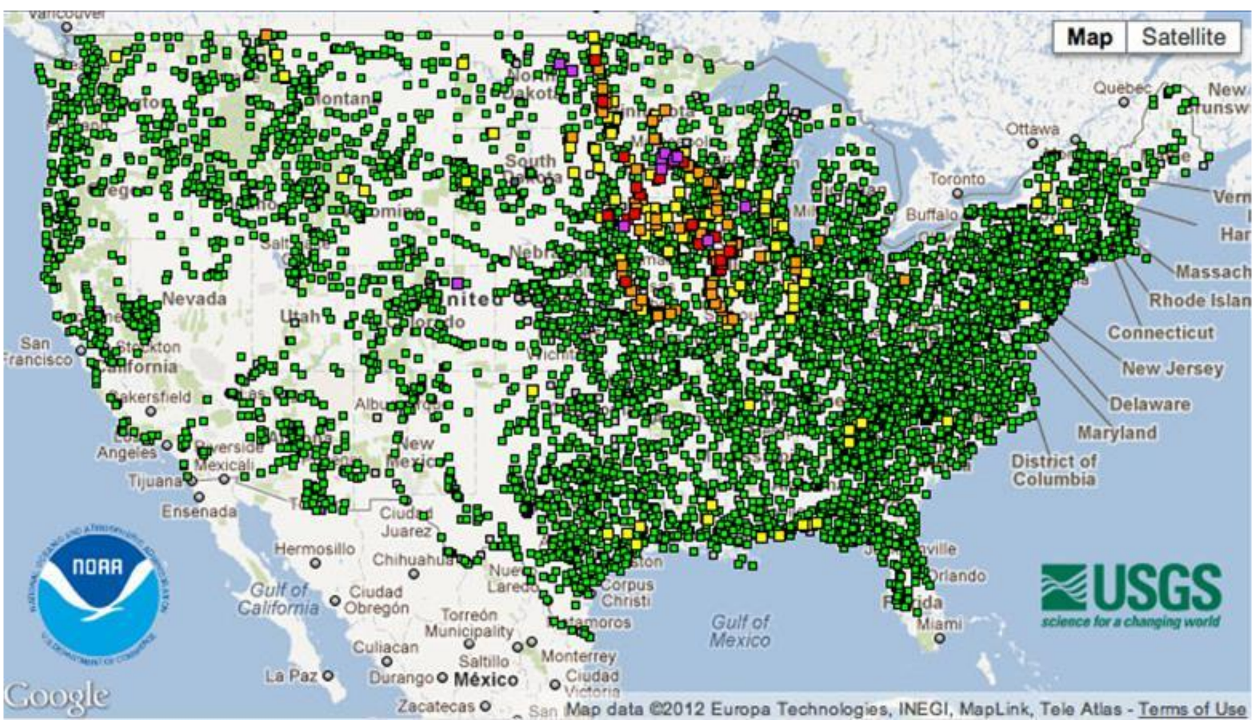
Floods can be caused by one or more of the following events:

1. Sudden or sustained rainfall into areas where the ground is already saturated, or there is insufficient drainage.
2. Melting of winter snow accumulated in northern regions. This may be intensified if accompanied by warm rain.
3. Sudden or slow raised water levels on a river or in a valley.
4. Failure of a water control device such as a dam or levee.
5. Coastal flooding associated with a tsunami, hurricane, tropical cyclone, or storm surge.

B. Measuring and Monitoring a Flood

Flood levels are monitored by NOAA's National Weather Service through a series of 6,401 gauges which monitor water level streams and lakes (Figure 40).

Figure 40: National Weather Service Flood Monitor Gauges[58]



Source: NWS

On any given date, the map shows insignificant and moderate flooding in the Midwest (orange and red squares, and major flooding (purple squares) in Minnesota and North Dakota. The rest of the gauges, shown in green, indicate no flooding was detected in the monitored areas.

The NWS has three categories for measuring high water:

1. **Bankfull Stage:** the height above which a rise in water level will cause the river or stream to overflow the lowest natural stream bank somewhere in the corresponding reach.
2. **Action Stage:** the stage at which the NWS or a partner needs to take mitigating action in preparation for possible significant hydrologic activity.
3. **Flood Stage:** the height above which a rise in water level begins to create a hazard to life, property, or commerce. Flood advisories and warnings are issued at this stage.

The NWS has three categories for measuring floods:

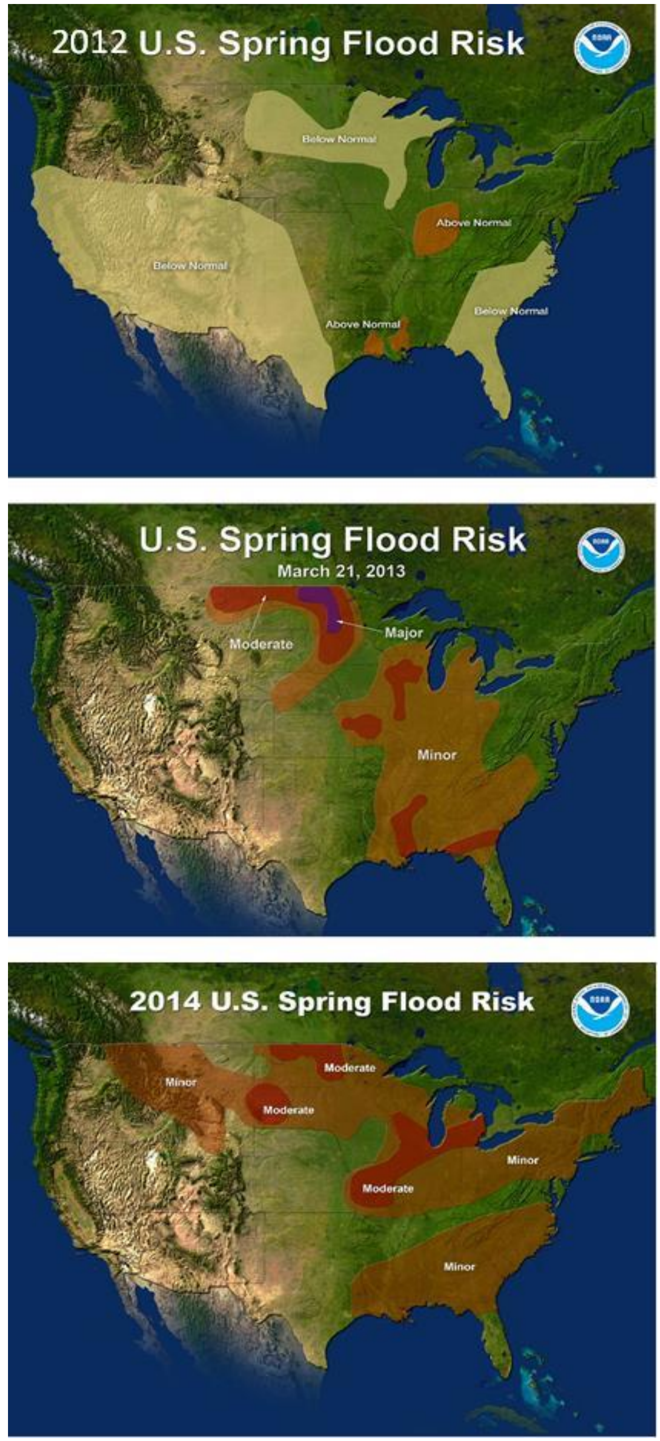
4. **Minor Flooding:** has minimal or no property damage but may pose a public threat. Flood conditions in this category include water overflowing banks and roads, and property in the lowest parts of town may be cutoff or experience water in the crawlspaces or home.
5. **Moderate Flooding**: has inundation of structures and roads near the stream, river, or bank. A moderate flood may require evacuation and/or transfer of property to higher ground. Flood conditions may include flooded buildings, infrastructure rendered temporarily useless or cutoff, water over roads deep enough to make driving unsafe, and general disruption of normal life.
6. **Major Flooding**: has extensive inundation of structures and roads and requires significant evacuation and/or transfer of property to higher ground. Flood conditions include the flooding and damage of significant numbers of structures, infrastructure destroyed or left unusable for an extensive period of time, erosion problems, flooding of airstrips, fuel tanks, and generators, loss of transportation access, communication, and power, and fuel tanks may float and spill and possibly be carried downstream.

C. Flooding in the United States

NOAA provides regular forecasts which identify the regions of the United States which are at risk of flooding. These regions change on a monthly and annual basis. In 2012, no area faced a high risk of major or record level spring flooding because of limited snowfall during the previous winter. That contrasts dramatically with the 2013 situation. In that spring, the potential existed for major flooding along the state line between eastern North Dakota and northwest Minnesota and along the Souris River in North Dakota. There were also elevated risks for flooding along the middle Mississippi, lower Missouri, and Ohio River basins. In 2014, rivers in half of the continental United States faced minor or moderate risks. The highest threats were in the southern Great Lakes region (Figure 41). Over the past decade several major floods have damaged the U.S. energy infrastructure.

D. Types of Damages

Figure 41: Changing Spring Flood Risk (2012 – 2014)



Source: NOAA

Flooding damage can be described under the following categories:

- Water damage.
- Damage to industrial structures.
- Damage to or disruption of electrical systems and power generation.
- Displacement of structures such as crude oil and product tanks.
- Supply interruption.
- Impact damage from debris or other things washed away by the flood.
- Loss of life.
- Erosion of soil affecting cropland or exposing buried pipelines and other infrastructure.
- Temporary or permanent diversion of natural water sources or rivers.
- Crop damage.
- Spills of products, crude oil, and other hazardous materials.

E. Threats to Oil and Gas TS&D

These types of damage can impact all components of the oil and gas transmission and distribution infrastructure. Depending upon the intensity of the flood and the location of the infrastructure on the floodplain, damage can be severe and longstanding.

As shown in past floods, damage to tanks and other industrial structures can be caused by the flooding and by impact with debris. Floods associated with Hurricanes are discussed in Hurricane section.

F. Historical Events

Colorado Floods, September 2013

Starting on September 9, 2013, portions of Colorado experienced a "100 year flood" caused by more than 15 inches of rain over eight days. The city of Boulder and surrounding areas were struck by walls of water nearly 20 feet tall. More than 20,000 homes, 50 bridges, and 500 miles of road, were damaged or destroyed by the flooding.[59] Ten people died. Before the water levels rose, more than 1,900 oil and gas wells were shut down by operators. 18,750 barrels of crude oil and 36 MMcf of daily natural gas production were lost; respectively 11.75% and 0.8% of Colorado's normal oil and gas production.

Crude holding tanks were damaged and contents spilled when their foundations were washed out by the flood. Pipelines were unearthed and damaged by debris. As a result, 15 crude oil releases occurred totaling 43,134 gallons (1,027 Bbl). There were 17 releases of produced water totaling 26,385 gallons (628.2 Bbl). Effects on production stretched more than 10 days; as of September 19th, only 300 had resumed production. The rest were awaiting inspection before restarting operations.

Mississippi River Floods, 2011

The Mississippi River flooded in April and May of 2011. This was one of the largest and most damaging floods along the U.S. waterways in the last century. The flood was a result of melting a snowpack nearly double the average thickness and record setting rains along the Ohio River and Mississippi River Systems.[60] In some locations nearly 20 inches of rain fell. The flood breached levees in Missouri, Arkansas, Mississippi, and Tennessee and resulted in thousands of evacuations.

The flood was a serious threat to the cities of New Orleans and Baton Rouge as well as ten refineries located along the Mississippi River. Those refineries were:[61]

- Alon USA, Krotz Springs, LA
- Chalmette Refining, Chalmette, LA
- ConocoPhillips, Belle Chasse, LA
- Exxon Mobil, Baton Rouge, LA
- Marathon Oil, Garyville, LA
- Motiva, Convent, LA
- Motiva, Norco, LA
- Murphy Oil, Meraux, LA
- Valero Energy, Memphis, TN
- Valero Energy, St. Charles, LA

The combined capacity of these refineries was 2.4 MMBbl/d. In addition, nearly 20 percent of the barge terminals monitored by the Coast Guard along the Ohio River were closed. Restrictions on barges traveling the Mississippi river were put in place: maximum length of 600 feet, minimum of 250 horsepower, speed of 3 miles per hour, and prior notification before starting navigation. The Smithland Lock and Dam was closed for navigation. Flooding in Tennessee resulted in reduced runs, to between 80 and 85%, at the Valero Memphis refinery. The refinery was unable to get crude in and products out of the facility because of high water and disrupted barge transit.

As a result of this threat, the U.S. Army Corps of Engineers (USACE) opened the Morganza Floodway to divert water to the Atchafalaya River Basin in Louisiana. More than 4,600 square miles were flooded in order to alleviate pressure on downstream levees and prevent flooding at Baton Rouge and New Orleans. Opening the floodway disrupted supply to Alon Krotz Springs refinery. The refinery operated at reduced levels and/or shut down for several days. Up to 169 wells were shut in between May 16 and July 27 resulting in the loss of 113,589 barrels of cumulative crude oil production. No fuel shortage was reported for this flood.

G. Likely Impact on TS&D Infrastructure

Looking at the historical U.S. floods, the impact can range from the very minor – flood damage to houses along the river bank or coast – to the devastating – destruction of large sections of housing, infrastructure, and hundreds of deaths. Key determining factors are the amount of rain, the ground saturation, the natural or artificial drainage of the site, the elevation, and the proximity to the flood site. Impacts of flooding on oil and gas infrastructure, from most likely to least likely, may include:

- Flooding.
- Inundation of industrial structures.
- Production loss from shut in wells and pipelines results in reduced runs at connected refineries and natural gas plants. Crude oil and natural gas leaks are possible.
- Very high river level and lock closure leading to barge traffic disruption and the inability to transport crude and products.
- Erosion could undermine storage tanks and expose pipelines leaving them vulnerable to deformation, breakage, debris impact, and spills.
- Evacuation of personnel for an extended period of time prior, during, and after the flood.
- Power loss.
- Flood damage to electrical generation and transmission systems.
- Damage to roads, bridges, tracks, and other transportation infrastructure.
- Inundation of farms and loss of crops; feedstock availability for local renewable fuel production.
- Diversion of waterways and damage to harbors.

Flooding is a widespread problem but has relatively low impact on oil and gas infrastructure (Table 28).

Table 28: Probabilty and Severity of Flood Damage to Infrastructure

Infrastructure	Probability of Damage	Severity of Damage
Loss of Electrical Power	Low-Med	Interrupting
Offshore Platforms	Low	Insignificant
Onshore Wells	Low-Med	Interrupting
Pumping/Compressor Stations	Low	Insignificant
Pipelines	Low	Insignificant
Rail	Low	Insignificant
Ports	Low	Insignificant
Crude Tank Farm	Low	Insignificant
Refineries	Low-Med	Interrupting
Natural Gas Plants	Low-Med	Interrupting
Product Storage	Low	Insignificant
Propane Tanks	Low	Insignificant
Underground Storage	Low	Insignificant
LNG Terminals	Low	Insignificant
Local Natural Gas Distribution	Low	Insignificant
Filling Stations	Low	Insignificant
SPR/NEHOR	Low	Insignificant

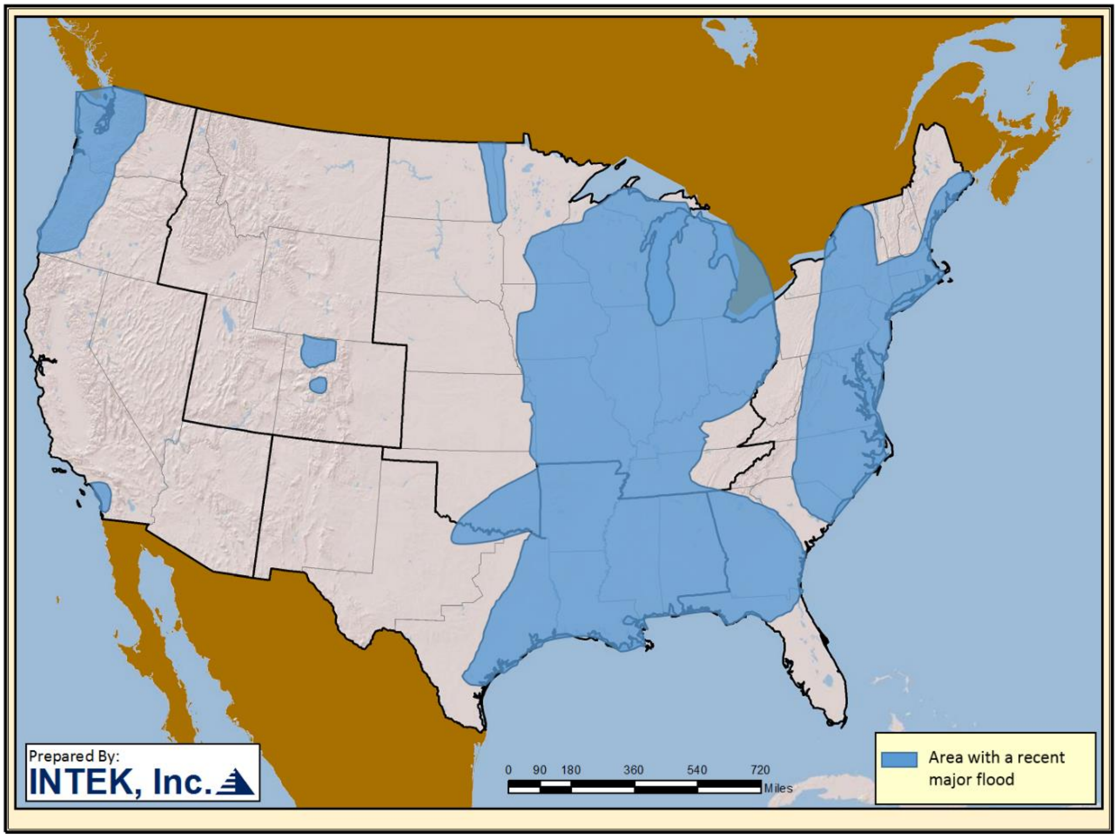
H. Hazard Areas

Since 2001, there have been more than 20 significant floods in the United States, located in the Northwest, along the East Coast, in Colorado and North Dakota, in Alaska and Hawaii, and throughout the Midwest from Minnesota to the Gulf Coast. Of them, eight were in the Midwest (Figure 42). While floods may be widespread, the damage to industry is localized and does not disrupt national supply.

1. Anacortes and Olympia, Washington

- **Refineries:** 4
- **Total refining capacity:** 591 MBbl/d
- **Imported crude:** 221 MBbl/d
- **Petroleum terminals:** 2
- **Crude pipelines:** Transmountain
- **Ports:** Anacortes Anchorage
- **Gas pipelines:** Northwest

Figure 42: Major U.S. Floods (2001 – 2013)



2. Los Angeles, California

- **Refineries:** 9
- **Total refining capacity:** 1,085 MBbl/d
- **Imported crude:** 481 MBbl/d
- **Petroleum terminals:** 27
- **Crude pipelines:** Plains All American, ExxonMobil West
- **Ports:** Port of Los Angeles
- **Product pipelines:** Kinder Morgan SFPP Southern and CALNEV
- **Natural gas plants:** 6
- **Gas processing capacity:** 13 MMcf/d
- **Underground gas storage:** 3 sites
- **Gas pipelines:** SoCal Gas

3. Midwest

- **Refineries:** 18
- **Total refining capacity:** 2,719 MBbl/d
- **Imported crude:** 1,508 MBbl/D
- **Petroleum Terminals:** greater than 300

- **Crude pipelines:** Shell, ExxonMobil, TransCanada, and others
- **Ports:** Along the Ohio, Mississippi, and Illinois Rivers
- **Product pipelines:** Explorer, TEPPCO
- **Natural gas plants:** 41
- **Underground gas storage:** 206
- **Gas pipelines:** ANR, NGPL, Viking Gas Transmission, Great Lakes Gas Transmission
- **Biodiesel plants:** 36
- **Ethanol plants:** 72

4. Gulf Coast

- **Refineries:** 40
- **Total refining capacity:** 8,208 MBbl/d
- **Imported crude:** 3,881 MBbl/d
- **Petroleum terminals:** 181
- **Crude pipeline:** ExxonMobil North Louisiana System, Capline, Ho-Ho, Amdel, and others
- **Ports:** Along the Mississippi River, Corpus Christi, along the Atchafalaya River
- **Underground gas storage:** 50
- **Gas pipeline:** ANR, Florida Gas Transmission, Transco, Columbia Gulf, Tennessee Gas Pipeline, Texas Eastern Transmission
- **Ethanol plants:** 3
- **Biodiesel plants:** 22

5. East Coast

- **Refineries:** 6
- **Total refining capacity:** 1,170 MBbl/d
- **Imported crude:** 701 MBbl/d
- **Petroleum terminals:** 233
- **Ports:** New York Harbor, along the Delaware River
- **Underground gas storage:** 3
- **Gas pipeline:** Algonquin, Texas Eastern Transmission, Transco, Maritimes and Northeast

I. Measures Taken by Industry to Address Vulnerability

Flooding is a widespread and common threat to the United States. As a result, industry, state governments, and the federal government have extensive experience and available tools for controlling and diverting flood waters. These tools include the system of levees, inflatable barriers, and sandbags. The most important tool is the regular monitoring and warnings provided by the National Weather Service. The NWS monitors snowpack and weather conditions in order to provide regular forecasts of flooding threats. The combination of flood experience and early warning, while not reducing the probability of a flood event, works to reduce the extent of damage to the oil and gas infrastructure.

XI. Severe Winter Weather

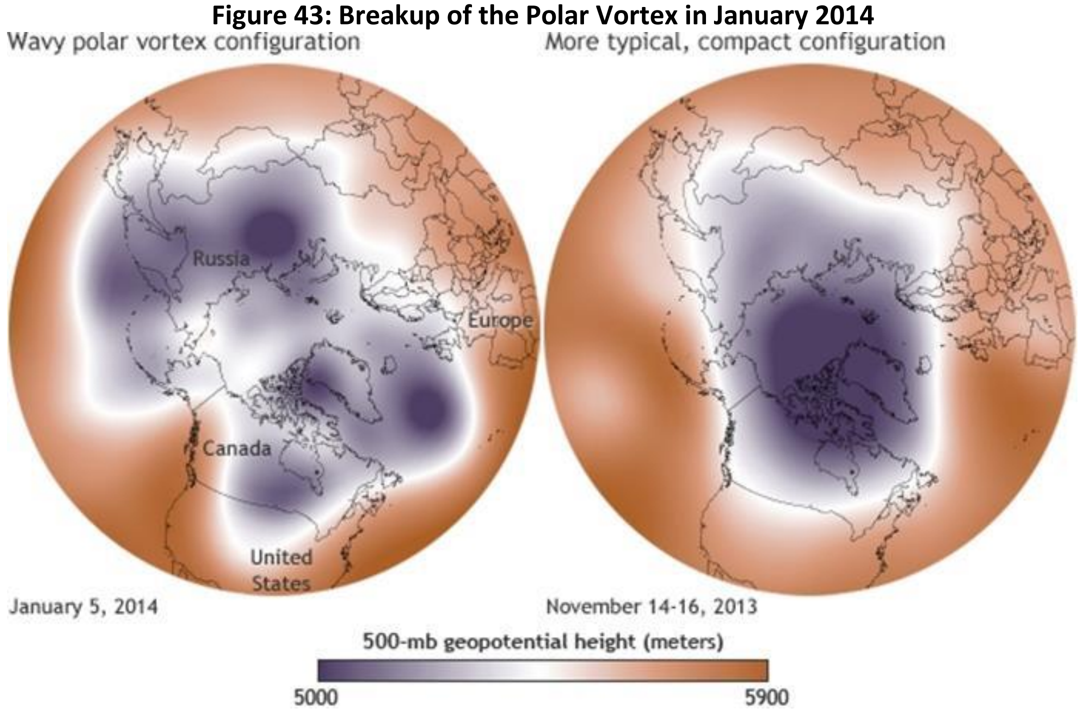
A. Introduction

Like heat waves, extreme cold weather can hit anywhere in the country and cause extensive damage and loss of life. Severe winter weather can include several phenomena such as blizzards, ice storms, cold waves, and global meteorological shifts like a breakdown of a polar vortex. Cold weather may also have significant impacts even if not extreme, if the regions affected are not used to experiencing such weather.

Unusual cold waves may occur in the United States in a couple of ways which involve the disruption of normal winter weather patterns. Generally, cold air from Canada moves across the northern part of the United States from west to east as warm Pacific air is pushed up over the Rocky Mountains and then back down towards the Great Lakes Region before moving out over the Atlantic. This path is largely dictated by the jet stream which stretches around the northern arc of the globe and separates the warmer air from the cooler air. The jet stream also both marks the boundary and contains the polar vortex, a cyclonic mass of cold air that forms during the winter months in the Arctic.

The first way a massive cold wave can hit deep within the United States is when the polar vortex weakens and allows the cold air contained within to drift south. The vortex may weaken either through the jet stream becoming more irregular or through what's called a Sudden Stratospheric Warming event. During this event, the circulation keeping the cold air in place slows to the point that it can no longer contain it and it spills south (Figure 43).

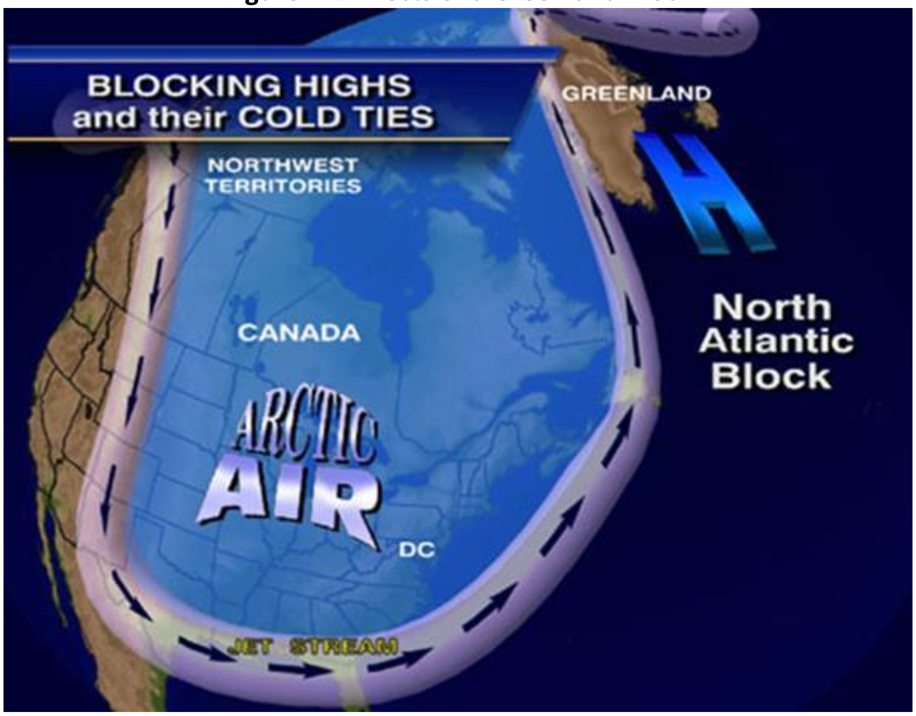
Figure 43: Breakup of the Polar Vortex in January 2014



Source: NOAA, Climate.gov

The second cause of cold waves is when a high pressure system forms over Greenland known as the "Greenland Block." This pressure system essentially pinches the jet stream and forces cold air further down into the United States (Figure 44). Events like this can keep cold temperatures in an area for prolonged times and may be exacerbated by another high pressure area off the Pacific coast.

Figure 44: Effects of a Greenland Block



Source: Washington Post

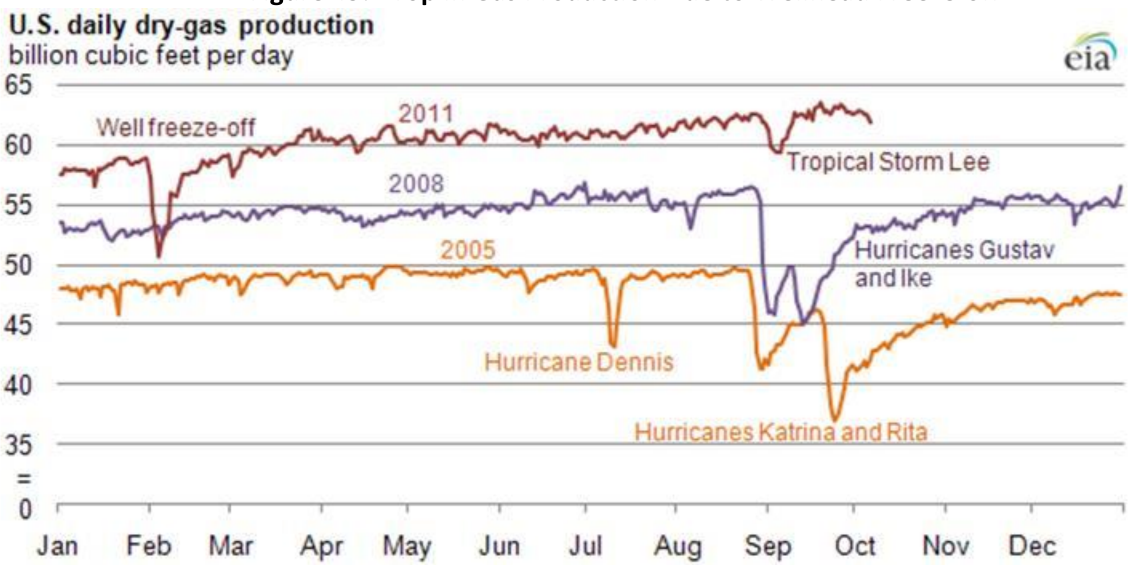
B. Threats to Oil and Gas TS&D Infrastructure

Cold waves can have several impacts on the fuels supply infrastructure ranging from equipment malfunction to transportation disruption. As with most natural disasters, power loss remains one of the primary disrupting factors. Ice storms and blizzards can easily take down power lines and trees while the road conditions make it more difficult for power to be restored. Power plants and generators also experience equipment failures which put further stress on the electricity grid and can lead to rolling blackouts. In addition, in extreme cold, people also use much more electricity and other sources for heating, creating possible supply issues.

Oil and gas production can be hampered from the extraction stage, particularly in areas not used to or prepared for cold weather. Drilling occurs all over the world, from the Arctic to the Equator and therefore requires different approaches for different climates. Wells in the Permian Basin have equipment to deal with extreme heat while drilling teams at Prudhoe Bay, Alaska maintain equipment to prevent constant freezing. Therefore, when cold temperatures and weather move into an area like the Permian Basin they can cause serious disruptions.

Trucking service to wells deliver water and provide support, but could halt under winter conditions such as snow or ice, thereby stopping production. Gas wells are especially susceptible to freezing temperatures due to wellhead freeze-off which occurs as water coming out of the well freezes at the wellhead and shuts production. These freeze-offs can disrupt supply as much as major hurricanes (Figure 45) Freezing temperatures can also cause pipelines connecting wells to storage tanks to freeze. Compounding the problems are hazards to workers who require longer and more frequent breaks to avoid frostbite and decrease the risk of accidents.

Figure 45: Drop in Gas Production Due to Wellhead Freeze-off



Source: EIA

Freezing temperatures create similar problems at crude and product terminals. Products and additives may jelly under cold temperatures, pipelines can freeze, and instruments will malfunction. Transportation is also severely restricted. Ice floes on rivers and ports can disrupt or altogether halt barge and tanker traffic, trucks face restricted access to roads, and railways may have problems with cracks in the tracks or switch malfunctions.

With myriad possibilities for supply disruptions, refineries and processing plants may face reduced runs while waiting for deliveries of crude or gas. The plants may also face problems related to equipment malfunctioning and pipelines freezing. Biofuel plants can also face a lack of feedstock during the summer and fall if a late freeze in spring destroys crops.

C. Historical Events

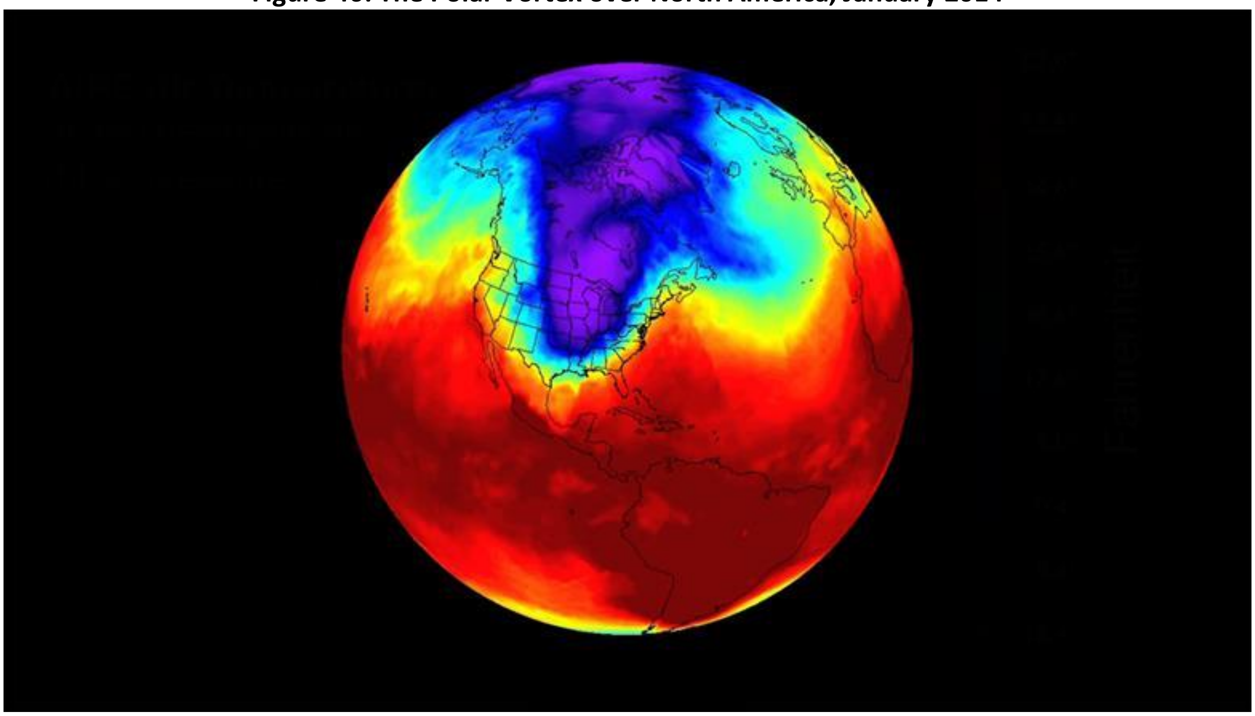
Some area of the country is affected every year by cold waves and extreme temperatures, yet the real threat is posed by widespread cold that transcends regions and persists for weeks. There is some evidence that these massive cold waves are becoming less frequent, occurring every couple years in the 19th century and every five to ten years before 1996.[62] While there have been polar vortex events covering most of the country in the past, they occurred too far back for a relevant analysis – one was in

1899 and another in 1985. A notable drop in gas production occurred in 2011 due to wellhead freeze-off across the Southwest. The estimated peak supply disruption was 7.5 Bcf/d, yet the cold wave's effects remained mostly regional. The most recent polar vortex cold wave occurred over the winter of 2013-2014, beginning in December and lasting into late March.

Winter 2013-2014 Polar Vortex

In December 2013 the polar vortex weakened and allowed a large mass of Arctic air to drift south into the Midwest, Southeast, and East Coast of the United States (Figure 46). Outside of the country, the vortex also spilled into Russia and Central Asia. The frigid air brought ice and snow storms that caused emergency situations throughout the southeast which was not prepared for or familiar with winter weather. Around 800,000 homes lost power throughout the affected regions.

Figure 46: The Polar Vortex over North America, January 2014



Source: NASA

The storms and freezing temperatures had a number of impacts on fuels supply infrastructure. Wellhead freeze-off occurred across the Permian Basin with estimates of around 25-30 Bcf lost production in December. Freeze-off losses continued into February, but there is some indication that the loss was not as severe as thought at the time.[63] Oil production also took a hit during the cold wave. Bakken production declined for the first time in a year by 53 MBbl/d after wells lost truck service and experienced problems with water freezing.[64]

Outside of supply interruption, midstream infrastructure was also impacted by the cold. Fuel terminals closed temporarily as pipelines, particularly those used to blend ethanol, froze. Products thickened and jellied under freezing conditions. There were equipment failures ranging from instrument malfunction, to one case of ice blockage causing a compressor valve to blow and release 72 Mcf of natural gas into the air. Natural gas pipeline operators in Alabama, Georgia, Pennsylvania, Illinois, and Utah all declared force majeure. The Colonial Pipeline was on reduced capacity temporarily due to power failures. Other transportation issues included problems along railways in the Midwest and disruptions in New York Harbor because of snow and ice.

Refineries in the Midwest and East Coast were on reduced runs due to instrument malfunction. The total capacity of all refineries affected was 800 MBbl/d but it is unclear exactly how much production was lost.[65]

Northeast Supply Problems

Perhaps the biggest problem caused and largest vulnerability exposed by the cold wave was within the Northeast natural gas and propane market. Natural gas withdrawals were at a record high with nearly 68 Bcf being withdrawn on January 7th alone to meet heating and electricity demands.[66] However, there were problems transferring the gas to Northeast and New England markets due to constrained pipelines. This lack of product caused prices to spike in the New York. Interdependence with the power system also caused problems as New England is increasingly reliant on natural gas for electricity, which provides over 50% of generation. As natural gas deliveries lagged, the states turned to importing electricity generated by other sources to make up for the loss, such as nuclear power which was able to generate power better thanks to the cold.[67]

The lack of propane also created problems. New England consumes about 6% of propane sales in the winter yet only has two storage sites that contain less than 1% of the nationwide propane stock. The Northeast’s propane problems were also impacted by a rainy summer which drove up demand for propane in the Midwest where it is used for crop drying. Maine was particularly hard hit as it had shifted from getting propane through the Newington, RI storage site to receiving shipments by rail through Canada. The most direct route through Canada took Maine’s propane through Lac-Megantic, Quebec, the site of a derailment and explosion which killed 47 people in July 2013. Since then the town has banned all hazardous substances transiting by rail thereby cutting off or severely delaying Maine’s propane supply.

Because of these factors, New England began receiving imports of propane from Norway during the cold wave in January 2014.

D. Likely Impacts on Infrastructure

Extreme cold has a variety of impacts on infrastructure both because of winter weather conditions like snow and ice, and also because of equipment being exposed to temperatures they were not designed to withstand. Therefore, the degree of damage and disruption done largely depends on how long a cold wave lasts. Sub-zero temperatures arriving overnight and leaving the next morning are unlikely to cause any disruptions, even in tropical locations, yet a week of prolonged cold can cause equipment to freeze and nearly halt all activity in places used to warm climates.

Because cold weather is somewhat relative to a region's normal climate, the extent to which a polar vortex spills south also matters in assessing impact. While freezing temperatures can shut down gas wells in the Permian Basin, wells in the Bakken are less likely to see a disruption because they expect cold weather and design their equipment accordingly or take pre-emptive steps, like building sheds around their wellheads.

In 1899, a disruption in the polar vortex caused snowstorms along the Gulf Coast and in Central Florida and ice floes in the Gulf of Mexico by route of the Mississippi. An event of this magnitude would have severe consequences simply because the places affected would be wholly unprepared, even while causing less disruptions in areas facing colder temperatures and worse weather effects.

Because of the difference in regions, the impacts below will be listed in order of most likely to occur to least likely to occur by the region affected by the cold wave.

Northern States

- Power outages caused by ice and snow.
- Limited road access due to ice and downed trees.
- Drilling disruptions due to lack of access or use of thawing equipment.
- Rail traffic disrupted due to cracked rails and equipment malfunctions.
- Waterways and ports obstructed by ice or extreme fog.
- Lack of natural gas and propane supplies.
- Smaller, localized pipelines freezing.
- Equipment malfunctions at refineries, pumping stations, compressor stations, and storage facilities.
- Power outages due to power plants going offline due to equipment malfunction.
- Crop damage due to late freezes.

Southern States

- Region-wide power outages caused by ice and snow.
- Extremely limited road and rail access.
- Wells shut due to wellhead freeze-off and pipelines freezing.
- Waterways and ports obstructed by ice or extreme fog.
- Equipment malfunctions at refineries, pumping stations, compressor stations, and storage facilities.
- Power outages due to power plants going offline due to equipment malfunction.
- Major pipelines shut due to loss of power.

Table 29 outlines the probabilities and severities of these types of impacts on the infrastructure. As with to heat waves, cold waves should be considered not just by damage caused but also by possible supply interruptions or other disruptions i.e. obstructed waterways or feedstock disruption.

Also, as shifts in a polar vortex often become more or less severe depending on the region affected, both northern and southern affects will be outlined. Southern states are less likely to be affected and experience cold waves in general and when they do will experience them for shorter times. These considerations will also be factored into each assessment.

Table 29: Probability and Severity of Cold Wave Damage to Infrastructure

Infrastructure	Northern Region		Southern Region	
	Probability of Damage	Severity of Damage	Probability of Damage	Severity of Damage
Loss of Electrical Power	Low-Med	Interrupting	Low-Med	Interrupting
Offshore Platforms	Low-Med	Interrupting	Low-Med	Interrupting
Onshore Wells	Low-Med	Interrupting	Low-Med	Interrupting
Pumping/Compressor Stations	Low-Med	Interrupting	Low	Insignificant
Pipelines	Low	Insignificant	Low	Insignificant
Rail	Low	Insignificant	Low	Insignificant
Ports	Low	Insignificant	Low	Insignificant
Crude Tank Farm	Low	Insignificant	Low	Insignificant
Refineries	Low	Insignificant	Low	Insignificant
Natural Gas Plants	Low-Med	Interrupting	Low	Insignificant
Product Storage	Low	Insignificant	Low	Insignificant
Propane Tanks	Low-Med	Interrupting	Low	Insignificant
Underground Storage	Low	Insignificant	Low	Insignificant
LNG Terminals	Low	Insignificant	Low	Insignificant
Local Natural Gas Distribution	Low-Med	Interrupting	Low	Insignificant
Filling Stations	Low	Insignificant	Low	Insignificant
SPR/NEHOR	Low	Insignificant	Low	Insignificant

E. Hazard Areas

Severe cold and winter weather can affect almost anywhere in the country, yet is extremely rare in places like Florida and the Southwest. Cold waves caused by polar vortexes are more limited as disruptions in the northern jet stream tend to shift in fairly consistent patterns. These disruptions cause arctic air to spill into the Eastern half of the country, affecting most of PADDs I and II. PADD III GCLA and the eastern parts of PADD IV might also be affected if the shift is severe. These PADDs contain 11.4 Bcf/d gas processing capacity and 5.1 MMBbl/d refinery capacity, accounting for 17.6% and 28% of national production capacity respectively. While extreme winter weather is unlikely to damage plants to cause shutdowns, they can cause reduced runs which may add up if a large area is affected for a long time. Fuel supply disruptions are also more likely to be felt with natural gas rather than gasoline. People rely on natural gas for heating whereas gasoline demand may decrease with widespread limited road access.

F. Measures Taken by Industry to Address Vulnerability

There are several potential solutions that can mitigate the impacts of polar vortex events on fuel supply. Some of these, like stationing the same kind of equipment used in cold weather in warm weather regions, are too costly and unnecessarily cumbersome. Others, like better management and preparation under the threat of winter weather are nearly self-evident. Instead, the focus should be primarily on supply problems faced by the Northeast. While the unusually harsh winter of 2013-2014 exposed this supply vulnerability, problems could persist even under normal winter conditions if supply remains lower than demand and the region continues to rely on just-in-time deliveries.

There are two ways to accomplish this. First is to increase natural gas and propane storage in the Northeast. With more stocks, supply can be easily transferred to power plants and other customers without fear of depletion and price spikes. Second would be to increase pipeline capacity to meet demand during winter. This second idea appears more palatable for the industry which both wants greater infrastructure development in the nearby Marcellus shale play, and the flexibility to both meet demand and continue to increase exports.

Furthermore, any fuel resiliency solution should take into account predictions of future polar vortex events. Climatologists have theorized that cold waves in the United States are becoming less and less frequent. If these events will only occur once every decade or so then solutions that focus on resiliency and flexibility would be better suited than any one that focuses on hardening the infrastructure.

XII. Regional Vulnerability Characteristics

Most natural disasters discussed above are regionally-specific and only threaten one area of the country. Hurricanes rarely threaten anywhere outside the Gulf Coast and Atlantic seaboard, earthquakes with any destructive strength rarely occur far from the Pacific Coast, and high-intensity tornadoes are much more frequent in a couple areas in the Midwest and Southeast. Meanwhile, floods, wildfires, extreme heat and extreme cold can threaten nearly all parts of the country, even if some areas are more prone than others. This section will step back and examine threats faced by each sub-PADD in preparation for an assessment of regional fuel resiliency. Table 30 summarizes the information below by assigning a risk level for each natural disaster to each region.

A. PADD I (East Coast)

PADD I has been relatively free of catastrophic natural disasters. The East Coast is not threatened by earthquakes or tsunamis, does not experience high-intensity tornadoes with any frequency of concern, and has low-intensity wildfires that occur away from populated areas. However, given the geographic diversity of the PADD, some areas experience considerably greater threat from certain events than others.

Sub-PADD IA (New England)

While New England is technically threatened by hurricanes, the cyclones rarely make landfall as hurricanes, but rather as tropical or extratropical storms or depressions, all of which are generally much weaker. Only two hurricane-strength storms have made landfall in PADD IA in the past 30 years, yet one notable Category 3 hurricane occurred in 1938 causing massive death and destruction. New England is also relatively free from the threats posed by earthquakes and tsunamis. Maine will occasionally see smaller earthquakes, yet the more populous southern New England area has not experienced a major earthquake since 1755.

The Sub-PADD is also under little threat from most other extreme weather events. Tornadoes and massive wildfires are exceedingly rare and derechos normally only affect the southern New England every several years. The main threat to PADD IA comes from severe winter weather. Even while the 2013-14 Polar Vortex event didn't directly impact New England, the region suffered through extreme cold during the course of a normal winter. Rather the extreme cold in other parts of the country created increases in demand that decreased supplies to New England. Therefore, while New England is prepared for the normal and likely event of severe winter weather, they are dependent on supplies from other parts of the country that might not be prepared for such weather.

Sub-PADD IB (Mid-Atlantic)

The disaster profile of the Mid-Atlantic states is much more diverse than New England. The region experiences extreme cold, extreme heat, derechos, and occasionally hurricanes. In 2012, a derecho caused widespread power outages throughout the region during the summer while “Superstorm” Sandy devastated the New Jersey coast and New York Harbor area in the fall.

However, while PADD IB faces diverse risks, they are all moderated by the region’s central geography. Hurricanes rarely trace that far up the Atlantic Coast with considerable strength while heat waves are lessened quicker due to the region’s northern climate. Polar vortex events and derechos might affect the western regions of PADD IB, yet the coastal areas are regulated by the Gulf Stream.

Sub-PADD IC (Lower Atlantic)

While PADD IC faces threats from a variety of natural disasters, they are all overshadowed by the threat from hurricanes. Florida and North Carolina are most susceptible to hurricane damages and will often experience storm impacts only marginally felt in the northern areas of Virginia and West Virginia. However, due to the petroleum and gas pipelines running through the Southeast, hurricanes impacting the southern parts of PADD IC can have significant fuel impacts on the rest of the region.

South Carolina also has the potential for destructive seismic activity, making it an anomaly in that region of the country. The state has not experienced a major earthquake since 1886 and it is unclear to what extent another earthquake of that magnitude would affect the rest of the Sub-PADD.

The Carolinas also host their own tornado alley. It is the fourth most active tornado region in the United States and capable of producing high-intensity twisters, although the relatively sparse population and infrastructure in the area lessens their overall risk.

Less significant threats in the region include wildfires, floods, derechos, and extreme temperatures.

- Florida and Appalachia will regularly experience significant wildfires yet the regions receive rainfall year-round which minimize the damage and spread of the fires.
- The Lower Atlantic is still on the outer fringes of high-frequency derecho regions and are only occasionally threatened by the fast-moving thunderstorms.
- Extreme temperatures can cause significant disruptions, especially if a cold wave and winter weather strikes the area. Heat waves can also take a toll but are less likely to cause droughts in the region.

B. PADD II (Midwest)

PADD II covers a geographically large area of the country, yet is all inland and therefore immune to the major effects of hurricanes and tsunamis. However, as the PADD contains a large amount of infrastructure such as refineries, pipelines, large storage terminals, and one of the top-producing areas of the country, its natural disasters arguably pose a greater risk to the supply chain than those of PADD I.

Sub-PADD II EAST

II East is a geographically diverse Sub-PADD, containing the hilly Pennyroyal Plateau of Kentucky to the often-cool Great Lakes region of northern Michigan. Despite that diversity, the region is predominantly threatened by derechos and tornadoes. It is technically possible to for tsunami-like waves to strike along the shores of the Great Lakes, yet such instances are not common and significant changes in water height are incredibly rare. Hurricanes may also reach as far inland as Kentucky and Ohio, yet their strength greatly diminishes over land to the point where little threat remains.

Anywhere in the region can expect to experience a derecho about once a year, and possibly some large tornadoes as the Sub-PADD lies on the fringes of Tornado Alley. It was also one of the regions hardest hit by the polar vortex event in 2013-14, and while temperatures were far colder than normal, the area's common experience with cold weather left them relatively well-prepared.

Sub-PADD II NORTH

Sub-PADD II NORTH is the largest Sub-PADD discussed yet its threat profile is considerably less diverse than others'. Like Sub-PADD II EAST, II NORTH has a high risk for tornadoes, derechos, and severe winter weather. The region contains both Tornado Alley and Hoosier Alley. Combined with derechos, the area can expect intense, yet localized, damages.

The region also contains part of the New Madrid/Tennessee Valley earthquake zone capable of producing devastating earthquakes. However, there has not been a major earthquake in the area since 1812. If a similar event happened today it could destroy key pipelines from PADD III and disrupt all traffic on the Mississippi River.

Sub-PADD II WEST

Sub-PADD II WEST is one of the smallest Sub-PADDs, both geographically and in terms of population. It is a major E&P center due to the Bakken shale and has fairly low risk from all natural disasters outside of winter weather and tornadoes. Both of these events occur with enough frequency that the region is well-prepared to deal with most disruptions.

Sub-PADD II KS/OK

The Kansas/Oklahoma region sits at the geographic center of the country and serves as the infrastructural center of at least crude and propane systems. The crude pipeline and storage hub at Cushing, OK and the propane storage hub at Conway, KS are both key pieces of the fuels supply system. The biggest threat to both the Sub-PADD and its infrastructure is tornadoes which are intense and pass through the states with regular frequency. Derechos and winter weather can also cause disruptions although they are not as frequent.

C. PADD III (Gulf Coast)

PADD III comprises the greatest risks to the nation's oil and gas both due to the sheer volume of storage terminals, production centers, processing facilities, ports, and pipelines in the region and the high frequency and ferocity of natural disasters.

PADD III GCLA

Gulf Coast Louisiana and the surrounding territories face threats from natural disasters on all fronts. The area is prone to flooding, droughts, heat waves, and wildfires, yet these are of the least concern. The high-intensity tornado zone known as Dixie Alley sits atop Mississippi and Alabama while the New Madrid earthquake zone lies underneath a large portion of Arkansas. The area is prone to both Gulf Coast hurricanes and East Coast hurricanes that transit the Florida peninsula. In the past decade Louisiana has been ravaged by hurricanes multiple times, most notably by Katrina and Rita in 2005 which left large areas of the state underwater. Derechos are also quite frequent throughout the area, but especially in Arkansas where they occur a little over once a year on average.

PADD III GCTX

Gulf Coast Texas encounters much the same problems as Gulf Coast Louisiana. Hurricanes form the main threat, not just to the region, but also to the offshore production that feeds into systems in the Sub-PADD. Texas is slightly less threatened from tornadoes than the Mississippi region and earthquakes pose no risk, but the state is more threatened by drought.

PADD III WTX/NM

The Permian Basin region is sparsely populated yet contains a considerable amount of natural gas infrastructure. It faces similar risks as Gulf Coast Texas but with one major difference: hurricanes are much less of a threat. New Mexico gets hit by hurricanes from both the Gulf of Mexico and those coming up the west coast of Mexico, yet both generally dissipate enough over land to only produce heavy rains at worst. Still, New Mexico receives relatively little precipitation, these storms can cause severe flooding in their wake.

D. PADD IV (Rockies)

PADD IV covers a large geographic area yet is sparsely populated and contains little oil and gas infrastructure. The region is also relatively free of the worst kinds of natural disasters. It does not get impacted by hurricanes, is only moderately threatened by earthquakes in its western regions and sees very little tornado activity outside of some places in Colorado. Polar vortex events would mostly miss the region and possibly even result in above average temperatures. Heat waves, droughts, and wildfires pose risks, albeit rather limited. Droughts have little impact on fuels supply as the region is not a large corn producer, doesn't rely on waterways, and is not a major fracking center. Similarly, wildfires occur in isolated areas, although they have shut down production at the wellhead recently.

E. PADD V (West Coast)

Outside of PADD III, PADD V possibly faces the largest threats from natural disasters. The region is almost never affected by hurricanes, yet is by far the most at risk from earthquakes and tsunamis. Small earthquakes along the West Coast are frequent, and large ones can range anywhere from slightly disrupting to completely catastrophic. If a tsunami accompanies a large earthquake the resulting damage could devastate highly-populated areas along the coast. Southern California is also in the midst of a chronic drought which has only served to heighten the risk of wildfires throughout the state. Stresses on water and resources could easily create a national emergency if they coincide with a large earthquake. A low-probability high-cost event could spark a fuel crisis and severe supply shortages.

Table 30: Regional Risks of Natural Disasters

PADD/Sub-PADD		Disasters								
		Hurricanes	Earthquakes	Tsunamis	Tornadoes	Heat Waves /Droughts	Derechos	Wildfires	Floods	Winter Weather
I	A	Low	Low	Low	Low	Low	Low	Low	Low-Med	High
	B	Med	Low	Low	Low	Low-Med	Med	Low	Low-Med	Med-High
	C	High	Low-Med	Low	Low-Med	Med	Low-Med	Low-Med	Low-Med	Med
II	NORTH	N/A	Med	N/A	High	Low-Med	Med-High	Low	Med	High
	EAST	N/A	Low-Med	N/A	Med-High	Low-Med	Med-High	Low	Med	High
	WEST	N/A	Low	N/A	Med	Low-Med	Low-Med	Low-Med	Low	High
	KS/OK	N/A	Low	N/A	High	Low-Med	Med-High	Low-Med	Low	Med
III	GCLA	High	Low-Med	Low	High	Med-High	Med-High	Low-Med	Med	Low-Med
	GCTX	High	Low	Low	Med	Med-High	Med	Low	Med	Low-Med
	WTX/NM	Low-Med	Low	N/A	Med	Med-High	Low-Med	Low-Med	Low	Low-Med
IV		N/A	Med	N/A	Low	Med	Low	High	Low	Med
V		Low	High	Med	Low	High	Low	High	Low-Med	Low-Med

XIII. Physical Vulnerability of TS&D Infrastructure

A. Characterization of Physical and Human Threats

Physical and human caused threats and vulnerabilities may be of four general types, two of which may be characterized as intentional and two which may be considered unintentional:

- **Human Error and Accidents:** Damage may be caused to TS&D infrastructure by a variety of human errors or accidents. Examples of such causes include, but are not limited to transportation accidents, excavation, maintenance accidents, or misoperation of controls and equipment.

- **Equipment / System Failure:** Equipment or system failures may include pipeline breaks, pump or compressor failures, valve failures, electrical shorts, vessel breakdown, or other communications system failures.

- **Intentional Damage by Direct Means:** Direct means could include damaging the physical infrastructure by means of sabotage, vandalism, terrorist acts, incursion by hostile military force, or other deliberate attacks on the physical infrastructure

- **Intentional Disruption by Indirect Means:** Indirect means of TS&D disruption could involve politically or economically motivated disruptions of oil, refined product or natural gas inputs to the supply system. This could include an embargo exports to U.S. markets, blockage of shipping channels, or other means that effectively reduce supply.

This paper describes and characterizes the vulnerability of natural gas, crude oil and refined product transportation, storage, and distribution infrastructure to damage or disruption as a result of intentional human threats.

B. Characterization of Infrastructure Vulnerability

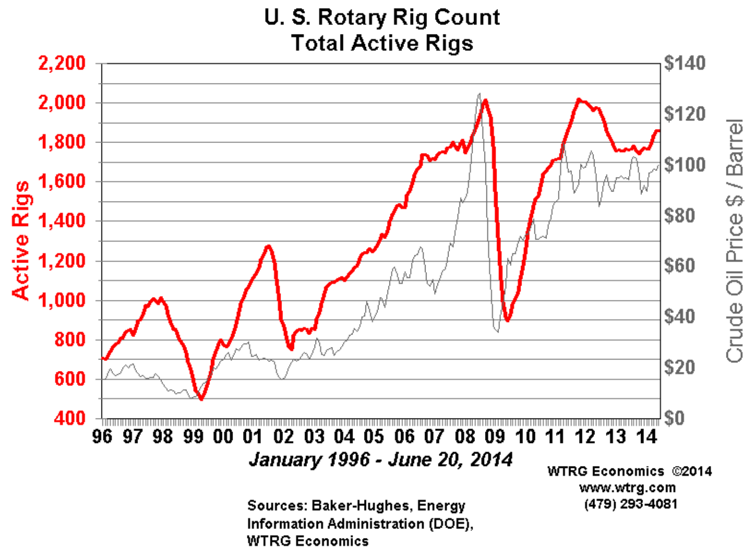
Risks to Oil and Refined Product Infrastructure

The exploration and production sector of the nation's fuels supply system is the focus of another part of EPSA's overall assessment. However, a brief description of its relative vulnerability to physical and human threats provides context for the discussion of the TS&D infrastructure vulnerability that follows.

The United States has hundreds of thousands of active oil and natural gas producing wells. These wells feed gathering systems that, in turn, transport crude oil and natural gas to storage facilities, gas processing, and oil refining facilities that produce a broad slate of fuels and products. Much of the infrastructure of oil and gas production wells is located subsurface, although surface wellheads, gathering systems, stock tanks, and controls and communications systems maybe vulnerable to physical damage. In addition to the producing wells themselves, exploration and production facilities include onshore drilling rigs, offshore drilling rigs and platforms, and a variety of storage facilities, gathering lines, and other supporting equipment and surface infrastructure.

As of June 20, 2014 there were 1,858 active rotary rigs drilling oil and gas wells in the United States. Of these, 1,545 or 83.2% of the rigs were drilling oil wells and 311 (16.7%) were drilling natural gas wells (Figure 47).

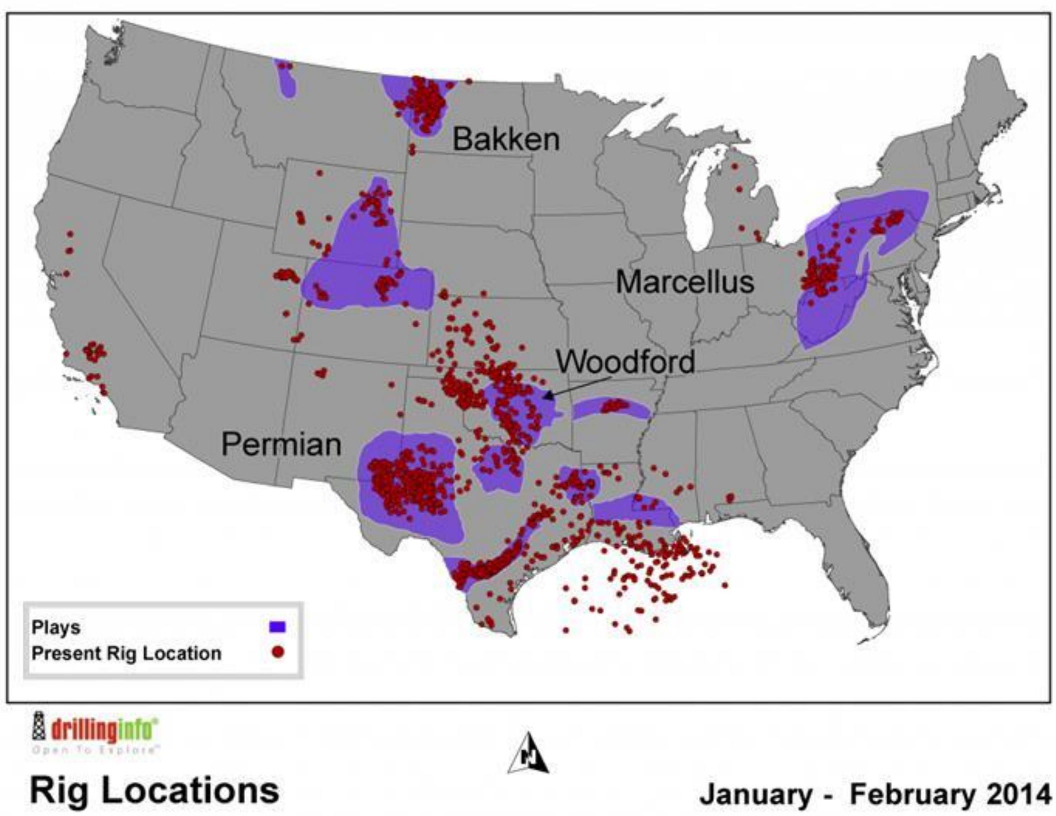
Figure 47: 2014 U.S. Rotary Rig Count



This drilling activity was distributed over 18 states. Fifty-seven of these active rigs (~3%) were deployed on offshore platforms or vessels in the Gulf of Mexico.

Tight oil and shale gas development continually requires a large number of new wells to maintain and increase total production volumes. Due to faster drilling times, improved efficiency, and reduced down-time for US rigs, that the number of active rigs has actually gone down over the last few years, even as production has increased.

Figure 48: Geographic Dispersion of Rotary Rigs



Source: Drillinginfo.com, 2014

The geographic dispersion of drilling operations over six major regions of the country and the large number of active rigs, significantly reduces the potential impact on supply that might be caused by the loss of a single drilling rig or platform to physical damage or destruction, regardless of cause (Figure 48).

The most vulnerable E&P facilities are found in the Gulf of Mexico, where rigs and wells operate from offshore platforms, some of which are unmanned and operated remotely and protected only by radar surveillance and marine or U.S. Coast Guard patrols. Many of the near shore platforms are located in shallow waters and have low production volumes. The much larger deepwater platforms typically operate multiple wells, have much greater oil and gas production levels, and are manned around the clock, including safety and security crews. Most of these larger deepwater offshore facilities represent capital investments measured in billions of dollars. Other offshore facilities vulnerable to damage include Floating Production and Storage Operations vessel (FPSOs) that receive and transport produced liquids from large offshore platforms to marine or coastal receipt points.

The disruption of a single onshore oil or gas production well or drilling rig will likely have minimal impact on overall oil or gas supply. However, the disruption of larger offshore production wells and platforms, if damaged by intentional acts, can reduce production and supply levels by tens of thousands of barrels per day of oil and billions of cubic feet of gas per day until the damage is repaired. Reduced flows of gas and oil to onshore pipelines, refineries, and gas processing plants, in turn reduces the supply of refined products and dry gas that are available to meet market and consumer demands.

Further, despite numerous and various environmental safeguards, the intentional damage of large, high-volume offshore production facilities can also result in extensive environmental damage, impacting coastal communities and economies, wildlife, and aquatic life.

TS&D Infrastructure Vulnerability

In the past 20 years several reports have looked at infrastructure vulnerability to physical threats. In October 1997, the President's Commission on Critical Infrastructure Protection[68] found that:

- The nation's largest refineries, those in California, Louisiana and Texas with capacities greater than 250,000 Bbl/d, might pose attractive targets for physical or cyber-attack.
- Above surface elements of gas and oil pipeline systems (such as river crossings, interconnects, valves, pumping stations and compression station) are vulnerable to damage by accident or attack.
- According to the Commission's report "threats to the US energy system arise from a number of sources, including hostile governments, terrorist groups, other organized groups of individuals, disgruntled employees, [and] malicious intruders…"

In June 2001, the National Petroleum Council characterized the vulnerability of the various components of the physical infrastructure of the nation's oil and gas industry to physical damage (by human means or natural disaster) in terms of the potential impact that the disruption of that component might have on energy supply, and consequently, economic activity and security (Table 31).

- **Low Vulnerability** refers to assets that, if damaged, could cause local disruptions of short durations.
- **Medium Vulnerability** refers to key assets that if damaged could cause disruptions that would have regional impacts of sufficient duration to cause hardship, economic loss, or injury or loss of life.
- **High Vulnerability** refers to critical assets that if damaged could have regional, national, or international impacts, and be of sufficient duration to cause major hardship, economic loss, or injury or loss of life.

Table 31: Oil and Refined Product Major System Vulnerability and Potential Impacts of Disruption

Infrastructure Component	Vulnerability to Intentional Damage or Disruption	NPC Impact on Supply, Economy, and Safety
Crude Oil Imports	Medium	High
SPR	Low	High
Crude Oil Pipelines	Low	High
Crude Oil Pumping Stations	Medium	High
Oil Storage Terminals and Hubs	Medium	High
Refineries	High	High
Refined Product Import Points (Ports)	Medium	Medium
Product Pipelines	Medium	High
Product Pipeline Interconnects	High	High
Refined Product Bulk Storage	Medium	High
Product Distribution (Rail, truck, Barge)	High	High
Fueling Stations	Medium	Low

Source: NPC, 2001

Due to the physical aspects, design, and locations of some elements of the oil and refined product infrastructure, some elements are more exposed and therefore more vulnerable to intentional damage or disruption than others.

Crude Oil Imports: Crude oil imports into the U.S. TS&D system are received via pipeline from Canada or by tanker ship from various locations in the western hemisphere, the Middle East and Europe.

The physical pipeline infrastructure from Canada is vulnerable at pumping stations and other points where the pipelines or supporting infrastructure are exposed. Subsurface pipelines are less vulnerable to damage, although open rights of way and markers make their locations readily identifiable. A single attack on one component of the pipeline infrastructure would not be catastrophic. However, coordinated attacks on multiple targets could have serious regional impacts.

Tanker ships may also be vulnerable to physical attack, hijacking and piracy, or interdiction by hostile entities. Offloading facilities, either offshore at facilities such as LOOP, or dedicated refinery marine terminals are also susceptible to intentional damage.

As the U.S. still relies on imports for some 40 percent of crude oil demand, the vulnerability and resiliency of oil import sources and infrastructure remains of critical importance.

Pumping Stations: Crude oil pumping stations are above surface facilities, located at approximately 50 mile intervals along a pipeline route. They typically employ electric powered pumps and controls. These facilities are susceptible to intentional damage and, if damaged, could disrupt the flow of crude oil to storage hubs or to refineries until operations are restored.

Crude Oil Storage: Major crude oil market hubs, such as the facilities located at Cushing, OK, Patoka, IL, and other sites, store and route large volumes of crude oil. These facilities are comprised of intake points, above ground storage tanks, and offtake points, with associated controls and infrastructure. Although well- guarded and secured, storage tanks and associated above-ground facilities are potentially vulnerable to attack and damage or destruction. The loss of a single tank would have relatively minimal short-term market, community, and economic impacts. The loss of multiple tanks or critical interconnection infrastructure, could have more significant impacts until the damage could be repaired.

Oil Refineries: Due their size and exposure, oil refineries can be susceptible to intentional damage inflicted from inside or outside the refinery gate. In some locations, where multiple refiners, or individual large refineries, are located near major public transportation corridors, refineries may be more susceptible to attack and damage from outside the facility as compared to those located in less concentrated numbers or more remote locations.

Intentional destructive acts are also possible from within the refinery, though refinery designs, safety and security systems, and facility controls make such acts difficult to achieve and provide for rapid response in the event an incident occurs. A potential solution to this vulnerability is to increase the perimeter around such facilities or otherwise obstruct physical and visual access to such facilities by various means.

Despite their vulnerabilities, oil refineries are very resilient to physical damage, whether caused by natural disaster, accident, or deliberate act. Large modern refineries are generally laid out in multiple process “trains”. So if a single train is damaged and becomes inoperable, the additional trains resume production. Further, because refinery operations are typically dispersed over a large site area, the likelihood of a single accident or intentional event affecting the full extent of refining operations is low. A highly coordinated attack however, could bring down an entire refinery. Further, an attack that releases a cloud of toxic gas could result in a major loss of life in the refinery and the adjacent area.

Surveys of damage to German refineries caused by Allied bombing during World War II revealed that even when bombing was extensive, the refineries demonstrated a high rate of recoverability, because most of the damage was quickly repairable. Vital equipment, including compressors, steam generation, transformers, oil distillation and cracking units, and gas purifying systems, were seldom destroyed due to their heavy construction and use of reinforced concrete to protect the most sensitive equipment. Other more lightly constructed facilities at refineries, including dewaxing, gasoline treatment, and cooling water systems were more susceptible to blast damage. Most of this damage was attributable to pipeline breaks, cable and wiring breaks, and fragmentation damage to towers, liquids storage tanks, and gas holding vessels. While all systems were generally reparable, the duration of outage was determined by the availability of parts, materials, and skilled labor. In most instances, refineries were able to resume limited operations (~65%) within a few weeks and full capacity within six weeks.

Refinery control systems are generally housed in a highly protected and hardened central control facility on or adjacent to the refinery site. Most refineries adhere to and apply American Petroleum Institute (API) guidelines for risk-based approaches to assess the probability and consequences of intentional destructive acts, including terrorism.

Refined Product Storage: Storage tanks can be vulnerable targets for intentional damage. However, most refineries maintain only very limited supplies of refined products (jet fuel, motor gasoline, distillates, residual fuel oil, and liquefied petroleum gases) on site. Most refined products are regularly shipped to bulk storage and distribution terminals or other markets via pipeline, tanker ship, barge, or rail. Destruction of refinery-site product storage facilities would likely have only short-term market effects due to the loss of product. Physical infrastructure can be restored within weeks.

Refined Product Pipelines: As with crude oil pipelines, refined product pipelines are largely subsurface pipelines, making them very difficult to access for intentional damage. Three refined product pipelines originating in the Gulf Coast region (PADD III) transport most of the fuels consumed in major East Coast (PADD I) markets from the southeast all the way to New England. The principal points of vulnerability are above ground pumping stations, power supply, pipeline interconnect points, and delivery points at bulk storage terminals and market hubs. As with crude oil and natural gas pipelines, the open rights of way and required markers make these pipelines easily identifiable. Because there is less redundancy in the refined product pipeline system than in the natural gas transmission system, a pipeline disruption could have significant impacts on refined product supplies in major markets. More interconnections between product pipeline systems along their routes could reduce market vulnerability to supply disruption should a segment of a given pipeline be interrupted by intentional, accidental, or natural disaster.

Refined Product Hubs and Interconnect Points: In some locations, multiple refined product pipelines interconnect at a single location to serve multiple end use markets, transport facilities, and strategic government facilities. These facilities receive, store, and distribute large volumes of refined products by pipeline, marine vessels, barges, rail tankers, and other means.

Local and Retail Distribution Points: Local and regional bulk storage facilities receive refined products and then distribute refined and blended fuels for sale at retail filling stations and other distribution points.

Local bulk storage facilities are well secured, but nonetheless susceptible to intentional damage. Disruption of these facilities could have short term market effects. However, supplies could be quickly be provided by truck, rail or other means to meet market demand during a short-term disruption.

At the retail level, a filling station could be damaged or destroyed by intentional acts. The large number and broad geographic dispersion of filling stations make it unlikely that the loss of a single station would have significant impact on supplies to consumers. Panic induced buying could draw down available local stocks in storage.

Natural Gas Transportation, Storage and Distribution Infrastructure Vulnerability

The nation's natural gas demand is primarily supplied by domestic gas production, although there are still significant pipeline gas imports from Canada, and to a lesser extent Mexico. The U.S. also has the capability to import liquefied natural gas (LNG) from foreign sources through a small number of LNG import facilities located in the Gulf Coast, the Mid Atlantic, and New England regions.

Domestic natural gas is produced in several regions of the country, with major producing areas being the Mid-Continent region, the Gulf Coast offshore, the Southwest, and Appalachia regions. The shale gas revolution has significantly increased domestic gas production, promising to make the United States a net natural gas exporter.

Gas produced from the wellhead is collected in gas gathering systems and transported to a gas processing plant where it is stripped of moisture, natural gas liquids, sulfur, and impurities before it can be injected as dry gas into the nation's natural gas transmission systems. Processed gas may be transported to underground storage facilities (depleted gas reservoirs or caverns) or it may be sold directly into the transmission system for transportation to city gates for distribution to consumers through local distribution systems.

The vulnerabilities of this critical natural gas transportation, storage, and distribution system to intentional damage or disruption, and the potential impacts of such disruptions on market supply is summarized in Table 32 and discussed below.

Table 32: Natural Gas TS&D Major System Vulnerability and Potential Impacts of Disruption

Infrastructure Component	Vulnerability to Intentional Damage or Disruption	NPC Impact on Supply, Economy, and Safety
Natural Gas Imports (Pipeline)	Low	Low
Natural Gas Imports (LNG)	Low	Low
Gas Processing Plants	Medium	High
Gas Transmission Pipelines	Low	High
Gas Compressor Stations	Medium	High
Gas Storage Facilities	Low	High
Gas Transmission Interconnect Points	Low	High
City Gate (LDC) Interconnections	High	High
Local Distribution Systems	Low	High

Source: NPC, 2001

C. Natural Gas Supply Vulnerabilities

As with crude oil, natural gas exploration and production activities are geographically dispersed. Hundreds of thousands of wells contribute to the nation's natural gas supply. So, the loss of one or more wells due to intentional acts is unlikely to have significant local, regional, or national impacts on gas supply or prices.

That having been said, significant volumes of the nation's domestic natural gas supply are produced from offshore wells and platforms in the Gulf of Mexico. Many GOM oil and gas platforms individually produce and transport to shore, via pipelines, substantial volumes of gas.

The loss of a major oil and gas platform, particularly in the deepwater offshore, could reduce natural gas flow to Gulf Coast processing plants and to the transmission and distribution systems that supply markets throughout the eastern and central United States.

Natural Gas Transportation Storage and Distribution System Vulnerabilities

While the oil and gas transmission industry is robust, critical above-ground facilities are vulnerable to attack. The likely impact of attack on key system components is discussed next.

Natural gas is only delivered to consumers by a pipeline operating on a real time basis. In this regard, the gas pipeline is similar in operation to the electrical grid system. Supply interruptions will be apparent immediately (in the case of electrical outages) or in a few days (in the case of disruption in the gas delivery system). Vulnerabilities in the gas pipeline system include:

Natural Gas Processing Plants: The United States has more than 500 natural gas processing plants, distributed throughout the gas producing regions of the country. On any given day, these plants collectively store more than 5 MMBbl of liquefied petroleum gases (LPG) that are a by-product of gas processing. The geographic dispersion of these plants, and their usual physical locations in remote areas, makes them unlikely targets for intentional damage or destruction by terrorist groups. As with refineries, gas processing plants have multiple components and processes spread out over a large geographic footprint. Multiple trains also make it unlikely that a single attack would destroy an entire facility.

Gas Transmission Lines: The U.S. natural gas pipeline system is a network of pipe of various sizes and operating at various pressures. Redundancy is inherent in the multiplicity of pipes running parallel in the right-of-way as well as the many right-of-ways managed by different companies. A coordinated attack would cause major disruption, particularly to a region totally dependent on a single pipeline.

Natural gas pipeline systems are designed, constructed, operated, and maintained using rigorous engineering practices. The Office of Pipeline Safety requires formal emergency response plans and annual drills to test those plans. The industry has experience with large-scale outages caused by natural disasters, third-party incidents, and vandalism. Based on this experience, it is not likely that any terrorist attack would cause mass destruction to the entire critical facility. Inventories of emergency and critical spare parts are stored in centralized warehouses and other physical locations. Inventory items include long lead-time parts for engines, pre-tested pipe, valves, and high yield fittings. Pipeline companies also have agreements with vendors to utilize their inventory for short lead-time items and for major construction materials. These inventories and the practice of sharing parts and supplies between companies and/or vendors provide means to quickly restore operations in an emergency situation.

Natural Gas Storage Fields: Natural gas storage facilities are used mostly for peak shaving to assure timely seasonal delivery of natural gas to customers. Reservoir and compressed gas cavern storage serve as a base load for the pipelines close to the end user.

- For reservoir storage, old natural gas fields are used to store natural gas at locations throughout the U. S. The facilities include compressor stations installed to inject and to pressure the withdrawn gas into the transmission line.
- Cavern storage utilizes old salt- and coal- mines, solution mined caverns with salt formations and hard rock mined caverns. The salt- and coal- mines are operated at much lower pressures than reservoir stored gas. In one old coalmine, the storage pressure does not exceed 60 psi. Newly created solution-mined caverns can operate at pressures equal to or greater than old oil and gas reservoirs, depending on depth.
- Propane caverns are mined into granite near the end user, usually the city gate, and loaded with propane, which is used for peak shaving. The propane is usually delivered by truck.
- Propane caverns and liquefied natural gas terminals serve peaking operation very near the end user. Reservoir and cavern storage wells are usually operated in conjunction with each other.

Most storage systems have a number of wells for injection and withdrawal of gas from storage. However, loss of one or more wells in a field would not impact gas transportation. Additionally there are many fields and the loss of any one would have minimal effect on transportation or market supply.

Gas Interconnections: Unlike the oil and refine product transmission systems, numerous redundancies are built into the gas distribution system at critical points, for example, at the interconnection between companies. However, destruction of gas interconnections would eliminate the possibility of rerouting flows and/or withdrawing gas from storage to meet market demand. However, the multiple interconnects among pipelines and systems reduce this risk considerably.

Gas Pipeline Control: Gas pipeline flow control facilities manage the transportation of gas. These facilities are designed with backup systems either centrally located or distributed. However, destruction of microwave towers could significantly damage system communications and gas pipeline operations.

Gas Compressor Stations: Stations usually have several compressors located in groups and often in separate buildings. Outage of several units or a group of units will not significantly affect gas transportation. However, the loss of one gas compressor station would cause a 25% reduction in flow. Loss of 2 or 3 stations in series could halt operation for extended periods.

Gas City Gates: The transfer from transmission to distribution usually takes place at the city gate which is located around the distribution grid. Most major cities have six or more city gates which reduces the impact of the loss of one station.

Alternative Fuel Plants: Alternative fuel plants are geographically dispersed and tend to be low volume production facilities when compared to major oil refineries. However, fuel plants could be targets and would have similar vulnerabilities as a refinery. The loss of an ethanol plant would have minimal overall fuel supply impact. Such impacts could be offset by supplies from other plants or from temporary waivers of blending requirements until infrastructure is returned to service.

XIV. Fuel-Based Chokepoints

A. Introduction

Chokepoints refer to either places within the fuels supply infrastructure where fuels may become congested or a junction of such considerable importance that numerous other infrastructures depend on it to function. These critical junctions inherently provide a large amount of vulnerability due to their importance to the system. Losing any one could have major repercussions in the fuel supply chain and cause ripples throughout the global market. This section will identify chokepoints within crude, product, natural gas, and propane delivery systems. Biofuels have limited chokepoint potential as they rely less on large infrastructure like pipelines.

B. Crude Oil Chokepoints

Any challenge facing crude oil delivery must exist between its production at the well and its delivery to the refinery. As the United States still relies on a sizeable amount of its crude from imports, the oil must travel long distances in between the well and the refinery, presenting several possible global external chokepoints. At the same time, the nation also has some internal chokepoints which it relies on to deliver oil from the producing regions to the refining regions.

Internal Crude Chokepoints

Cushing, Oklahoma

Located in the middle of Oklahoma, the Cushing area is a concentrated gathering of several crude oil receiving and storage tank farms, serves as a crucial market hub and interconnect system for north and south, and acts as the market hub for West Texas Intermediate (WTI) crude oil. The terminals serve as the transit connection point for over two dozen pipelines, connects to 11 refineries, and has an approximate storage capacity of 80 MMBbl. The minimum operating level for Cushing area terminals is about 16 MMBbl.

As the largest crude oil storage terminal outside of the SPR, Cushing has historically been the main chokepoint of all crude oil supplies. This configuration is now changing.

Until 2014, Cushing inbound capacity exceeded its outbound capacity, leading to a high level of stockpiles at the terminal. During the recent Bakken boom, Cushing inventories began increasing as crude was shipped south to Gulf Coast refineries. This congestion was lightly alleviated by the following rail and barge boom which sought to bypass Cushing. However, when TransCanada's Cushing Marketlink pipeline came online in early 2014 Cushing's outbound capacity exceeded its inbound, leading to a substantial decrease in the stocks held as they moved to the Gulf Coast refineries.

Cushing is now becoming less, albeit still largely, important as a storage hub and terminal. Barge and rail shipments have provided alternative routes of delivering crude to market and enough flexibility to bypass the Cushing chokepoint. Its congestion problems have also been relieved with expanded southbound capacity and the reversal of the Seaway pipeline.

As the junction of a large number of pipelines, Cushing will remain a crucial chokepoint in the near future, yet the changing fuels production landscape and the flexibility of rail and barge shipments have lessened the vulnerability traditionally associated with Cushing.

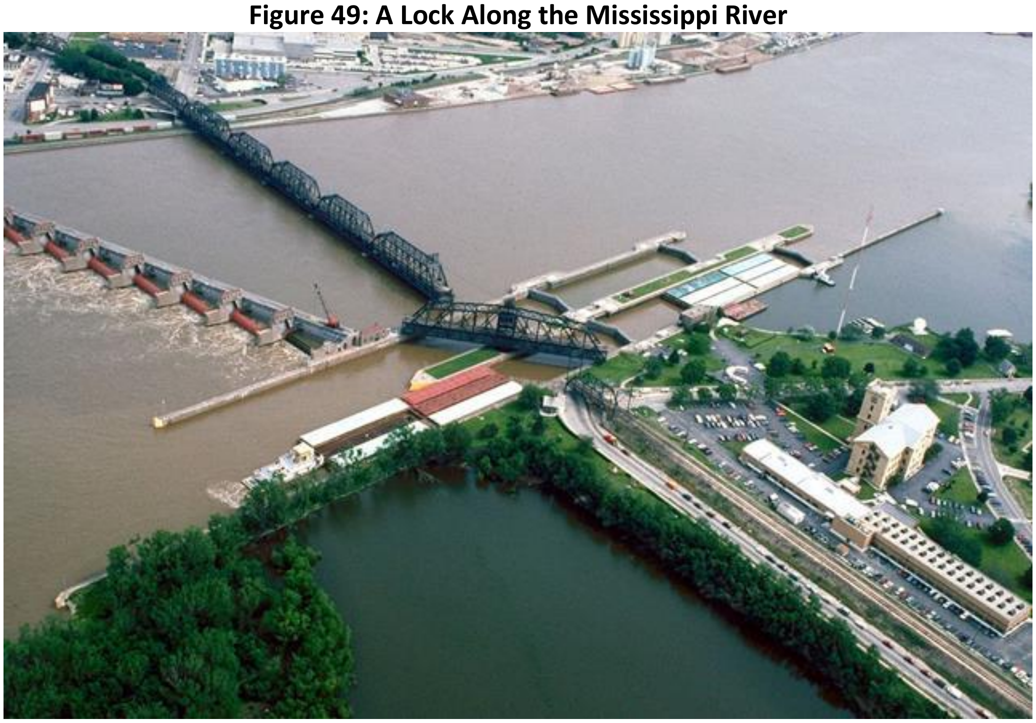
The Mississippi River

As Cushing's importance is being moderated by rail and barge traffic, the Mississippi River is returning to prominence. The river and its tributaries provide not only a route to the Gulf Coast refineries, but also access to a large number of refineries and key ports. The largest port in the United States, the Port of Southern Louisiana, is located along the Mississippi.

The Mississippi River, while not a chokepoint in itself, can act as a chokepoint under various circumstances. If sections of the river are shut down or traffic is limited then barge shipments will be severely disrupted. In recent years, parts of the river have become unnavigable due to flooding and drought, and the river has been closed to traffic because of Gulf hurricanes, upstream flooding, accidents, and oil spills.[69]

A large number of locks which control the flow of water and traffic on the Mississippi river. Each of these locks acts as a chokepoint and any malfunctions will cause delays and congestion affecting the transport of refined products and crude oil (Figure 49).

Figure 49: A Lock Along the Mississippi River



Source: United States Army Corps of Engineers

Sabine Pass and the Houston Ship Channel

Sabine Pass is a narrow waterway connecting Sabine Lake to the Gulf of Mexico. Its importance comes from the access it provides to crude oil and product terminals at Port Arthur, Nederland, and Beaumont, TX to the Gulf. It also is the site of an LNG import terminal with plans to expand to an export terminal. As the Port Arthur area in general becomes more important to the oil and gas industry, the Sabine Pass will gain further importance as well and its existence as a chokepoint will come to increase overall system vulnerability.

While the Sabine Pass is expected to play a large role in the future, the Houston Ship Channel is already one of the most trafficked waterways in the United States and serves the second largest port in the nation. Houston has a large number of refineries and receives crude through several pipelines. The channel is 52 miles long and connects downtown Houston and its refinery row to Galveston Bay and further along to the Gulf of Mexico. About 8% of U.S. refining capacity is located along the channel (Figure 50).[70]

Figure 50: The Houston Ship Channel and Sabine Pass

Source: INTEK/Google Earth 2014

The channel has also already seen the effects of closures. In 2013, winter fog closed the channel a number of times for a cumulative total of 320 hours of blocked ship channel access. In March 2014, the channel was closed for several days following an oil spill from a barge that left around a hundred ships stranded.[71] The Port Authority estimates that closing the channel for a day costs about $330 million in lost commerce.

Hundreds of ships transit the channel daily and its congestion is expected to worsen in the coming years. There are also concerns about the channel's need for constant dredging which is much more costly than the port's current budget allows.

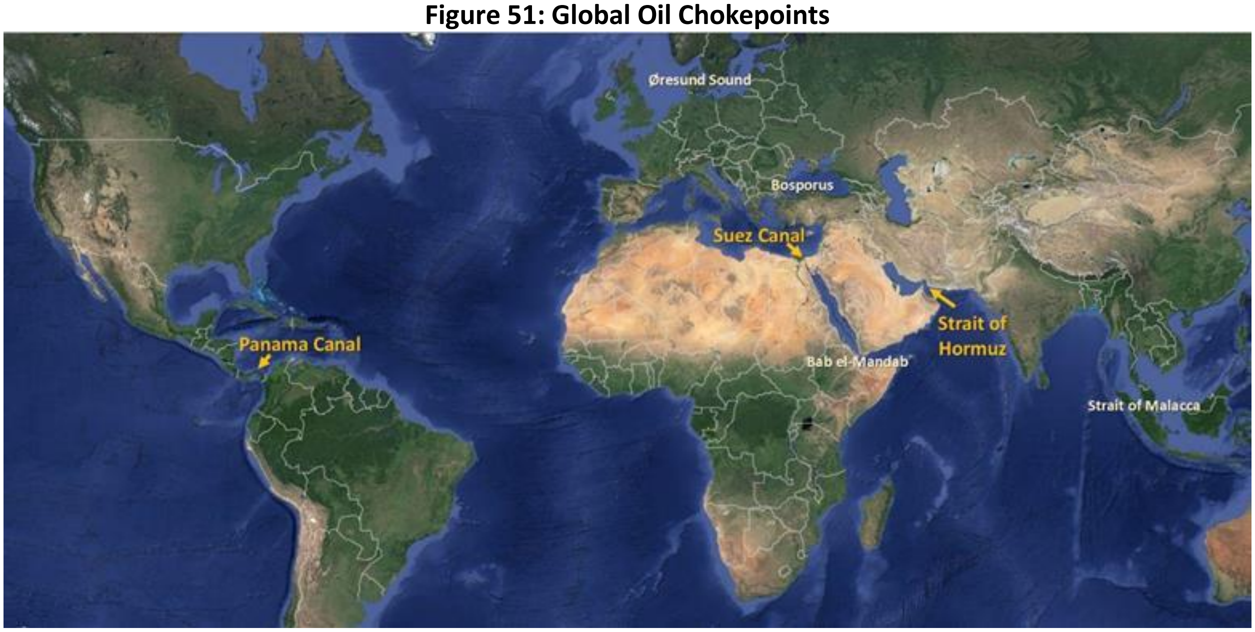
Louisiana Offshore Oil Port (LOOP)

In terms of imports, the Louisiana Offshore Oil Port and its associated storage sites are among the most important pieces of infrastructure in the nation. LOOP is the only port that can handle offloading the Ultra Large Crude Carriers (ULCC's) and the Very Large Crude Carriers (VLCC's). Besides handling imports, LOOP has also been used in recent years to offload Eagle Ford crude transferred by barge. LOOP further connects to pipelines which gather oil produced in the Gulf of Mexico. From LOOP crude can be fed into the pipeline system for transfer to their storage facilities at Clovelly and St. James and moved to refineries in the Gulf region, sent by way of the Capline pipeline to the Midwest, or sent to the SPR storage site at Bayou Choctaw by the Red Stick Pipeline. Reduced imports have reduced volumes of oil handled by LOOP. None the less, with the nation still more than 40% oil import dependent, LOOP remains critical infrastructure.

External Crude Chokepoints

EIA has identified seven world oil transit chokepoints (Figure 51): the Panama Canal, the Øresund Sound, the Bosporus, the Suez Canal, the Strait of Hormuz, Bab el-Mandab, and the Strait of Malacca.[72] Large volumes of oil are shipped through each of these heavily trafficked waterways. Not all of these shipments are destined for the United States but the loss of any of these waterways would significantly impact our global supply, markets, and products. Of the seven, only the Panama Canal, the Strait of Hormuz, and the Suez Canal are of major direct import importance for the United States.

Figure 51: Global Oil Chokepoints

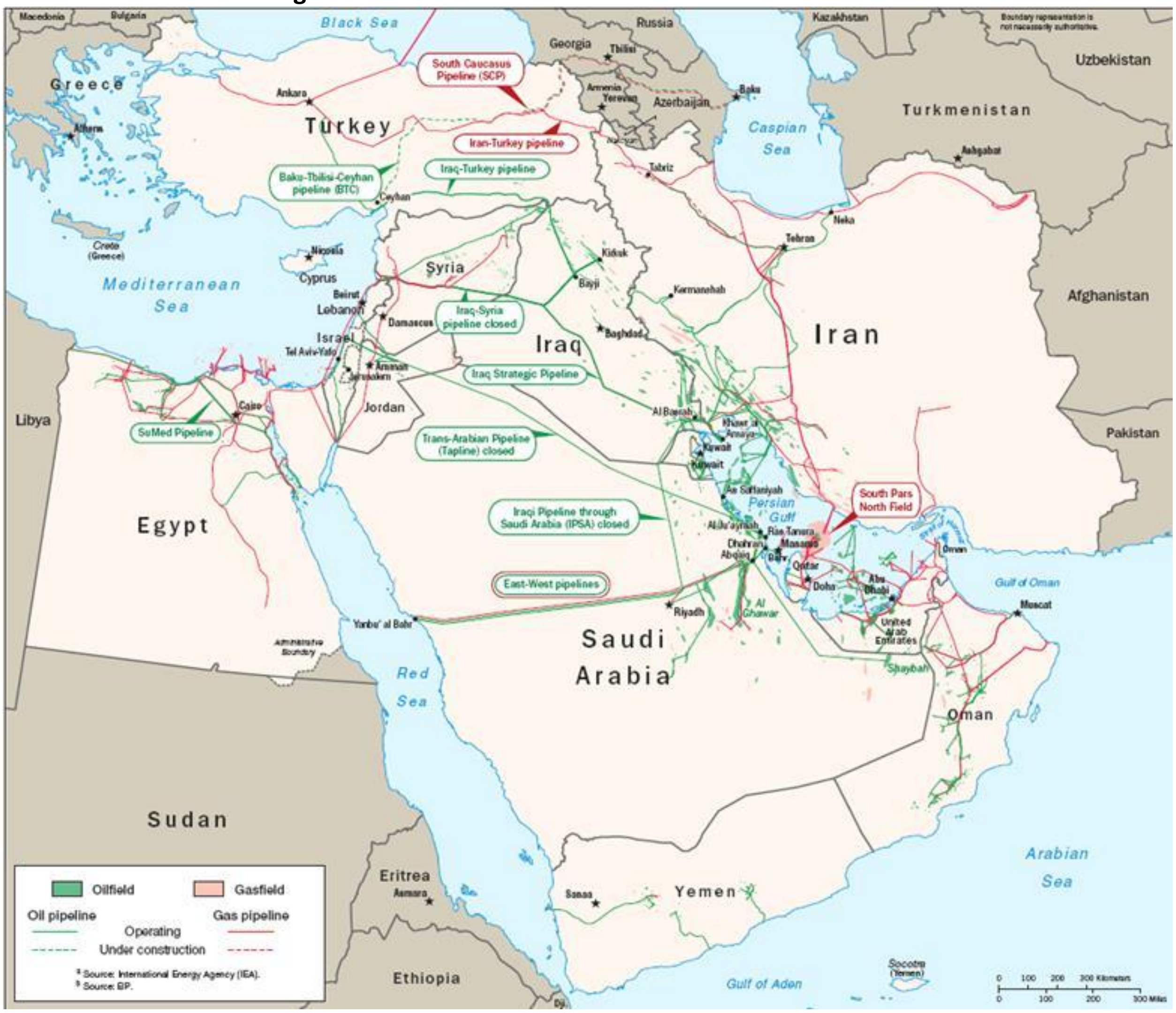


Source: EIA/INTEK, Google Earth 2014

Strait of Hormuz

The Strait of Hormuz is the most important global chokepoint for crude oil. Around 17 MMBbl/d passed through the strait in 2011, accounting for about 35% of all seaborne oil and 20% of all traded oil.[73] The strait also sees large traffic of LNG exports from Qatar, which also account for about 20% of global LNG trade. The strait's importance is further solidified as very few options remain to bypass it. They are a major choke point for transit of Middle East oil (Figure 52).

Figure 52: Oil and Gas Infrastructure in the Middle East



Source: EIA

Suez Canal

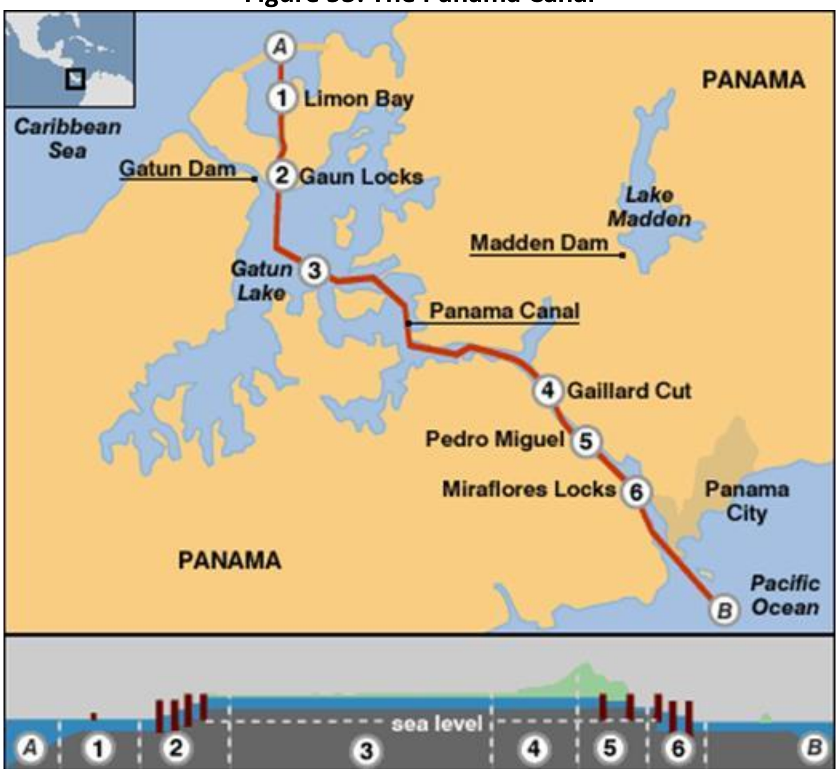
The Suez Canal connects the Mediterranean Sea and the Red Sea, thereby connecting the Atlantic Ocean and the Indian Ocean without the cumbersome voyage around the southern tip of Africa. If the canal closed, the trip around the Cape of Good Hope would add an additional 2,700 miles to the journey. Therefore, it is highly important to the United States as a large amount of the nation's oversea imports pass through it. Overall, almost 3 MMBbl/d transited the Suez Canal in 2012, accounting for 7% of total seaborne traded oil. Whereas the majority of oil transiting the Strait of Hormuz is destined for Asia, the oil passing through the Suez is headed towards Europe and North America.

The Suez works in conjunction with the SUMED Pipeline as well. This pipeline connects the Gulf of Suez and the Mediterranean Sea. Some VLCCs and ULCCs are unable to transit the canal and therefore offload their oil into the pipeline where it can be loaded again in the Mediterranean.

Panama Canal

The Panama Canal is one of the world's most important shipping routes as it saves vessels going from the Atlantic to the Pacific and vice versa nearly 8,000 miles (Figure 53). Nearly 60% of all traffic going through the canal is U.S. coast-to-coast shipments, yet only a small amount of this trade is crude oil. In 2011, only a little over 100 MBbl/d of crude was shipped through Panama. Nonetheless, it remains a vital route in the event of a disruption in crude deliveries to West Coast refineries.

Figure 53: The Panama Canal



Source: BBC News via EIA

While the Panama Canal is the sole route linking the Atlantic and Pacific without going around South America or through the Northwest Passage, it may soon face some competition. A Chinese firm has recently signed a deal with Nicaragua to build another canal through the Central American country in the next five years.[74] The project has just been proposed, and a certain amount of skepticism still surrounds it. It remains to be seen whether this project will be feasible.

C. Petroleum Product Chokepoints

After the refinery, petroleum products are pumped into product pipelines or tankers for delivery to bulk terminals and from there to end-market users like filling stations and airports. In the United States, this flow is largely from the refinery-heavy PADD III to the consumer-heavy PADDs I and II. PADD V is not connected to PADD III by pipeline but receives a significant amount of products by tanker.

Panama Canal

As mentioned above, the Panama Canal serves as a minor chokepoint for crude oil. However, it transits far more refined product to the West Coast than crude. In 2011, about 640 MBbl/d of petroleum products passed through the canal, the vast majority of it destined for the West Coast.

Colonial and Plantation Pipelines

The Colonial and Plantation pipelines follow parallel routes from the Gulf Coast through the Southeast and into the Mid-Atlantic with the Plantation terminating in Northern Virginia and Colonial terminating in Linden, NJ. Both pipelines are the primary suppliers of products to the Southeast and Colonial is of critical importance to the Northeast as it feeds into the Buckeye system at the Intra Harbor Transfer at New York Harbor. If these pipelines go offline then all of PADD I faces a serious supply shortage.

The Arthur Kill and the Kill van Kull

The Arthur Kill and Kill van Kull are two waterways separating Staten Island, NY from New Jersey (Figure 54). Both also contains a large number of petroleum terminals along their banks (Figure 55). These waterways were exposed as product chokepoints during Hurricane Sandy when the terminals were flooded and petroleum spilled into the river. Immediately following Sandy, both waterways were closed or heavily restricted for over a week due to the spill and debris. Their closure exacerbated the fuel shortages facing New York and New Jersey.

Figure 54: The New York Harbor Area with Arthur Kill and Kill van Kull Highlighted

Source: INTEK/Google Earth 2014

Figure 55: Arthur Kill and Kill van Kull with Petroleum Terminals

Source: INTEK/Google Earth 2014

D. Natural Gas Chokepoints

The natural gas supply chain is relatively free of chokepoints due to the large amount of redundancy in the system. Compared to oil, there are more miles of natural gas pipeline than crude or product pipelines, and more processing plants than refineries. Transmission pipelines connect at over 40 market hubs across the country, providing a web-like configuration capable of bypassing all congested points except for some regional outposts. Compressor stations, which move natural gas through the pipeline system, are also designed to handle much higher capacities than needed and able to increase pressure if one should fail further down the pipeline. However, despite the redundancy, there are some possible regional chokepoints.

LNG Import Terminals

The U.S. currently has 11 LNG re-gasification terminals, all of which are located along the East Coast and Gulf Coast. These terminals can play a vital role in supplying natural gas to certain regions or acting as storage sites in case of supply disruption. As LNG imports arrive by ship, global LNG chokepoints are similar to the global crude chokepoints as both transit similar shipping routes. However, LNG imports are becoming less vital. In 2013, LNG made up only about 3% of imports and has shown a steady decline over recent years. The vast majority (~97%) of natural gas imports come from Canada while less than 1% comes from Mexico.

Canadian Entry Points

While natural gas imports have been decreasing, Canada still exports a significant amount to the U.S. In 2013 the country provided nearly 2.9 Tcf, 90% of which came through six entry points. These entry points are: Port of Morgan, Eastport, Sherwood, Noyes, Sumas, and Waddington.

Northeast Pipeline Chokepoints

The Northeast region has been struggling to meet its demand for natural gas in recent years. This situation is due to several factors. First, the region is increasingly reliant on natural gas for its power supply as regulations on the coal industry have shuttered coal plants in favor of natural gas. Second, the region relies on limited transmission pipeline capacity. Only two major pipelines extend into the New England area, the Tennessee Gas Pipeline Company system, and the Algonquin Gas Transmission Company system, which is partially fed by the former. Third, the past winter of 2013-2014 reduced stocks considerably and made it difficult to supply the region with a constant stream of gas. New England has no underground storage reservoirs.

All these factors make the Northeast, and New England in particular, vulnerable to supply disruptions, especially during peak demand in the winter months. However, as the past winter has demonstrated, New England, while facing pipeline bottlenecks, was not isolated. The region was able to bypass those bottlenecks by turning to Canadian imports.

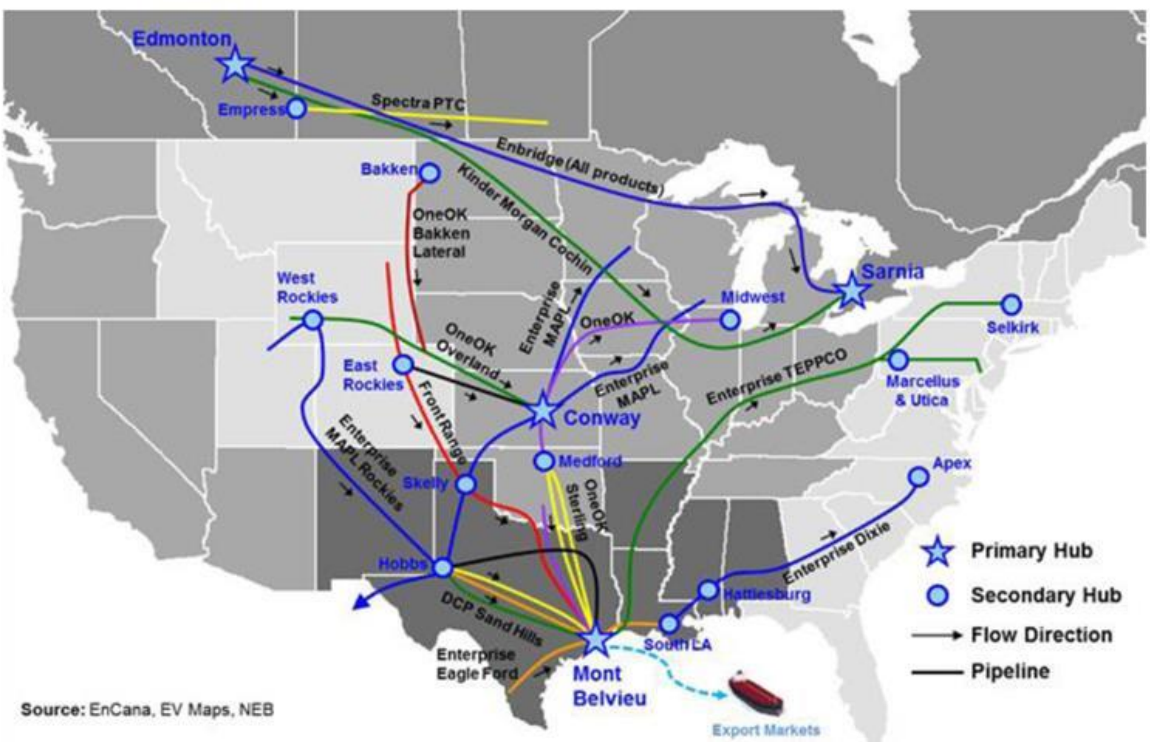
E. Propane Chokepoints

Propane, like natural gas, is relatively free of chokepoints. The system relies on a diverse transportation portfolio consisting of pipelines, rail, trucks, and barges (Figure 56). Imports have dwindled in the past years and the country now is a net exporter of the gas. However, recent years have also exposed vulnerabilities within the system, and future developments might further exacerbate propane's TS&D growing fragility.

One of the major changes in the propane supply system is Kinder Morgan's reversal of its Cochin pipeline. The pipeline originated from a propane storage site in Edmonton, Canada and served markets throughout the Midwest. In early 2014, the company reversed the flow to deliver NGL's to Edmonton, cutting off a major supply source for Midwest markets. Regional energy analysts believe this reversal could cause major supply problems if the Midwest experiences a colder winter again in 2014-2015.

Other supply problems were already exposed in the 2013-2014 winter as propane was in short supply in the Northeast. This shortage was due to low stocks from an unusual wet crop harvest in the Midwest (where propane is used to dry the crops), increased NGL demand along the Gulf Coast by the petrochemical industry and the growth in exports, and the closing of a key rail passage in Lac-Megantic, Quebec due to a high-fatality derailment and explosion. In the Gulf Coast, propane is exported largely through the Houston Ship Channel a highly-trafficked maritime chokepoint.

Figure 56: Major Propane Hubs and Pipelines



Source: Natural Resources Canada

Conway, KS

Conway, KS hosts the second largest propane storage site in the country in underground salt caverns (Figure 57). It acts as a pipeline crossroads for propane travelling south to the petrochemical plants on the Gulf Coast and north for residential and industrial use. In this sense, the Conway storage hub serves a similar role with propane that Cushing does with crude oil. As the Midwest relies on the storage at Conway to deliver propane to local markets during times of high demand, a disruption at Conway could severely limit supplies and spark a crisis.

Figure 57: Brine Ponds at Conway used for Extracting Propane Stocks

Source: Google Earth 2014

Mont Belvieu, TX

The largest propane storage facility is located in Mont Belvieu, TX, just outside of Houston, which hosts a number of large underground salt caverns ideal for storing the gas. Together with Conway, the sites hold approximately 75% of all propane in the country. While Conway serves as a transfer point and chokepoint for the flow of propane supplies, Mt. Belvieu presents a different challenge.

Large amounts of propane are being sent to and stored at the Mt. Belvieu complex for fractionation – the process of converting “y-grade” NGL’s into usable gases. As more companies invest in fractionation plants at Mt. Belvieu, the storage site will become a chokepoint between raw mix feedstock and separated NGL products that can be transported along the TEPPCO pipeline to the Northeast or the Dixie pipeline to the Southeast.

XV. Interdependencies

The nation's electric power, liquid fuels, and natural gas transportation, storage, and distribution systems are part of a vast, interconnected, and interdependent system that fuels the nation's economy. This system also extends to Canada and Mexico, interconnecting North American economic, commercial, and social functions. A disruption to any major element of the system can therefore, have effects throughout the system and the end-use sectors it serves.

Petroleum Products and Alternative Fuels: The major products of refineries and alternative liquid fuels plants, and associated transport, storage, and distribution systems include:

- Jet fuel for commercial, military, and private aviation
- Motor gasoline for public and private vehicular transportation
- Distillate fuels (including diesel and biodiesel) for transportation and residential heating
- Marine transportation fuels
- Residual fuel oil for heating, power generation, and industrial uses.
- Liquefied petroleum gases for commercial and industrial use
- Ethanol for use as a primary fuel or blending stock for fuel oxygenation
- Lubricants, and
- Feedstock for medical, petrochemicals, plastics, and fertilizers.
- Many plants also contribute excess electric power to the electrical grid

Natural Gas Fuels and Products: The natural gas supply, transport, storage, and distribution system supplies natural gas for:

- Residential and commercial heating,
- Steam generation and industrial processes
- Electric power generation (base load and peak shaving)
- Transportation fuel for fleet and individual vehicles
- Exports by pipeline or liquefied natural gas (LNG) systems.
- It also produces and supplies natural gas liquids (NGLs) for refinery, petrochemical, and heating.

The supply, transport, storage, and distribution systems are interdependent in that oil and gas and alternative fuels production, transmission, storage and distribution systems all require electric power for their operations, monitoring and control systems, and communications. Today, electric power generation is less dependent on oil as a primary energy source, but is increasingly reliant on natural gas supply and distribution systems. Further, natural gas processing produces natural gas liquids that serve as fuels and feedstock for oil refineries. And some refining and gas processing plants generate excess electricity to the power grid.

In the past, the electric power, liquid fuels, and natural gas systems were largely separate, independent, and nearly autonomous. Each could function largely on its own with minimal dependencies on external systems. Today, the advance of computing and information technology, telecommunications, and the evolution of modern business practices to improve operating efficiencies has made the electric, natural gas, and petroleum industries not only more interconnected and interdependent, but also more dependent on external systems. While revolutionizing business communications, monitoring capabilities, and system controls, the advent of cyber technology, and the industry's increasing reliance on external cyber systems and networks, has introduced a significant new vulnerability to our energy transportation, storage, and distribution infrastructure.

Most energy companies now rely, at least in part, on external systems for telecommunications, control systems, and data processing and storage systems, and transportation of feedstock and products. Many functions, such as maintenance and servicing, that were once internal systems, are now outsourced.

Liquid fuels and natural gas remain the primary fuels for the transportation systems that support the nation's economic and social activity. Increasingly, due to the abundant gas resources that have been made technically and economically accessible by technological advances, natural gas is becoming a fuel of choice for base load electric power generation in addition to its historic role as a peak shaving fuel. These fuels are also essential for government operations, first responders, and national defense. Thus, the systems that transport, store, and distribute these fuels to commercial, institutional, government, and individual end-users must be deemed critical infrastructure.

A. Intra-System Interdependencies

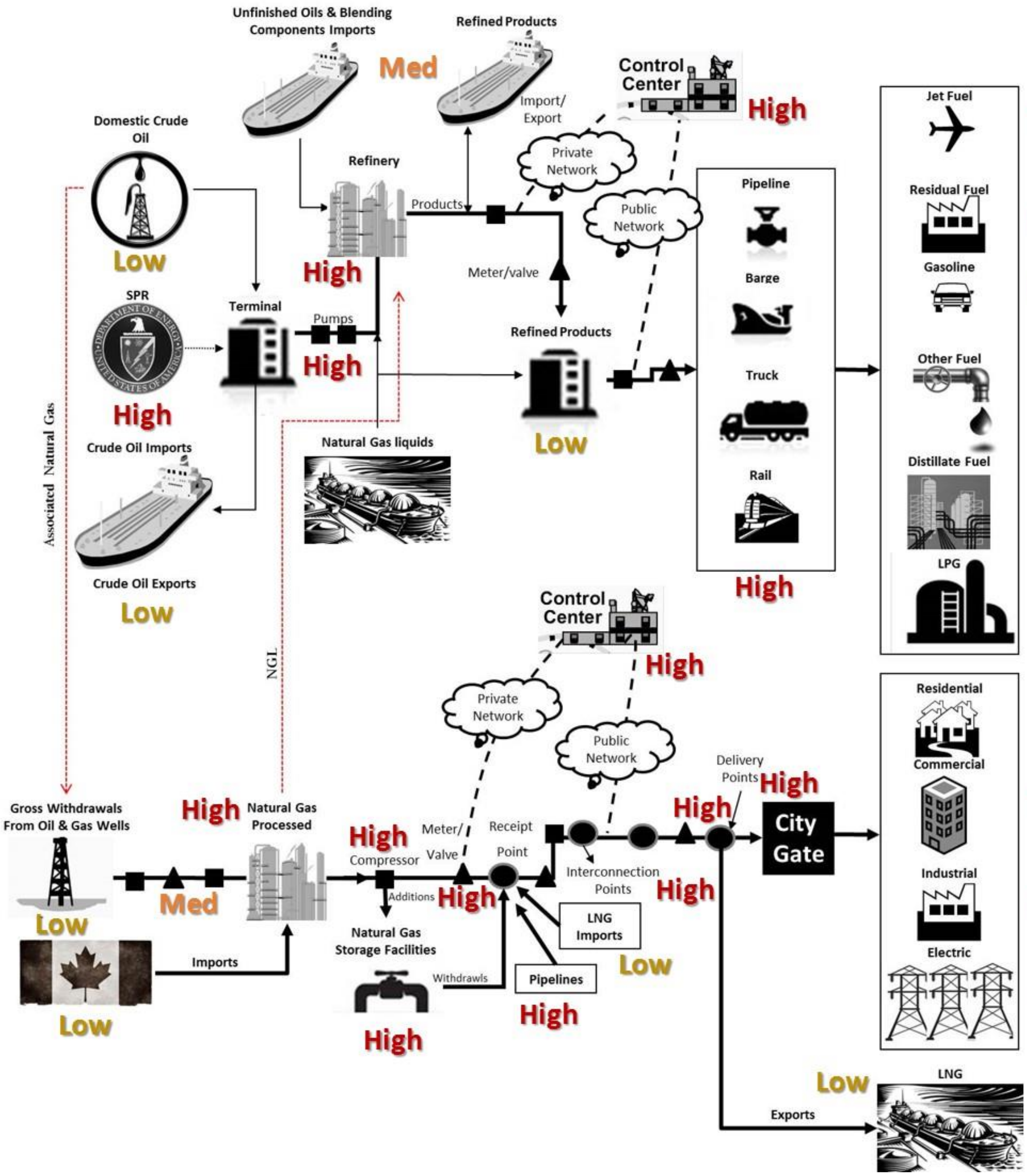
Both the liquid fuels and the natural gas systems have major interdependencies within the respective systems. For the liquid fuels system, refineries cannot operate without crude oil supply, refined products cannot be supplied without refineries, and fueling stations cannot supply consumers without supplies of refined products received from bulk storage terminals that are served by product pipelines. The oil and gas supply chains are illustrated in Figure 58, below.

Theoretically, any break in the supply chain caused would interrupt supplies of oil or products to the next elements of the supply chain, ultimately resulting in loss of supply to the end-users. Redundancy in the individual components of the supply chain, as well as the existence of multiple supply chains, contributes to the overall resiliency of the system and reduces the vulnerability of the market to a disruption.

In the oil and refined products supply chain, multiple oil fields, platforms, wells, pipelines, rail lines, ports, and transport systems supply crude oil to storage terminals and refineries. When a source or transport system is interrupted, supply can often be provided from another source or by a different means of transport.

For example, if a hurricane in the Gulf of Mexico shuts in oil production from offshore platforms, coastal refineries can rely on crude oil in storage or oil received by pipeline or rail from another source to make up the shortfall until production can be restored. In the event of a prolonged outage, the supply shortage could be offset by a release of oil from the Strategic Petroleum Reserve.

Figure 58: Vulnerabilities in the Oil and Gas Supply Chain



Source: INTEK, NPC 2001

Similarly, if pipeline access to a refinery were interrupted, the refinery may be able to receive crude oil by ship barge, or rail. Recently, when chokepoints in the pipeline system made it difficult to transport crude oil from Corpus Christie to Houston refineries, producers barged it to the offshore LOOP facility for delivery into the pipeline system.

Multiple refineries also help ensure the continuous production and flow of refined products to major markets. The effectiveness of this redundancy is evidenced by the uninterrupted flow of products to markets when various refineries go offline for maintenance and seasonal adjustments from winter to summer product slates.

Two major refined product pipeline systems originating in the Gulf Coast PADD III refining centers, Colonial and Plantation, serve the Southeast, Mid-Atlantic, and new England PADD I markets. Each system operates multiple lines with interconnections between the lines. If service on one line is interrupted, products can be routed and supplied through the other line until a disruption is resolved.

Market hubs and bulk storage terminals also provide resiliency and redundancy to the system, allowing products to be supplied from storage during a temporary supply disruption. The greater the number of interconnects and hubs between and among various systems, the greater the redundancy and resiliency is for the system.

The intersection of infrastructure at major market hubs, provides significant flexibility to transfer products among systems in times of supply disruptions. However, the concentration of facilities in a single location can also make the overall system more vulnerable, particularly when the hub is a critical choke point that limits or controls supply to markets further along the chain. For example, the concentration of systems intersecting at Linden, NJ in the New York Harbor area, allowed products and crude oil to be transferred by marine vessels when power to pipeline systems was interrupted. At the same time, major damage to facilities at Linden, particularly critical system interconnect points, could restrict supplies to northeast markets that depend on the terminals at Linden. Refined products could, however, be supplied by marine vessel or tanker truck to New England markets in the event of a major infrastructure disruption at Linden.

B. Natural Gas Infrastructure Interdependencies

Because of the greater number of interconnections between and among natural gas transmission systems, along the trunklines and at market hubs, the presence of high capacity underground gas storage, and redundancies built into city gate and local distribution systems for most major markets, it can be argued that the natural gas system has greater redundancy and is more resilient than the liquid fuels distribution system.

The broad geographic distribution of natural gas basins, fields, gathering systems, gas processing facilities, and gas storage fields in the United States generally assures that the interruption of a single well, field or processing facility will not significantly impact gas supply to the system. In the event of major prolonged natural gas supply loss, such as from a severe hurricane in the Gulf of Mexico, gas could be withdrawn from storage or obtained from other parts of the system to meet market needs.

Interconnections along trunklines allow gas to be rerouted in the event of disruptions to a gas pipeline. Similarly, the loss of a compression station along a major trunkline can be adjusted for by increasing compression elsewhere along the line while the equipment is repaired or replaced. Most cities and major metropolitan areas are served by multiple city-gates that serve as the physical custody transfer point from the trunkline provider to the local distribution company. The loss of gas supply via one citygate may be overcome by increasing gas into the local distribution system from another city gate.

Many users with dedicated connections to the trunkline or local distribution system, such as gas-fired power plants or major industrial users, also maintain on-site gas storage in the form of liquefied natural gas to provide emergency supply or meet peak shaving needs.

The major threat to local distribution systems is loss of electric power and effects of flooding on buried and exposed gas mains and distribution lines which can interrupt service to consumers during and after major storms until system inspections can verify system integrity and safety.

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