What Threats Pose the Greatest Risk to the Energy Infrastructure - Understanding Regional Risks

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Argonne NATIONAL LABORATORY

U.S. DEPARTMENT OF ENERGY

Outline of Presentation

- Definition of Energy Risk
- Definition of PADDs
- Natural Disasters by PADD
- Causes of disruption to Electric Transmission and Distribution
- Major threats to Petroleum Transport
- Petroleum Refinery incident data
- Results for Natural Gas Transport
- Conclusions

Definition of Energy Risk

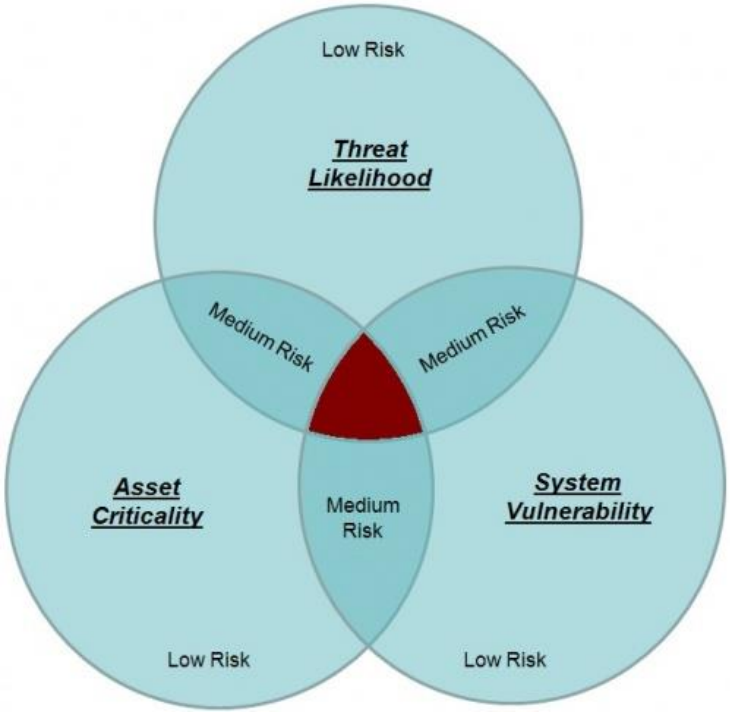
- **Risk** is the potential for an unwanted outcome resulting from an incident, event, or occurrence, as determined by its likelihood and the associated consequences:

Risk = function(threat, vulnerability, consequence)

Threat is the likelihood of a disruption or attack on the asset.

Vulnerability is a physical feature or operational attribute that renders an entity open to exploitation or susceptible to a given hazard.

Consequence is the effect of an event, incident, or occurrence.



- **Energy risk** accounts for the three interrelated energy segments: electricity, petroleum, and natural gas.

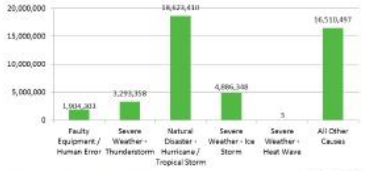
Example Energy Risk Template for East Coast

East Coast Region — ENERGY SECTOR RISK PROFILE

Electric Transmission

- According to NERC, the leading cause of electric transmission outages in the East Coast Region is All Other Causes.
- The region experienced 456 electric transmission outages from 1992 to 2009, affecting a total of 45.2 million electric customers.
- Natural Disasters – Hurricanes/Tropical Storms affected the largest number of electric customers as a result of electric transmission outages.

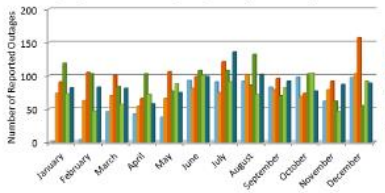
Electric Customers Disrupted by NERC-Reported Electric Transmission Outages by Cause (1992–2009)



Number of NERC-Reported Electric Transmission Outages by Cause (1992–2009)

Electric Distribution

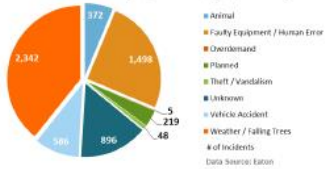
Electric Utility Reported Power Outages by Month (2008–2013)



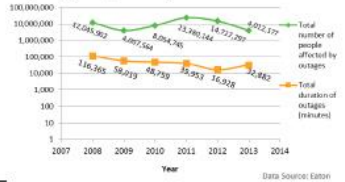
- Between 2008 and 2013, the greatest number of electric outages occurred during the month of July in the East Coast Region.
- The leading cause of electric outages during 2008 to 2013 was Weather/Falling Trees.
- On average, the number of people affected annually by electric outages during 2008 to 2013 was 11 million.
- The average duration of electric outages in the region during 2008 to 2013 was 52,150 minutes or 869 hours a year.

Data Source: Eaton

Causes of Electric-Utility Reported Outages (2008–2013)



Utility Outage Data (2008–2013)

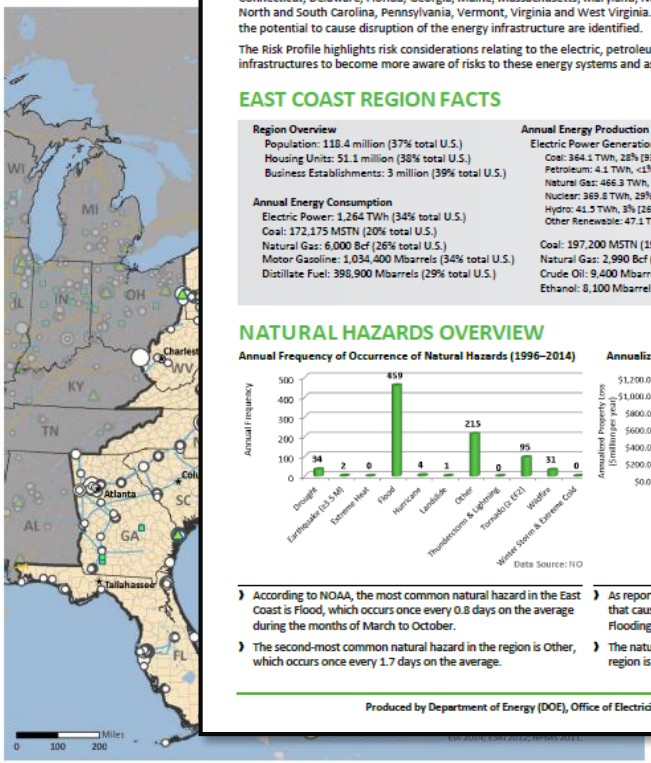


- NOTE: # of Incidents – The number within each pie slice is the number of event incidents attributable to each cause.

Produced by Department of Energy (DOE), Office of Electricity Delivery & Energy Reliability (OE)

ENERGY SECTOR RISK PROFILE

PETROLEUM



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East Coast Region
ENERGY SECTOR RISK PROFILE

This Energy Risk Profile examines the relative magnitude of the risks that the East Coast's energy infrastructure routinely encounters in comparison with the probable impacts. The East Coast Region consists of the States of Connecticut, Delaware, Florida, Georgia, Maine, Massachusetts, Maryland, New Hampshire, New Jersey, New York, North and South Carolina, Pennsylvania, Vermont, Virginia and West Virginia. Natural and man-made hazards with the potential to cause disruption of the energy infrastructure are identified.

The Risk Profile highlights risk considerations relating to the electric, petroleum and natural gas infrastructures to become more aware of risks to these energy systems and assets.

EAST COAST REGION FACTS

Region Overview
- Population: 118.4 million (37% total U.S.)
- Housing Units: 51.1 million (38% total U.S.)
- Business Establishments: 3 million (39% total U.S.)

Annual Energy Consumption
- Electric Power: 1,264 TWh (34% total U.S.)
- Coal: 172,175 MSTN (20% total U.S.)
- Natural Gas: 6,000 Bcf (26% total U.S.)
- Motor Gasoline: 1,034,400 Mbarrels (34% total U.S.)
- Distillate Fuel: 398,900 Mbarrels (29% total U.S.)

Annual Energy Production
- Electric Power Generation: 1,295 TWh (32% total U.S.)
  - Coal: 364.1 TWh, 28% [93.5 GW total capacity]
  - Petroleum: 4.1 TWh, <1% [143.3 GW total capacity]
  - Natural Gas: 466.3 TWh, 36% [35.7 GW total capacity]
  - Nuclear: 369.8 TWh, 29% [42.8 GW total capacity]
  - Hydro: 41.5 TWh, 3% [26.4 GW total capacity]
  - Other Renewable: 47.1 TWh, 4% [13.4 GW total capacity]
- Coal: 197,200 MSTN (19% total U.S.)
- Natural Gas: 2,990 Bcf (13% total U.S.)
- Crude Oil: 9,400 Mbarrels (<1% total U.S.)
- Ethanol: 8,100 Mbarrels (3% total U.S.)

NATURAL HAZARDS OVERVIEW

Annual Frequency of Occurrence of Natural Hazards (1996–2014)

Annualized Property Loss due to Natural Hazards (1996–2014)

- According to NOAA, the most common natural hazard in the East Coast is Flood, which occurs once every 0.8 days on the average during the months of March to October.
- The second-most common natural hazard in the region is Other, which occurs once every 1.7 days on the average.
- As reported by NOAA, the natural hazard in the East Coast Region that caused the greatest overall property loss during 1996 to 2014 is Flooding at $1,027.1 million per year.
- The natural hazard with the second-highest property loss in the region is Hurricanes at $712.4 million per year.

Produced by Department of Energy (DOE), Office of Electricity Delivery & Energy Reliability (OE)

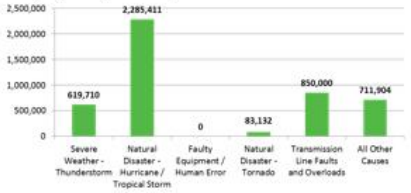
Example Energy Risk Template for Alabama

URL: http://energy.gov/oe/state-energy-risk-assessment-initiative-state-energy-risk-profiles

Electric Transmission

- According to NERC, the leading cause of electric transmission outages in Alabama is **Severe Weather - Thunderstorm.**
- Alabama experienced **33 electric transmission outages** from 1992 to 2009, affecting a total of **4,550,157** electric customers.
- **Natural Disaster - Hurricane/Tropical Storm** affected the largest number of electric customers as a result of electric transmission outages.

Electric Customers Disrupted by NERC-Reported Electric Transmission Outages by Cause (1992–2009)



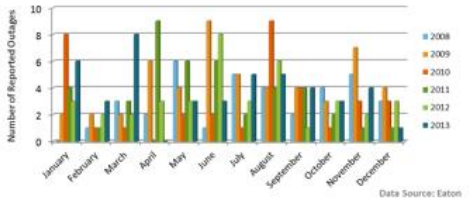
Data Source: NERC

Number of NERC-Reported Electric Transmission Outages by Cause (1992–2009)

Data Source: NERC

Electric Distribution

Electric Utility Reported Power Outages by Month (2008–2013)



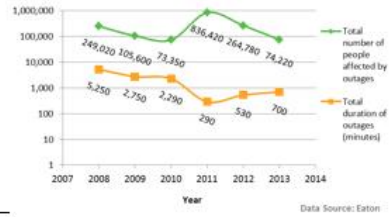
Data Source: Eaton

- Between 2008 and 2013, the greatest number of electric outages in Alabama has occurred during the month of **August.**
- The leading cause of electric outages in Alabama during 2008 to 2013 was **Weather/Falling Trees.**
- On average, the number of Alabama's customers affected annually by electric outages during 2008 to 2013 was **267,232.**
- The average duration of electric outages in Alabama during 2008 to 2013 was **1,968 minutes or 32.8 hours a year.**

Electric Utility-Reported Outages by Cause (2008–2013)

Data Source: Eaton

Utility Outage Data (2008–2013)



Data Source: Eaton

- NOTE: # of Incidents – The number within each pie chart piece is the number of outages attributable to each cause.

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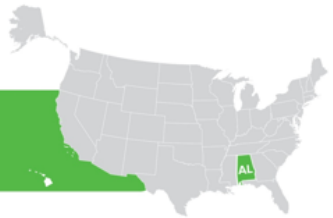


State of Alabama
ENERGY SECTOR RISK PROFILE

This State Energy Risk Profile examines the relative magnitude of the risks that the State of Alabama's energy infrastructure routinely encounters in comparison with the probable impacts. Natural and man-made hazards with the potential to cause disruption of the energy infrastructure are identified.

The Risk Profile highlights risk considerations relating to the electric, petroleum and natural gas infrastructures to become more aware of risks to these energy systems and assets.

ALABAMA STATE FACTS

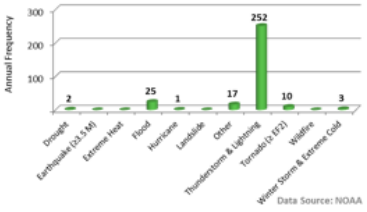
State Overview
- Population: 4.83 million (2% total U.S.)
- Housing Units: 2.19 million (2% total U.S.)
- Business Establishments: 0.10 million (1% total U.S.)

Annual Energy Consumption
- Electric Power: 86.2 TWh (2% total U.S.)
- Coal: 24,300 MSTN (3% total U.S.)
- Natural Gas: 87 Bcf (<1% total U.S.)
- Motor Gasoline: 47,300 Mbarrels (2% total U.S.)
- Distillate Fuel: 27,900 Mbarrels (2% total U.S.)

Annual Energy Production
- Electric Power Generation: 152.9 TWh (4% total U.S.)
  - Coal: 45.6 TWh, 30% [12.6 GW total capacity]
  - Petroleum: 0.1 TWh, <1% [0 GW total capacity]
  - Natural Gas: 55.7 TWh, 36% [13.5 GW total capacity]
  - Nuclear: 40.8 TWh, 27% [5.3 GW total capacity]
  - Hydro: 7.4 TWh, 5% [3.3 GW total capacity]
  - Other Renewable: 0 TWh, 0% [0 GW total capacity]
- Coal: 19,500 MSTN (2% total U.S.)
- Natural Gas: 220 Bcf (1% total U.S.)
- Crude Oil: 9,500 Mbarrels (0% total U.S.)
- Ethanol: 0 Mbarrels (0% total U.S.)

NATURAL HAZARDS OVERVIEW

Annual Frequency of Occurrence of Natural Hazards in Alabama (1950–2010)



Data Source: NOAA

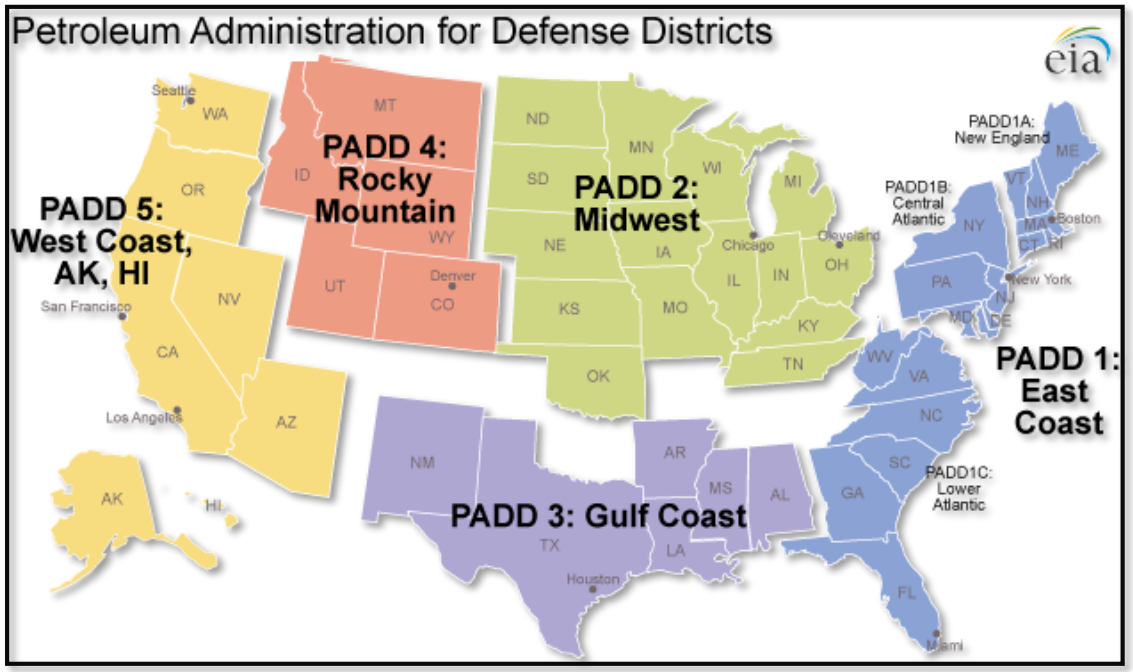
Annualized Property Loss due to Natural Hazards in Alabama (1996–2014)

Data Source: NOAA

- According to NOAA, the most common natural hazard in Alabama is Thunderstorm & Lightning, which occurs once every 1.5 days on the average during the months of March to October.
- The second-most common natural hazard in Alabama is Flood, which occurs once every 14.6 days on the average.
- As reported by NOAA, the natural hazard in Alabama that caused the greatest overall property loss during 1996 to 2014 is Tornado at $99.0 million per year.
- The natural hazard with the second-highest property loss in Alabama is Flood at $20.5 million per year.

PADDs

- Petroleum Administration for Defense Districts (PADDs) are geographic aggregations of the 50 States and the District of Columbia into five districts:
  - PADD 1 is the East Coast
  - PADD 2 - Midwest
  - PADD 3 - Gulf Coast
  - PADD 4 - Rocky Mountain Region
  - PADD 5 - West Coast



- Energy risk data shown in this presentation provided at the PADD-level

What Natural Disasters Cause the Most Damage?

- Data from NOAA Storm Events Database analyzed for 1986 to 2014.
- Property Damage values from previous years escalated to current year dollars using GDP deflator.
  - GDP deflator is a measure of price inflation.

Top-Five Natural Disasters and Weather Extremes by PADD (1986-2014)					
Rank by Property Damage	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
1	Flood	Flood	Hurricane	Thunderstorm & Lightning	Wildfire
2	Hurricane	Thunderstorm & Lightning	Drought	Flood	Thunderstorm & Lightning
3	Tornado	Drought	Flood	Wildfire	Flood
4	Winter Storm & Extreme	Tornado	Thunderstorm & Lightning	Tornado	Winter Storm & Extreme
5	Thunderstorm & Lightning	Winter Storm & Extreme	Tornado	Winter Storm & Extreme	Earthquake

- Above ranking reflects the significance of extreme weather events, such as:
  - The New England Flood of October 1996 and Mid-Atlantic United States flood of 2006 (PADD 1).
  - The Great Flood of 1993 and the 2011 Mississippi River floods (PADD 2).
  - Hurricanes Ivan, Katrina, Rita, etc. in the Gulf Coast (PADD 3).
  - Hail storms in Colorado and Wyoming (PADD 4).
  - California wildfires of October 2007 (PADD 5)

What Hazards Posed the Greatest Threats to the Electric Transmission Grid?

- NERC "System Disturbance Report" data was analyzed to determine the most-likely causes of electric transmission – related outages.
- Total of 941 events from 1992 to 2009.

Top-Five Causes of NERC-Reported Electric Transmission Outages (1992 - 2009)					
Rank by Number of Customers	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
1	Hurricane / Tropical Storm	Thunderstorm	Hurricane / Tropical Storm	Transmission Line Faults and Overloads	Transmission Line Faults and Overloads
2	Complete Electrical System Failure	Complete Electrical System Failure	Thunderstorm	Fuel Supply Deficiency	High Winds
3	Ice Storm	Winter Storm	Faulty Equipment / Human Error	Faulty Equipment / Human Error	Thunderstorm
4	Thunderstorm	Ice Storm	Transmission Line Faults and Overloads	Unknown Cause	Faulty Equipment / Human Error
5	High Winds	High Winds	Heat Wave	Physical Impact / Attack	Heat Wave

- Each region appears to be vulnerable to different hazards.
- Greatest impact to PADD 1 (East Coast) and PADD 3 (Gulf Coast) due to hurricanes.
- PADD 2 (Midwest) subject to extreme weather such as storm and high winds.
- Transmission line faults or overloads most-significant threat in PADD 4 (Rocky Mountain) and PADD 5 (West Coast), due to major transmission paths with high congestion.

What are the Major Threats to Electric Distribution?

- Data indicates that 90% of customer outage-minutes are due to events which affect local distribution systems.
- Top-five causes vary by PADD, with weather events predominating for PADDs 1 to 4 - *most power outages are caused by damage from trees and tree limbs falling on local electricity distribution lines and poles*.
- Faulty equipment / human error tops the list for PADD 5.

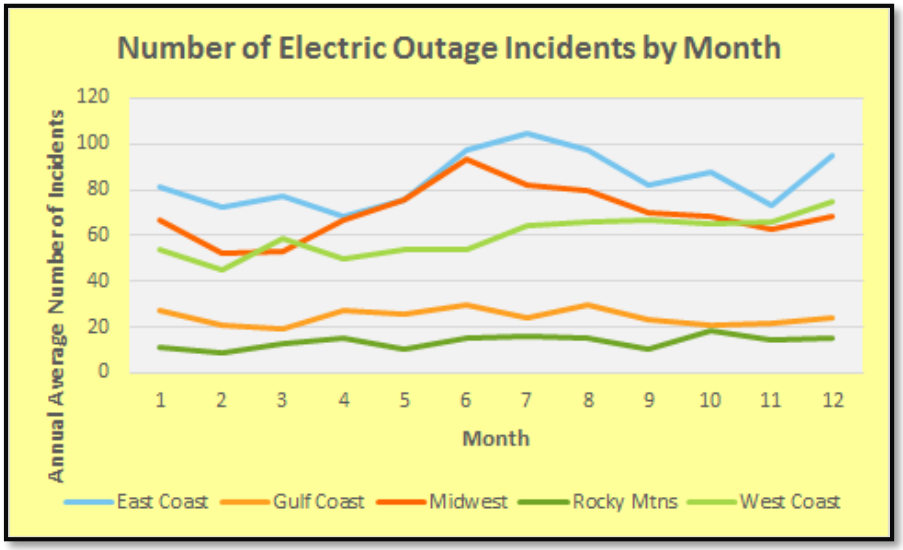
Top-Five Causes of Electric Distribution Outages by PADD (2008 - 2014)					
Rank by Number of Incidents	PADD 1 (East Coast)	PADD 2 (Midwest)	PADD 3 (Gulf Coast)	PADD 4 (Rocky Mtns)	PADD 5 (West Coast)
1	Weather / Falling Trees	Weather / Falling Trees	Weather / Falling Trees	Weather / Falling Trees	Faulty Equipment / Human Error
2	Faulty Equipment / Human Error	Faulty Equipment / Human Error	Faulty Equipment / Human Error	Faulty Equipment / Human Error	Weather / Falling Trees
3	Unknown	Unknown	Unknown	Unknown	Unknown
4	Vehicle Accident	Animal	Vehicle Accident	Vehicle Accident	Vehicle Accident
5	Animal	Vehicle Accident	Animal	Planned Outage	Planned Outage

- "Unknown" events include those with "multiple initiating" causes.
- Outages are also caused by vehicles driving into components of the electric system.

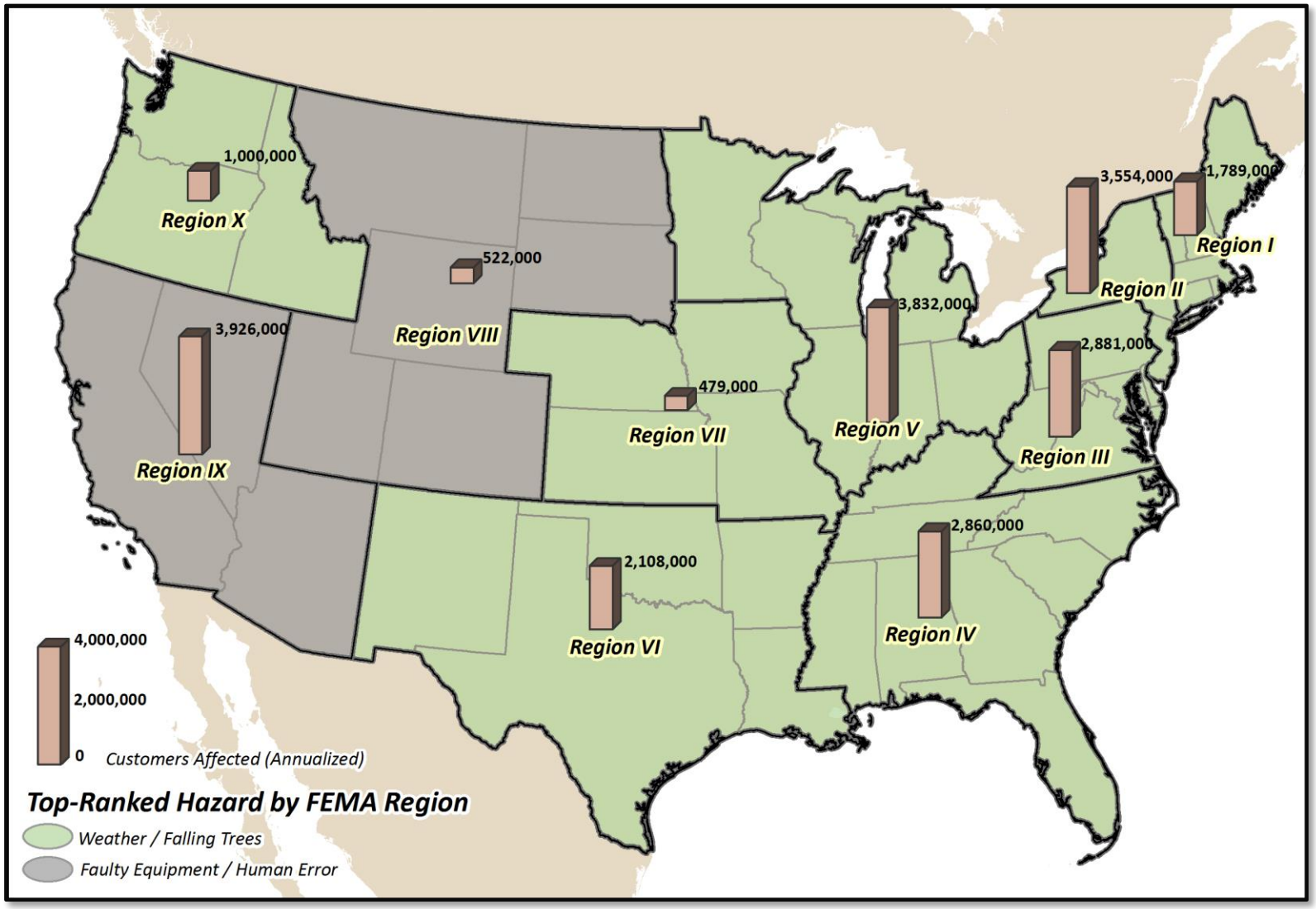
Data on Electric Distribution Outages

- According to data from the U.S. DOE and the North American Electric Reliability Corporation, the U.S. power grid has the most customer outage minutes per year for its economic size:
  - Typically 2 to 3 thousand power outages annually
  - Between 14 to 42 million people affected
- East Coast topped the list with the most affected electric customers, followed by Midwest and West Coast:
  - Apparently due to combined effects of Hurricane Irene and Superstorm Sandy.
- Peak outage season for PADDs 1 to 3 occurs during the summer:
  - Due to potential for severe weather during the summer
  - Peak for PADDs 4 and 5 occurs during the fall-winter seasons

Electric Distribution Outage Statistics (2008 - 2014)			
PADD / Region	Annual Number of Incidents	Annualized Total Affected Customers	Annualized Total Duration of Outage (days)
East Coast	1,013	10,282,000	36
Gulf Coast	294	2,261,000	10
Midwest	839	5,034,000	37
Rocky Mtns	159	560,000	10
West Coast	720	4,823,000	36



Data on Electric Distribution Outages by FEMA Region



What are the Major Threats to Petroleum Transport?

Top-Five Causes of Major Rail and Truck Incidents Involving Crude Oil and Petroleum Transport by PADD (1971 - 2014)					
Rank by Economic Loss	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
1	Collision / Rollover	Collision / Rollover	Collision / Rollover	Collision / Rollover	Collision / Rollover
2	Miscellaneous / Unknown	Miscellaneous / Unknown	Miscellaneous / Unknown	Miscellaneous / Unknown	Miscellaneous / Unknown
3	Natural Forces	Natural Forces	Natural Forces	Incorrect Operation	Natural Forces
4	Incorrect Operation	Incorrect Operation	Incorrect Operation	Natural Forces	Incorrect Operation
5	Material / Weld Failures	Material / Weld Failures	Material / Weld Failures	Material / Weld Failures	Material / Weld Failures

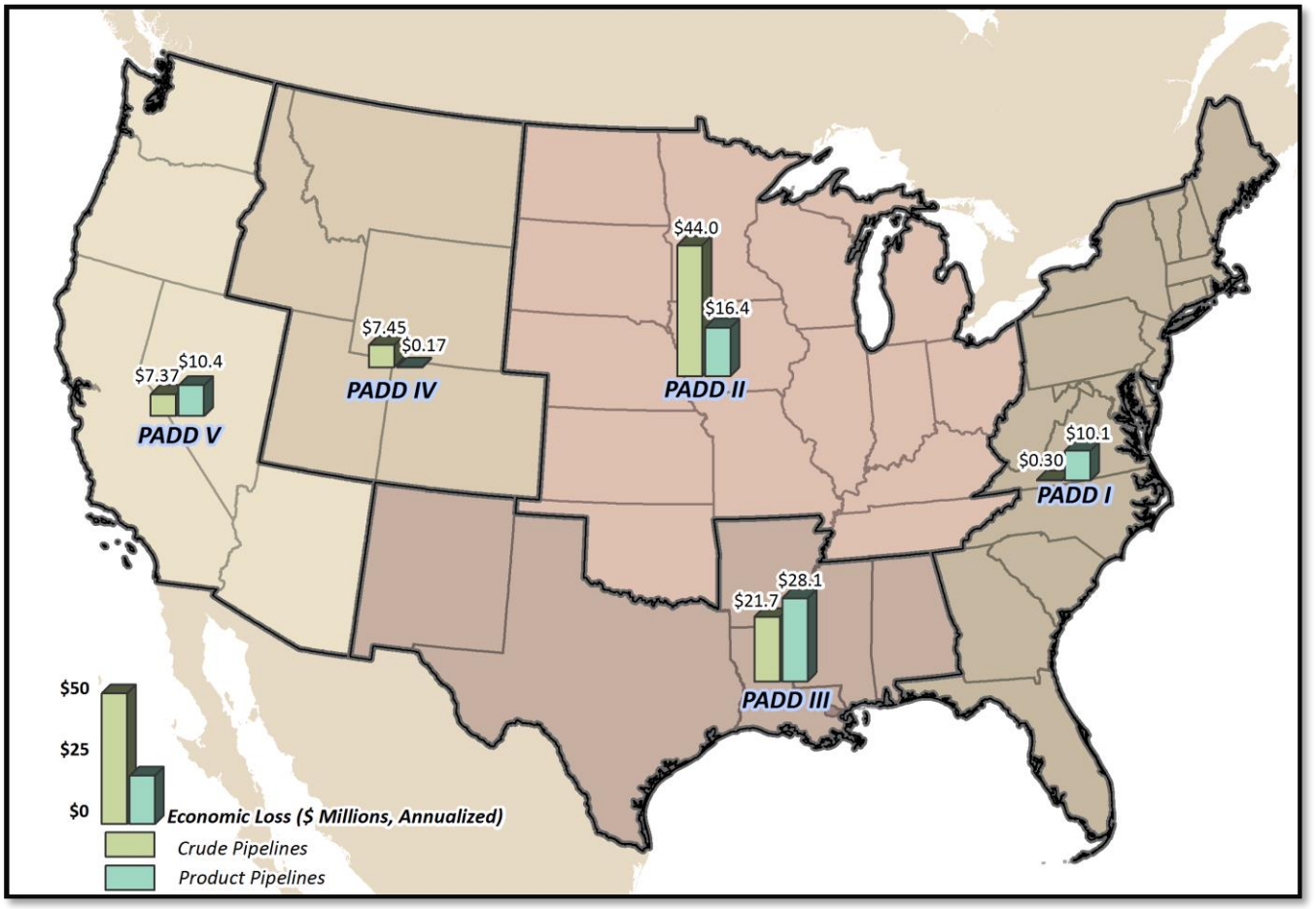
- Collision / Rollover is a type of vehicle accident in which a vehicle tips over onto its side or roof.
- Miscellaneous / Unknown denotes incidents in which the cause is unknown or has multiple causes (e.g., Collision / Rollover with Corrosion).

- Outside Force damage results from some external force such as excavation activities ("third-party" damage).
- Natural Force Damage occurs as a result of naturally occurring events such as flooding, earthquakes, and lightning.

Top-Five Causes of Major Incidents Involving Crude and Petroleum Pipelines by PADD (1986 - 2014)					
Rank by Economic Loss	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
1	Corrosion	Material / Weld Failures	Outside Force	Natural Forces	Outside Force
2	Outside Force	Corrosion	Corrosion	Outside Force	Miscellaneous / Unknown
3	Material / Weld Failures	Outside Force	Natural Forces	Corrosion	Corrosion
4	Miscellaneous / Unknown	Miscellaneous / Unknown	Material / Weld Failures	Incorrect Operation	Incorrect Operation
5	Equipment Failure	Incorrect Operation	Miscellaneous / Unknown	Material / Weld Failures	Material / Weld Failures

Pipeline Transport of Crude and Petroleum

- More miles of pipeline generally results in more incidents – *due to "third party" damage*
- Unit failure rate (incidents per mile of pipeline) higher for crude versus refined – *higher corrosion with crude*
- Higher economic loss in PADD 2 due to Kalamazoo River crude oil spill in July 2010



Causes of Petroleum Refinery Disruptions

Top-Five Causes of Petroleum Refinery Outages by PADD (2003 - 2014)					
Rank by Number of Incidents	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
1	Equipment Failure or Damage	Maintenance / Turnaround	Equipment Failure or Damage	Fire and/or Explosion	Maintenance / Turnaround
2	Maintenance / Turnaround	Equipment Failure or Damage	Operational Upset or Process Problem	Maintenance / Turnaround	Operational Upset or Process Problem
3	Operational Upset or Process Problem	Operational Upset or Process Problem	Maintenance / Turnaround	Loss of Electric Power or Other Utility Service	Equipment Failure or Damage
4	Loss of Electric Power or Other Utility Service	Cause Not Specified	Loss of Containment / Flaring	Equipment Failure or Damage	Loss of Containment / Flaring
5	Cause Not Specified	Fire and/or Explosion	Cause Not Specified	Cause Not Specified	Loss of Electric Power or Other Utility Service

- Similar causes for petroleum refinery disruption observed throughout the U.S.
- The U.S. Gulf Coast (PADD 3) has some of the world's most sophisticated refineries – contains much equipment that can fail
- A turnaround is a planned break in production so that maintenance may be performed - most refineries go through a turnaround every three to five years

Petroleum Refinery Incidents

- Data collected from DOE-OE "Energy Assurance Daily" on petroleum refinery outages – planned and unplanned
- Typically between 600 to 700 refinery incidents per year
- Highest recent number of refinery incidents occurred in 2013 (nearly 1,300)

Petroleum Refinery Outage Data by PADD (2003 - 2014)				
PADD	Annual Number of Incidents	Number of Operable Refineries (2014)	Average Production Impact (Kbpd)	Percent of PADD Refining Capacity (%)
PADD 1	51	10	109.0	8.4%
PADD 2	106	27	310.2	8.1%
PADD 3	331	56	216.5	2.4%
PADD 4	12	17	56.2	8.8%
PADD 5	132	32	104.8	3.5%

- PADD 3 generally has the most incidents – but also the most refineries
- Average production losses less than 10% of PADD refining capacity for PADDs 1, 2, and 4 – these regions contain the least number of refineries
- Impact of refinery outages on product supplies depends on many factors – loss of a single refinery can lead to price spikes

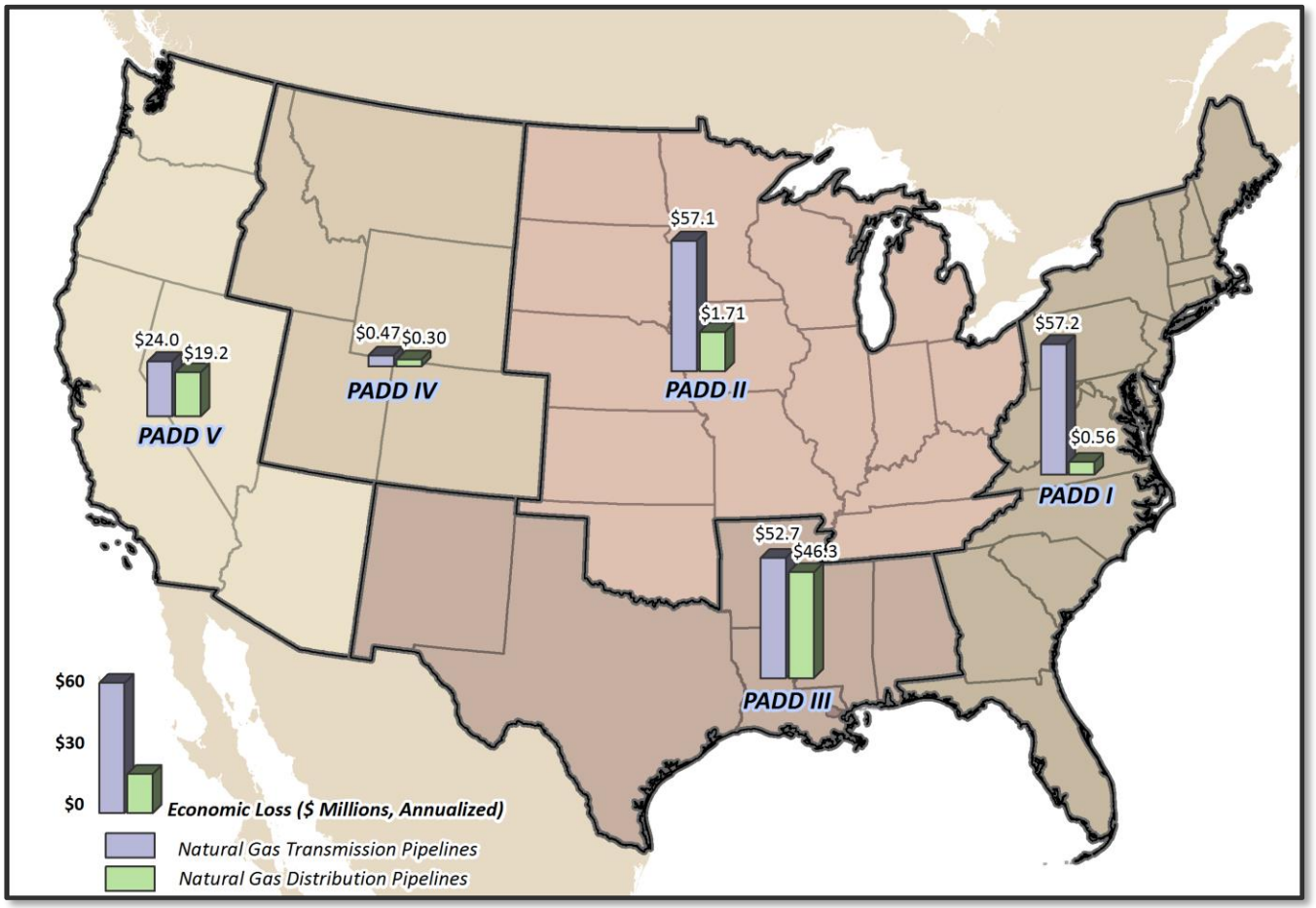
What are the Major Threats to Natural Gas Transport?

Top-Five Causes of Major Incidents Involving Natural Gas Distribution and Transmission Pipelines by PADD (1984 - 2014)					
Rank by Economic Loss	PADD 1	PADD 2	PADD 3	PADD 4	PADD 5
1	Miscellaneous / Unknown	Outside Force	Outside Force	Outside Force	Material / Weld Failures
2	Outside Force	Miscellaneous / Unknown	Natural Forces	Miscellaneous / Unknown	Outside Force
3	Natural Forces	Natural Forces	Miscellaneous / Unknown	Natural Forces	Miscellaneous / Unknown
4	Corrosion	Corrosion	Corrosion	Material / Weld Failures	Natural Forces
5	Material / Weld Failures	Incorrect Operation	Material / Weld Failures	Equipment Failure	Corrosion

- Outside Force damage is generally the primary cause of disruption to the natural gas pipeline network.
- Natural Forces such as flooding and lightning is also a major cause.
- Corrosion of natural gas pipelines is less of a concern compared with petroleum pipelines.

Natural Gas Pipeline Incidents

- DOT/PHMSA data available on natural gas pipeline accidents and their causes.
- Unit failure rate (incidents per mile of pipeline) similar for transmission and distribution
- Higher economic losses in Gulf Coast region due to high pipeline density in this region.



Conclusions

- Regional profiles present most common threats and outages impacting energy infrastructure:
  - Based on Energy Risk Profiles developed for 50 States and District of Columbia.

- The energy sector in the various regions of the U.S. face different threats and hazards:
  - The East and Gulf Coasts (PADDs 1 and 3) historically disrupted by hurricanes and associated severe weather conditions.
  - Hazards affecting the Midwest (PADD 2) include storms, floods, and other forms of extreme weather.
  - Thunderstorms and lightning have a major impact on the Rocky Mountain States (PADD 4) and West Coast (PADD 5).

- Sufficient historical data exists to estimate the likelihood and impacts of disruptions to energy sector components:
  - One very useful source is the DOE-OE “Energy Assurance Daily”

Thank you very much!

We look forward to your questions and comments!