National Academy of Sciences Report of Electric System Resiliency:

Natural Gas and Electric System Interdependencies

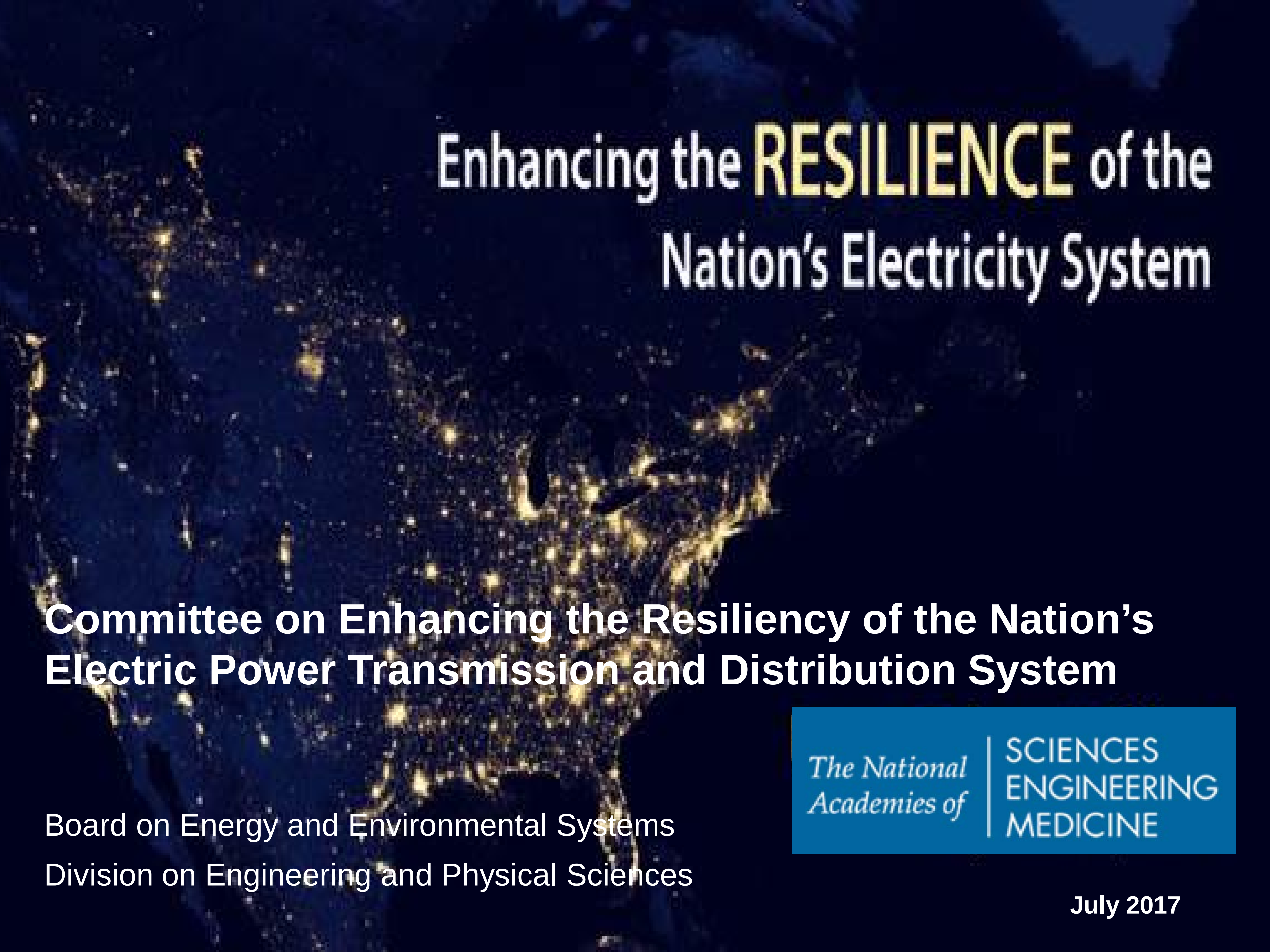
Sue Tierney

NAESB Meeting, September 2017









Committee on Enhancing the Resiliency of the Nation's Electric Power Transmission and Distribution System

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Division on Engineering and Physical Sciences

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Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Electric-system resilience is different than reliability

re·sil·ient

rəˈzilyənt/

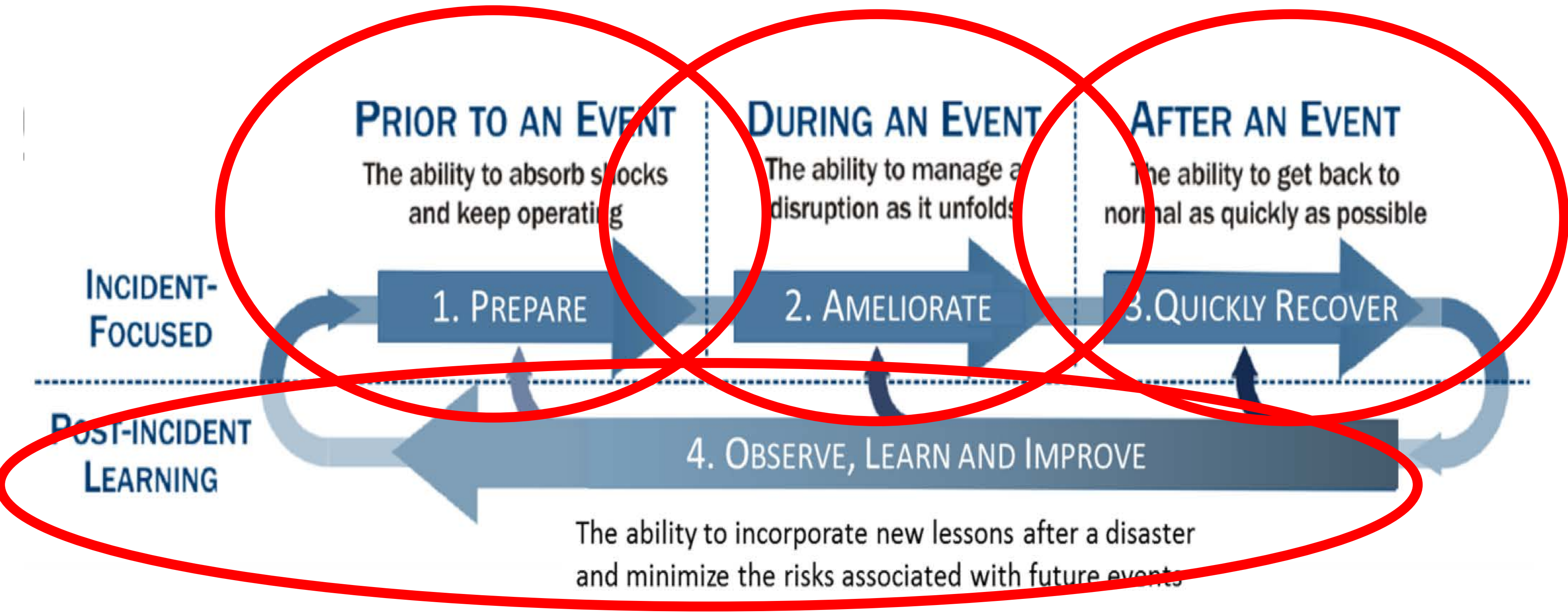
adjective

"the power or ability to return to the original form, position, etc. after being bent, compressed, or stretched . . . [the] ability to recover from illness, depression, adversity, or the like . . . [to] spring back, rebound."

Random House

A resilient system is one that acknowledges that outages can occur, prepares to deal with them, minimizes their impact when they occur, is able to restore service quickly, and draws lessons from the experience to improve performance in the future.

"Resilience Cycle"



This framing was originally laid out in an article by S.E. Flynn in *Foreign Affairs* (2008). An earlier version of the diagram was produced by the National Infrastructure Advisory Council (NIAC, 2010). The committee modified it for our report

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Most disruptions are brief and local

Such outages are *not* the subject of this report.

The NAS report focused on long, large-scale outages.

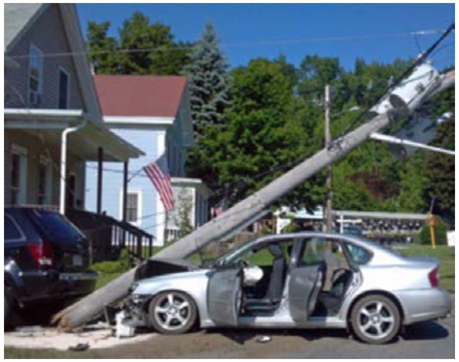


Image sources: wcvb.com; wikipedia; consumerwarningnetworrk.com; lightingsafety.com; rhizome.com

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Causes of grid failure

Human induced

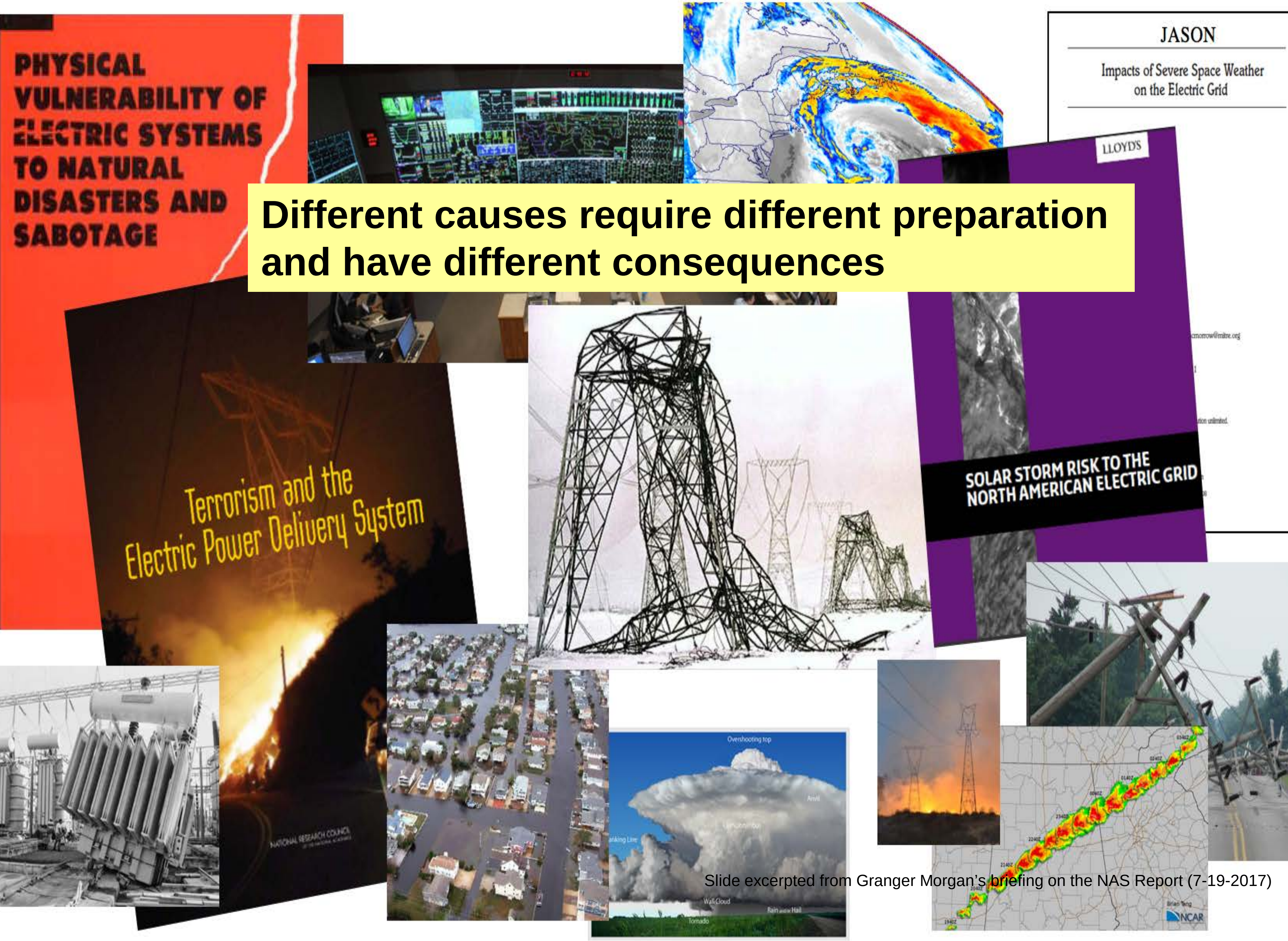
- **Physical attack**
- **Cyber attack**
- **Operat(or/ion) error(s)**

Natural events

- **Drought and associated water shortage**
- **Earthquake**
- **Flood/storm surge**
- **Hurricane**
- **Ice storm**
- **Pandemic**
- **Regional storms and tornados**
- **Space weather**
- **Tsunami**
- **Volcanic events**
- **Wild fire**

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Different causes require different preparation and have different consequences



Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Large outages are more common than one might think

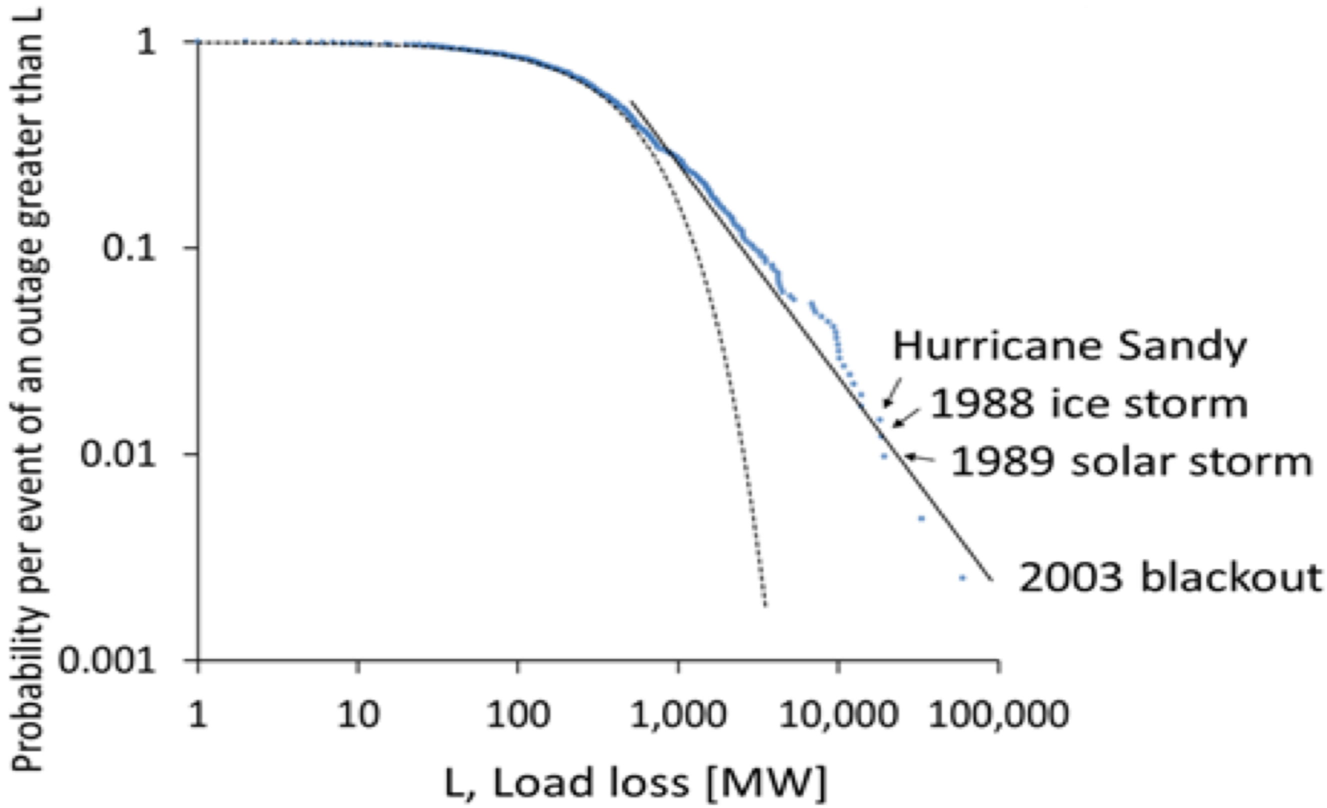
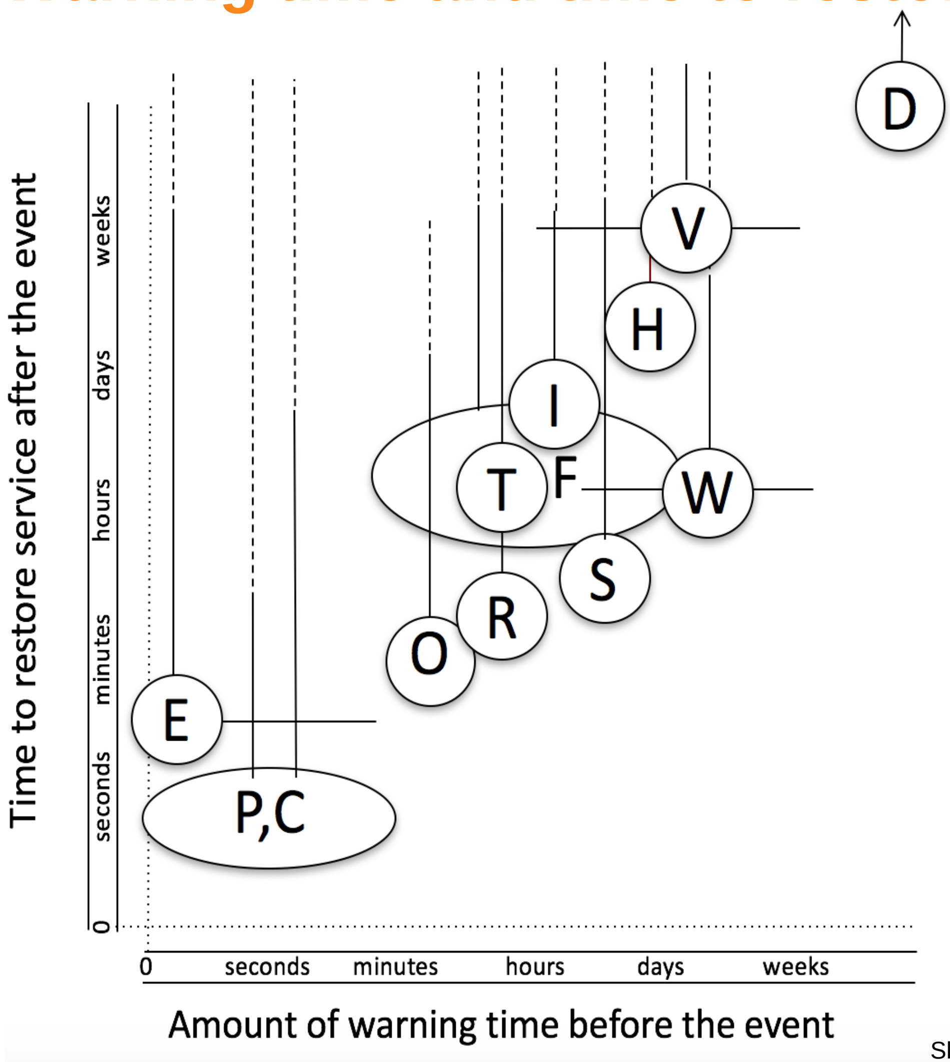


FIGURE 1.1 The relative frequency of outages in the U.S. bulk power system over the period from 1984 to 2015. The figure includes 1,002 events with load loss (loss in electricity demand) greater than 1 MW. The dashed line fits an exponential distribution to the more frequent events with load loss below 500 MW. Note that large outage events do not fit this line and are much more common than one might expect from an extrapolation of the frequency of smaller events. SOURCE: Data are from EIA (2000-2015), NERC (2000-2009), and NRC (2012).

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Warning time and time to restore



C = cyber attack (ranging from state/pro on left to good hacker on right)
D = drought and associated water shortage
E = earthquake (in some cases with warning systems)
F = flood/storm surge
H = hurricane
I = ice storm
O= major operator error
P = physical attack
R = regional storms and tornados
S = space weather
T = tsunami
V = volcanic events
W= wild fire

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Observations in the study

- **Electricity is critical to modern society – and everyone depends upon a reliable power system.**
- **For the next several decades+, most customers will continue to depend on the bulk power electric grid.**
- **The grid is undergoing dramatic change.**
- **No single entity is in charge of planning the evolution of the grid.**
- **Large outages of long duration have occurred and will occur.**
- **Virtually no one has a primary mission of building and sustaining increased system-wide resilience.**

Gas/electric interdependence

At least in the near term, the U.S. natural gas industry and the U.S. electric industry are and will continue to be highly interdependent:

- **The electric industry will become even more dependent upon natural gas than it has been in the past**
- **The natural gas industry will rely on power sector demand for a growing and important share of its market for some years to come**

Similarities across the electric and gas industries

Both industries:

- separated the delivery function from commodity supply
- allow market-based prices for commodity supply
- have rate-regulated transmission service (FERC)
- have state-regulated local distribution companies
- have predominantly private ownership of assets
- have systems that cross state lines
- have regional varied markets

Differences: Physical footprint, different regulatory history

Natural gas:

- **Reflects a history of needing to connect production regions to distant consumption regions**
- **Federal siting of interstate pipelines – but increasingly contentious and controversial certification proceedings**

Electricity:

- **Rooted in local generation serving local end users (with fuel moved to power plant locations from source)**
- **State siting of interstate power lines – with long-standing challenges to approvals**

Differences: Lateral versus network systems

Natural gas:

- **Long-distance pipeline systems owned by individual companies with end-users served off a company's system, with limited numbers of transfer points along the lateral systems.**

Electricity:

- **Physically interconnected and networked bulk-power system with power flows linking supply and demand within each Interconnection (East, West, Texas).**

Differences: Commodity markets

Natural gas:

- **Unregulated upstream production**
- **Competitive commodity prices**
- **Demand highly sensitive to price**

Electricity:

- **Regulation of production through state and federal agencies**
- **Market-based wholesale energy prices subject to FERC review**
- **Demand is somewhat sensitive to price**

Differences: Many more….

Universal service:

- **Natural gas: does not have universal service**
- **Electric utilities: obligation to serve, retail universal service**

Demand outlook:

- **Natural gas demand: growing overall; flat demand in LDC markets**
- **Electricity demand: is flat at retail and wholesale levels**

Market and operational time scales:

- **Natural gas: moves at a 15-20 mile/hour pace on the interstate system**
- **Electricity: operates in fractions-of-seconds time scales**

Differences: Industry reliability organizations & standards

Natural gas:

- **No mandatory industry-wide reliability organization**
- **Operating standards reflect a combination of FERC policy, NAESB standards and business practices of companies**

Electricity:

- **Post EPACT 2005, FERC/NERC mandatory reliability standards re: planning, operational, communications, cyber – with NAESB standards for many practices**
- **Utilities and other industry participants have voluntary agreements for cooperative support for reliability purposes**
- **States largely hold resource adequacy requirements – with FERC's role in RTO markets with a capacity market design**

Some implications for electricity:

Issues relating to market design, operational schedules and coordination issues – e.g.,:

- **Across and within regions – incentives vary for generators' committing to firm transportation on interstate pipelines**
- **In some regions – chicken-and-egg timing problems**
  - **Generators need to commit to move gas volumes before knowing whether their energy offers have been accepted**
  - **Generators need to offer prices into such energy markets without fully knowing the price of their natural gas**
  - **Generators and grid operators need highly flexible gas supply over the course of a day**
- **FERC, NAESB, industry participants have been considering and are still wrestling with how to address these issues**

Some implications for electric resiliency:

Different attitudes exist across the two industries regarding:

- **the urgency of anticipated changes in natural gas supply associated with growing use for electricity generation**
- **the need for improved and more nimble delivery capability of gas in light of changing electric mix and dispatch**

There will be continuing need to stay ahead of changing conditions in the two industries

Strains at the intersection of gas and electric systems

Too little coordinated information exchange…..makes resilience too difficult to realize….

NAS Report

"Decisions by myriad market actors and institutions do not typically reflect coordinated information about the performance of systems either across industry segments (e.g., across the electric and gas industries) or within industry supply chains (e.g., from production sources across interstate transmission systems)."

"In the context of the events that occur in one or more parts of the industries' systems, this absence of coordination mechanism may make some aspects of resilience—preparing for outages so as to limit their impact, sustaining service during an outage, and/or in restoring the systems to normal operations after the event—difficult to realize."

Strains at the intersection of gas and electric systems

The two industries – broadly defined – need to pay more attention to the gas/electric coordination issue

NAS Report

"For the electric system to become more reliable and resilient, attention must be paid to assuring the availability of adequate natural gas resources at all periods of time, including through investment in natural gas infrastructure (e.g., contractual arrangements and siting and construction of pipelines or storage), where it is economical to do so, fuel diversity for electric generators and natural gas compressors, and the alignment of planning and operating practices across the two industries."

Recommendation #4.7: to FERC and NAESB

"The growing interdependence of natural gas and electricity infrastructures requires systematic study and targeted efforts to improve coordination and planning across the two industries."

"FERC and NAESB, in conjunction with industry stakeholders, should further prioritize their efforts to improve awareness, communications, coordination, and planning between the natural gas and electric industries. Such efforts should be extended to consider explicitly what recovery strategies should be employed in the case of failed interdependent infrastructure. Fuel diversity, dual fuel capability, and local storage should be explicitly addressed as part of these resilience strategies."

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

National Academies of Sciences, Engineering, and Medicine. 2017. *Enhancing the Resilience of the Nation's Electricity System*. Washington, DC: The National Academies Press. https://doi.org/10.17226/24836.

https://www.nap.edu/catalog/24836/enhancing-the-resilience-of-the-nations-electricity-system

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Supplemental slides:
Overarching recommendations from the NAS Report

Overarching Recommendation: #1

Operators of the electricity system, including RTOs, IOUs, coops, and munies **should** work individually and collectively, in cooperation with the Electricity Subsector Coordinating Council, regional and state agencies, FERC, NERC, to **conduct more regional emergency preparedness exercises that simulate accidental failures, physical and cyber attacks, and other impairments that result in large-scale loss of power and/or other critical infrastructure** sectors—especially communication, water, and natural gas. Counterparts from other critical infrastructure sections should be involved, as well as state, local, and regional emergency management offices.

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Overarching Recommendation: #2

Operators of the electricity system, including RTOs, IOUs, coops, and munies **should** work individually and collectively to **more rapidly implement resilience-enhancing technical capabilities and operational strategies that are available today and to speed the adoption of new capabilities and strategies as they become available**.

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Overarching Recommendation: #3

DOE…should sustain and expand the substantive areas of RD&D now being undertaken by the Office of Electricity Delivery and Energy Reliability and Office of Energy Efficiency and Renewable Energy, with respect to grid modernization and systems integration, with the explicit intention of improving the resilience of the U.S. power grid. Field demonstrations of physical and cyber improvements that could subsequently lead to widespread deployment are critically important. The Department of Energy should collaborate with parties in the private sector and in states and localities to jointly plan for and support such demonstrations.

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Overarching Recommendation: #4

Through public and private means, the U.S. should substantially increase the resources committed to the physical components needed to ensure that critical electric infrastructure is robust and that society is able to cope when the grid fails. Some of this investment should focus on making the existing infrastructure more resilient and easier to repair.

- DOE should launch a program to manufacture and deploy flexible and transportable three-phase recovery transformer sets that can be pre-positioned around the country.
- State and federal regulatory commissions and RTOs should evaluate whether grids under their supervision need additional pre-positioned replacements for critical assets that can help accelerate orderly restoration of grid service after failure.
- Public and private parties should expand efforts to improve their ability to maintain and restore critical services—such as power for hospitals, first responders, water supply and sewage systems, and communication systems.
- DOE, DHS, ACOE, the Electricity Subsector Coordinating Council, and other federal organizations, should oversee the development of more reliable inventories of backup power needs and capabilities
- DOE should continue to support the development of a new generation of high-voltage transformers

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Overarching Recommendation: #5

DOE, DHS, academic research teams, the national laboratories, and companies in the private sector, **should carry out a program of RD&D activities to improve the security and resilience of cyber monitoring and controls systems**, including:

- **Continuous collection of diverse (cyber and physical) sensor data**;
- **Fusion of sensor data with other intelligence information** to diagnose the cause of the impairment (cyber or physical);
- **Visualization techniques** needed to allow operators and engineers to maintain situational awareness;
- Analytics (including machine learning, data mining, game theory, and other artificial intelligence-based techniques) to generate **real-time recommendations for actions that should be taken in response to the diagnosed attacks, failures, or other impairments**;
- **Restoration of control system and power delivery functionality** and cyber and physical operational data in response to the impairment; and
- Creation of **post-event tools for detection, analysis, and restoration** to complement event prevention tools.

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Overarching Recommendation: #6

DOE and DHS should jointly establish and support a "visioning" process with the objective of systematically imagining and assessing plausible large-area, long-duration grid disruptions that could have major economic, social, and other adverse consequences, focusing on those that could have impacts related to U.S. dependence on vital public infrastructures and services provided by the grid.

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Overarching Recommendation: #7

FERC and NERC should establish small system resilience groups, informed by the work of the DOE/DHS "visioning" process, to assess and, as needed, to mandate strategies designed to increase the resilience of the U.S. bulk electricity system.

NARUC, with NASEO, should provide guidance to state regulators on how best to respond to identified local and regional power system-related vulnerabilities.

Each state PUC and energy office should have capability to identify vulnerabilities, identify strategies to reduce local vulnerabilities, develop strategies to cover costs of needed upgrades, and help the public to become better prepared for extended outages.

Slide excerpted from Granger Morgan's briefing on the NAS Report (7-19-2017)

Metrics

Metrics for reliability are fairly straight forward because they involve looking at the statistics of past outages

SAIFI, SAIDI, CAIDI, CAIFI, MAIFI

Developing metrics for resilience is extremely challenging because that involves assessing how well we are prepared for, and could deal with, very rare events, some of which have never happened.

DOE should work on improved studies to assess the value to customers of full and partial service during long outages as a function of key circumstances.

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