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Sandia National Laboratories



Energy Infrastructure Resilience

Framework and Sector-Specific Metrics

U.S. DEPARTMENT OF ENERGY | NNSA National Nuclear Security Administration

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The Purpose of This Exercise

- The President mandated a Quadrennial Energy Review to be jointly conducted by several US Departments.
- The concepts on resilience being discussed today will establish a foundation for a national roadmap in resilience, including:
  - Strategic national thrusts
  - R&D thrusts

Defining Resilience

Presidential Policy Directive (PPD) 21

"the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."

-PPD-21: Critical Infrastructure Security and Resilience

"without some numerical basis for assessing resilience, it would be impossible to monitor changes or show that community resilience has improved. At present, no consistent basis for such measurement exists. We recommend therefore that a National Resilience Scorecard be established."

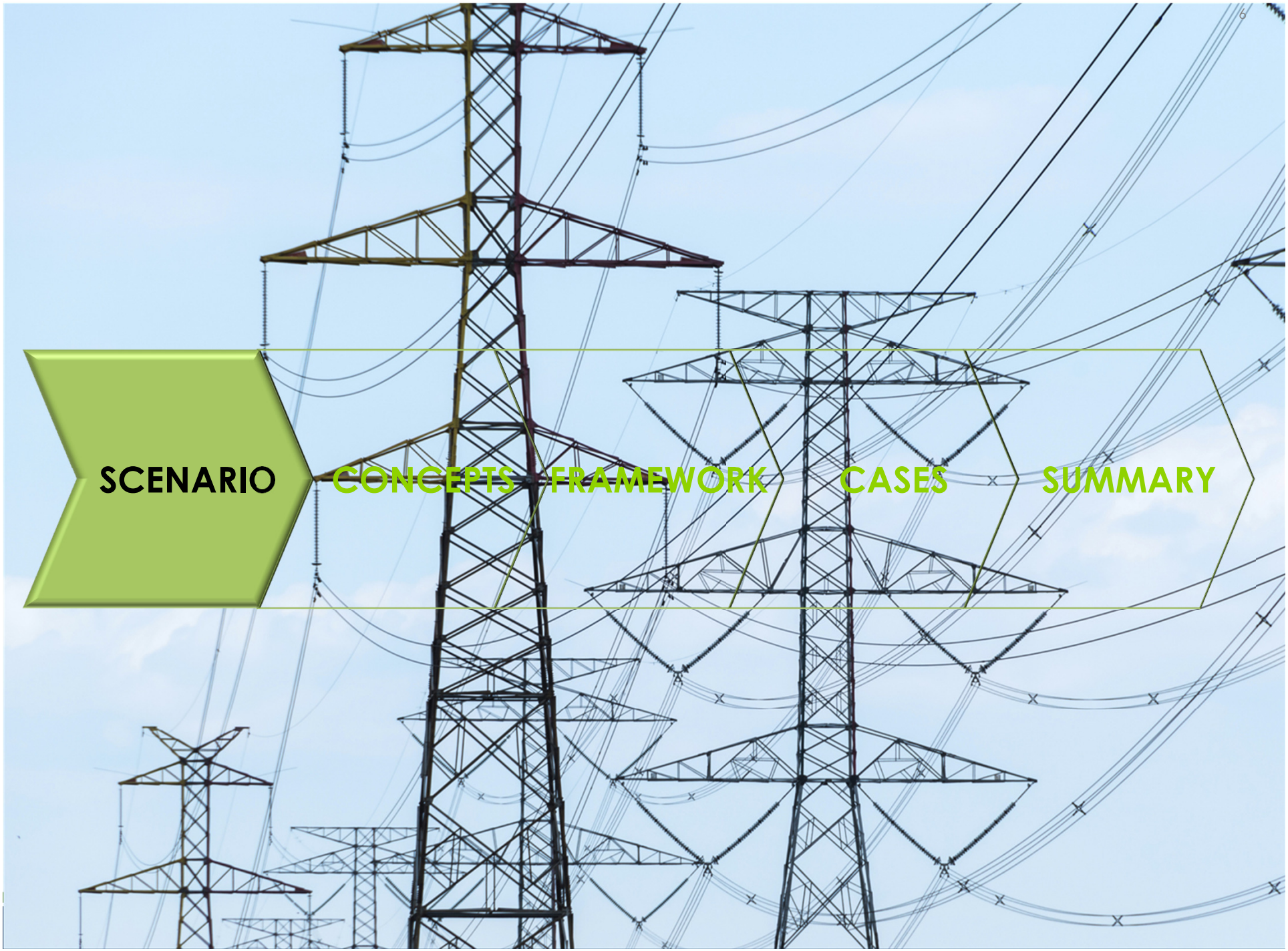
-Disaster Resilience: A National Imperative, National Academy of Sciences

Goals For Today

- Begin a discussion about how to measure resilience
- Explore a general framework for developing energy resilience metrics
- Discuss ‘prototype’ resilience metrics for Oil, Gas, and Electricity
- Review plausible use-cases for electricity resilience metrics
- Collaboratively outline next steps

Takeaway Points

- R&D is needed to address this critical national problem.
- Metrics are needed to enable resilience goals and decisions for our US national strategy.
- The proposed framework applies common principles across energy sectors
- We’re looking forward to your help!


SCENARIO
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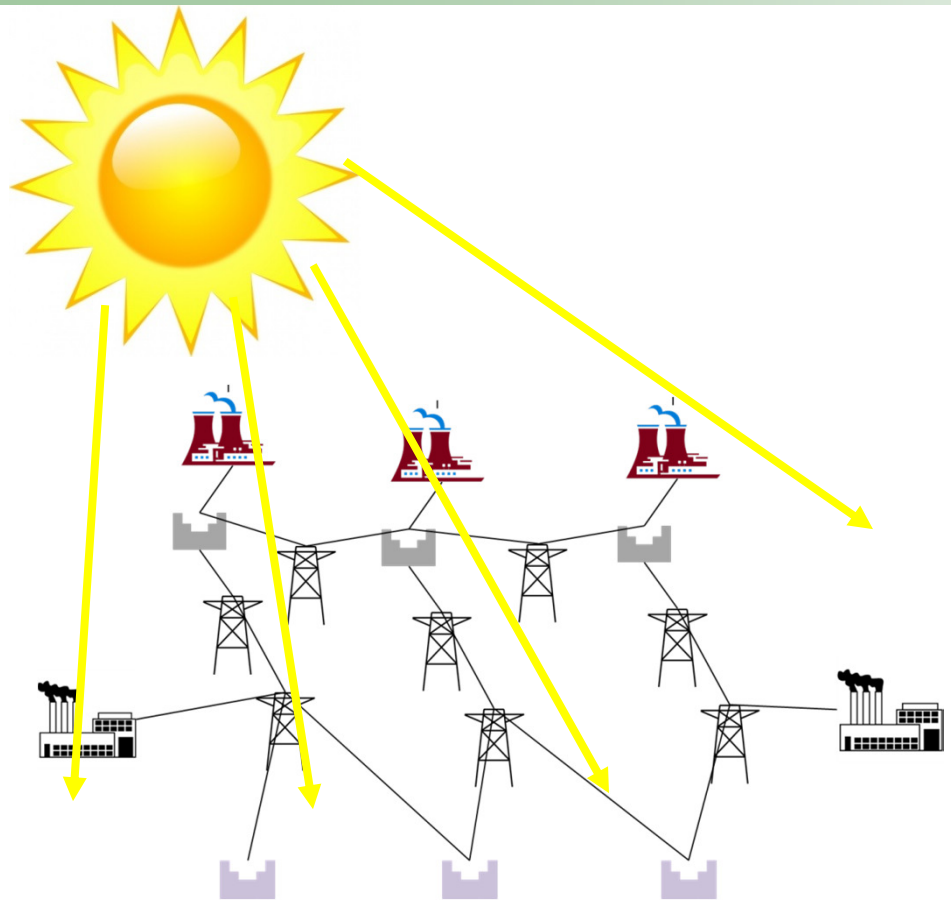
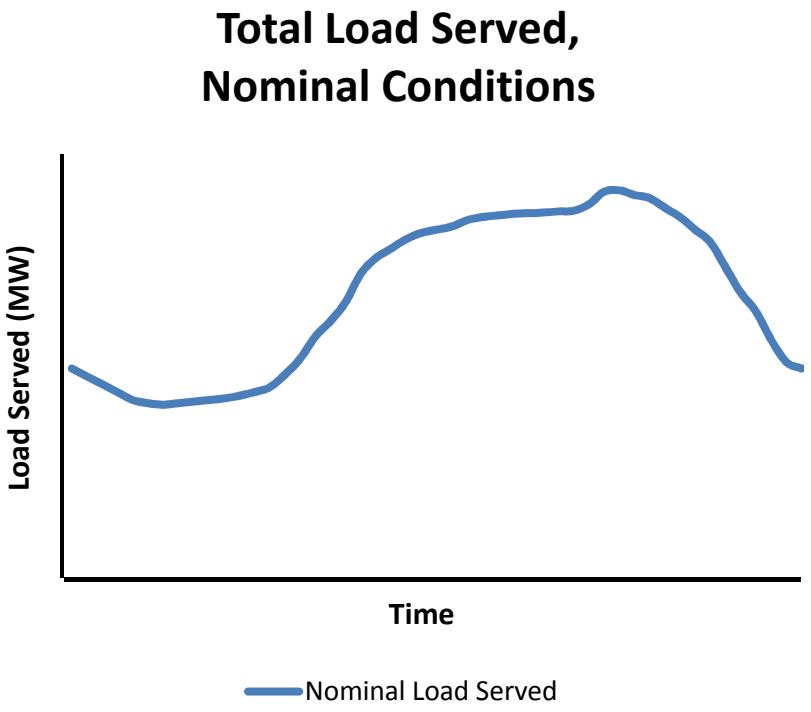
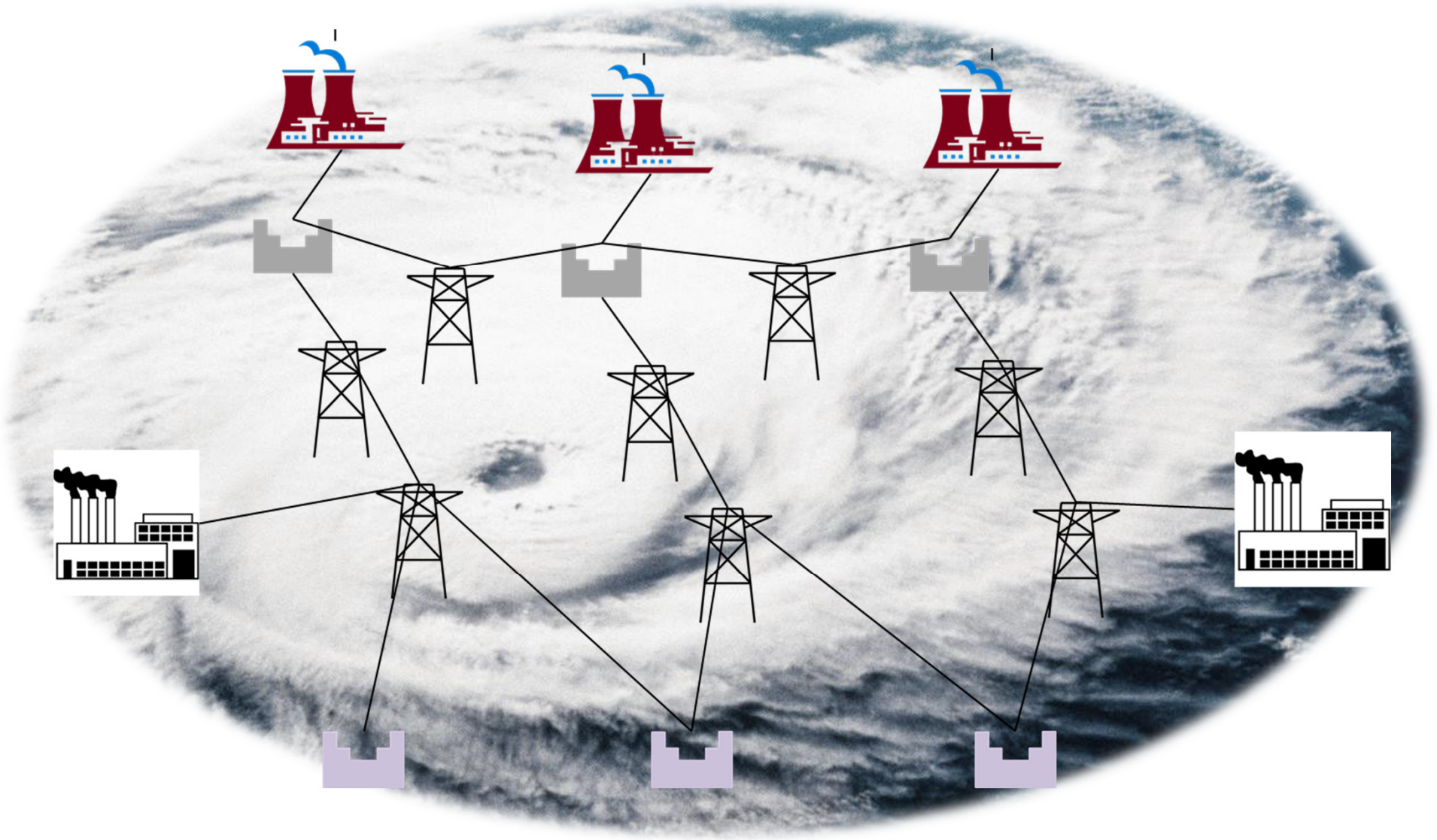
SUMMARY

Illustrative Scenario: Nominal Conditions

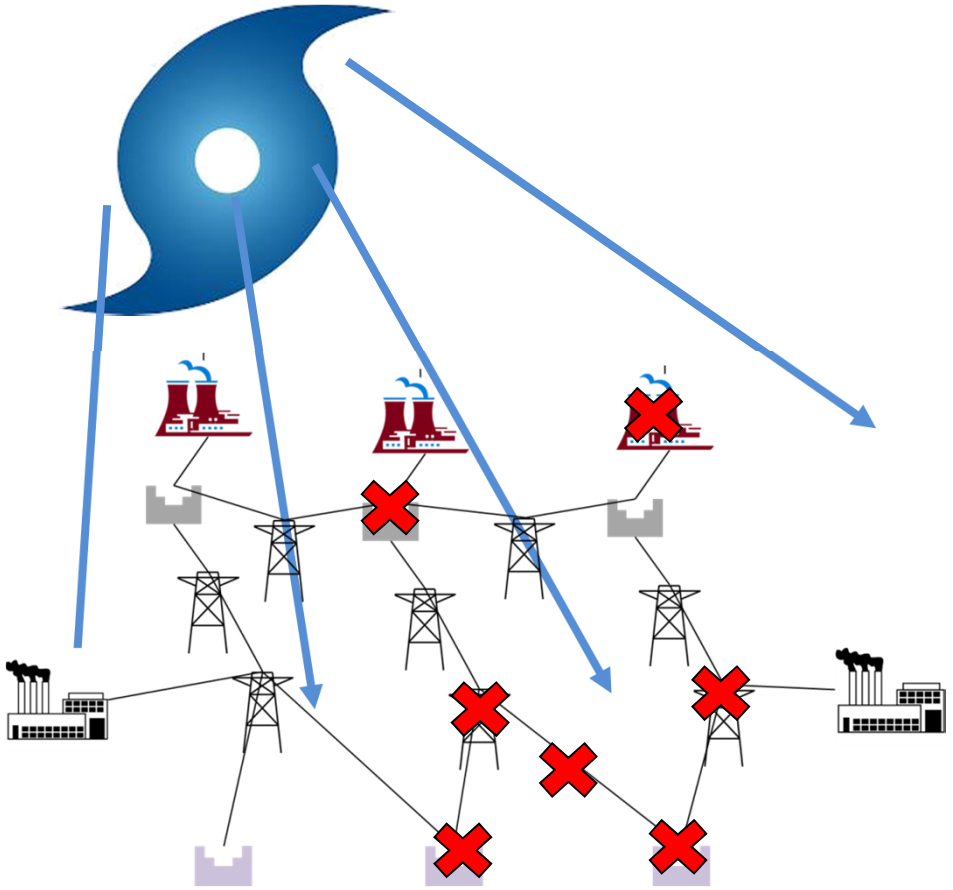


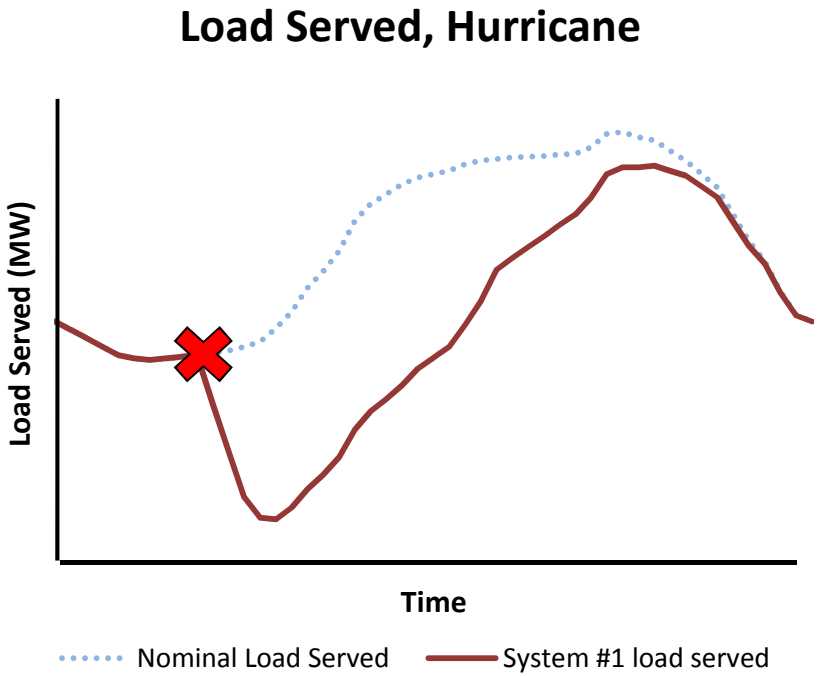


Illustrative Scenario: Hurricane



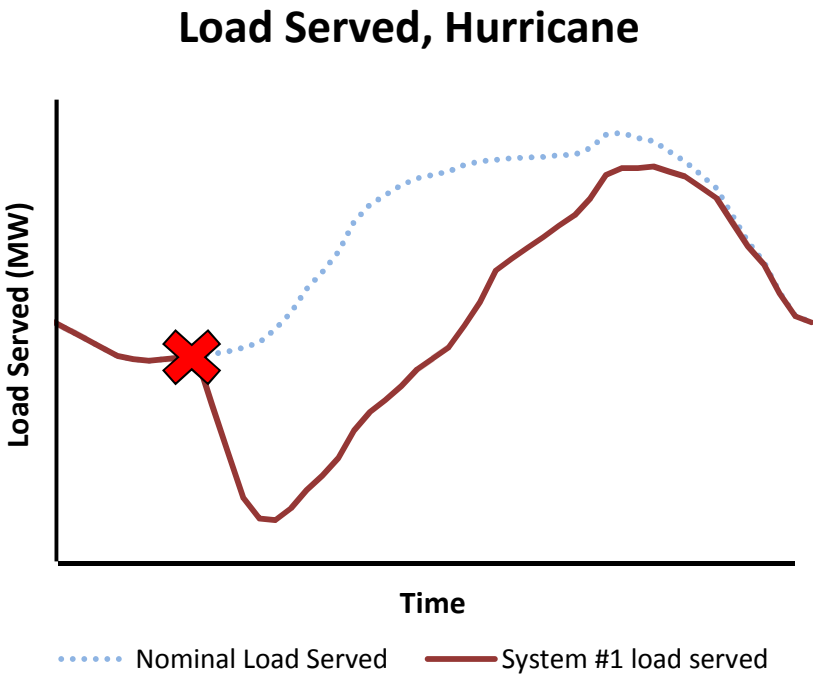
Illustrative Scenario: Impact on Load Served

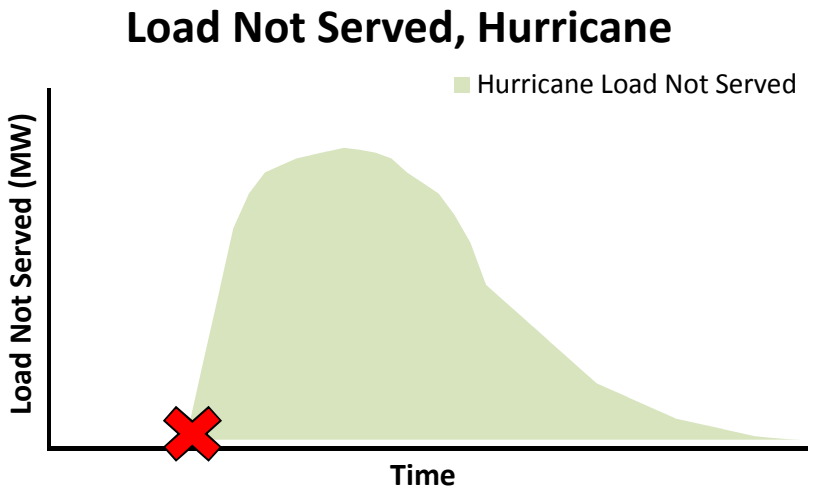


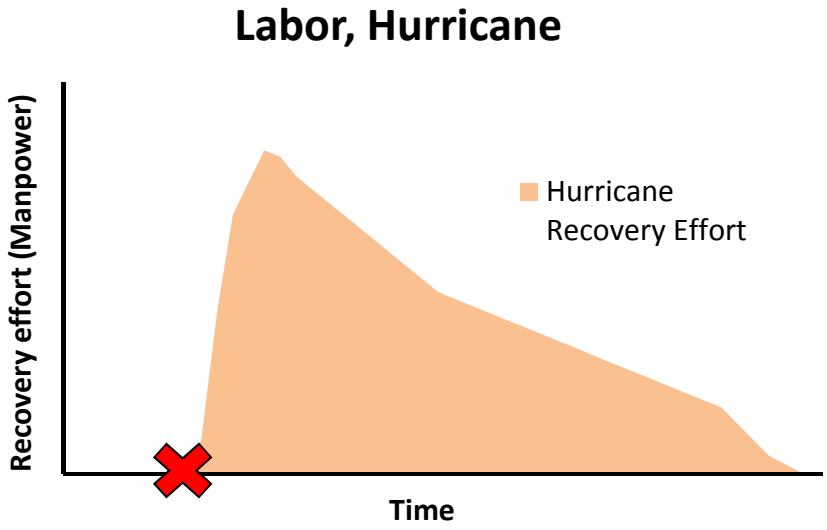


Hurricane affects ability to provide grid services

Illustrative Scenario: Hurricane Impacts







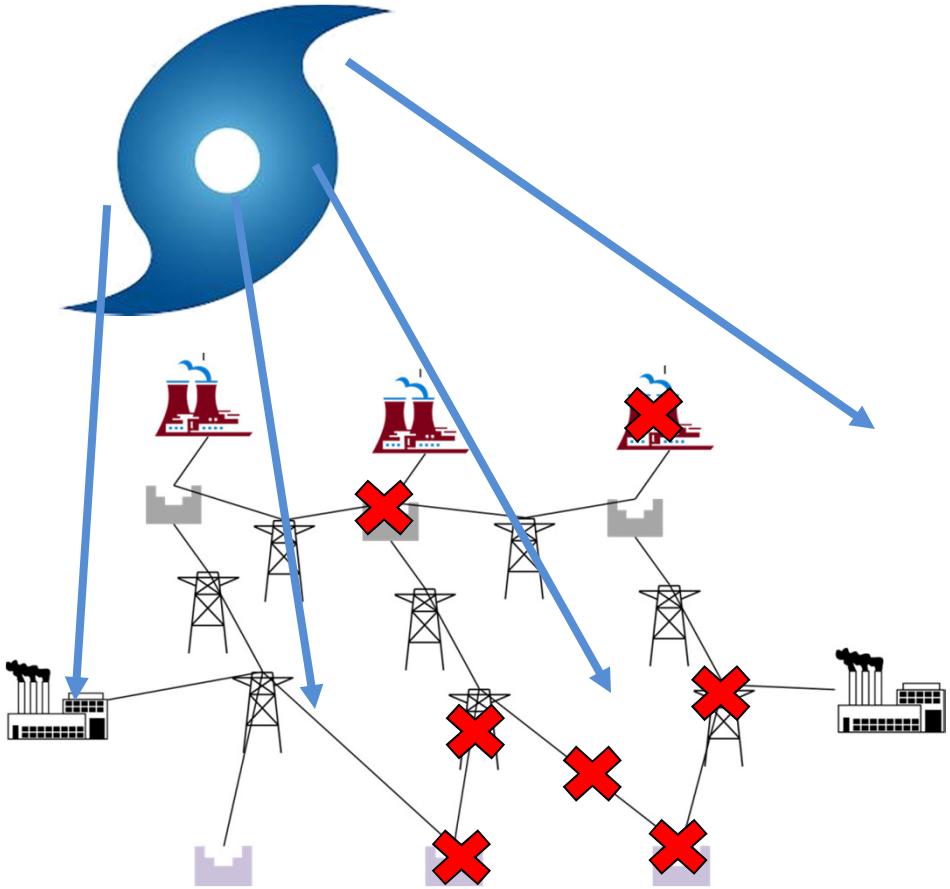
Hurricane damage yields significant impacts

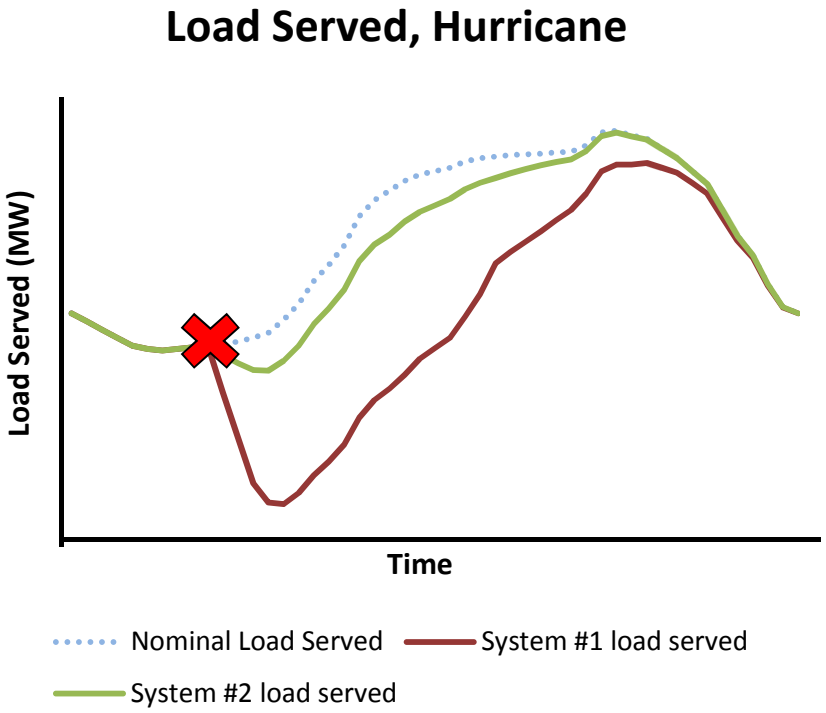
Resilience-Enhancing Activities

- Utility prepares for hurricane
  - Pre-positions recovery supplies
  - Key assets outside of flooding areas
  - Charges battery reserves
- While trying to cope with effects of damage, the utility
  - Brings backup generation online
  - Reconfigures lines to circumvent damaged assets
  - Uses battery and reservoir discharge
- More rapid, less resource-intensive recovery

Illustrative Scenario:

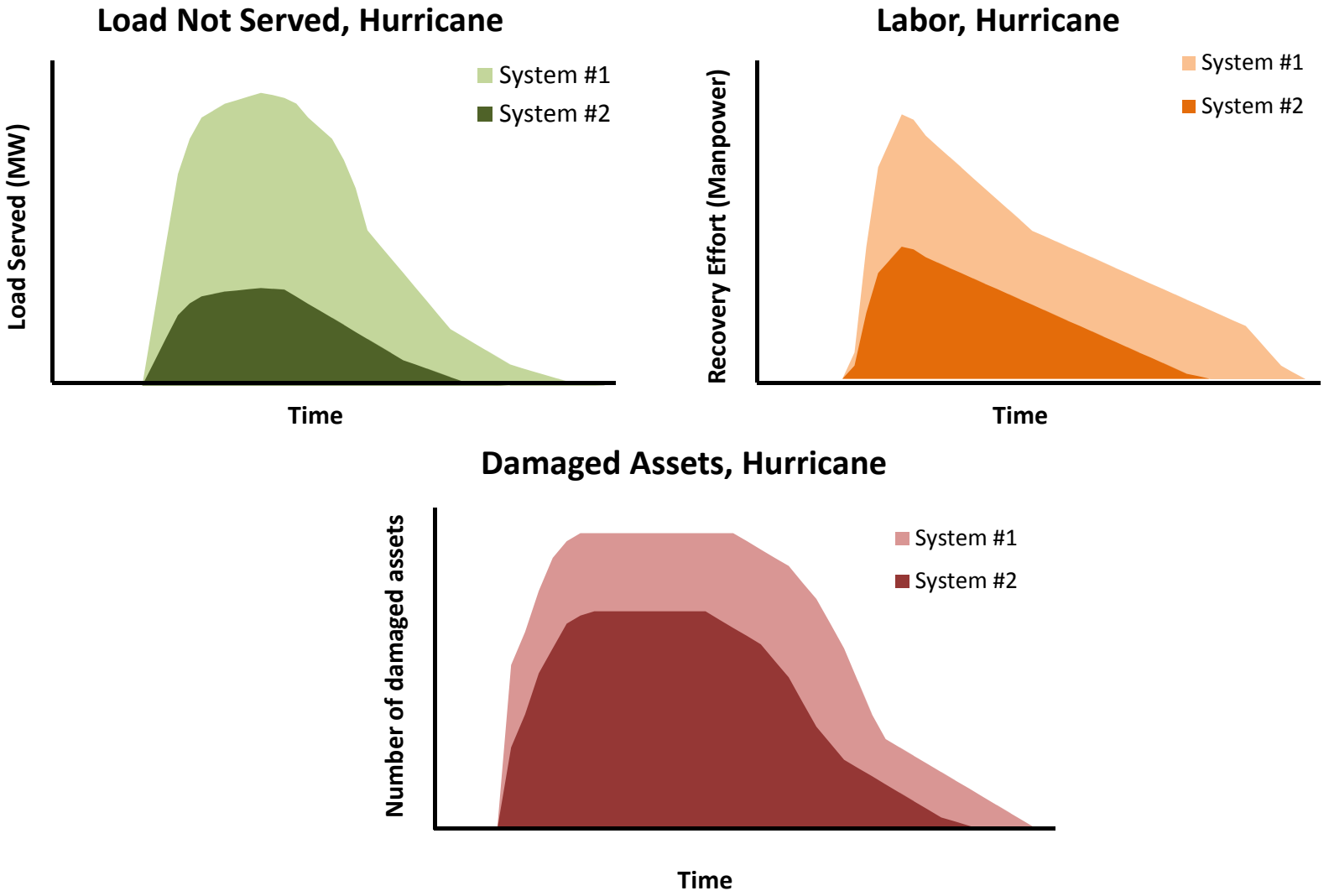
Performance of a more resilient system





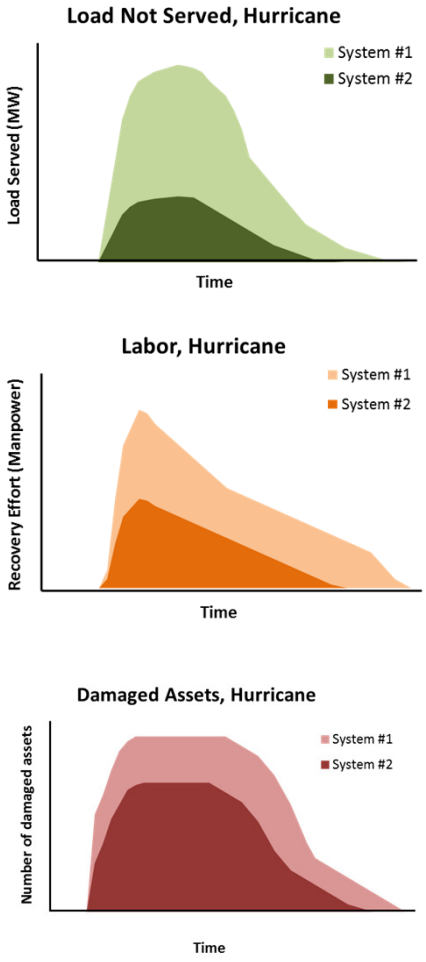
A more resilient system exhibits improved performance

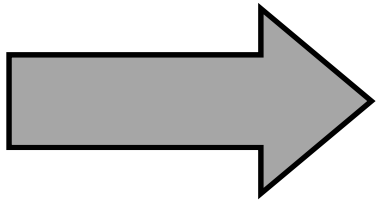
Comparison of Performance Indicators

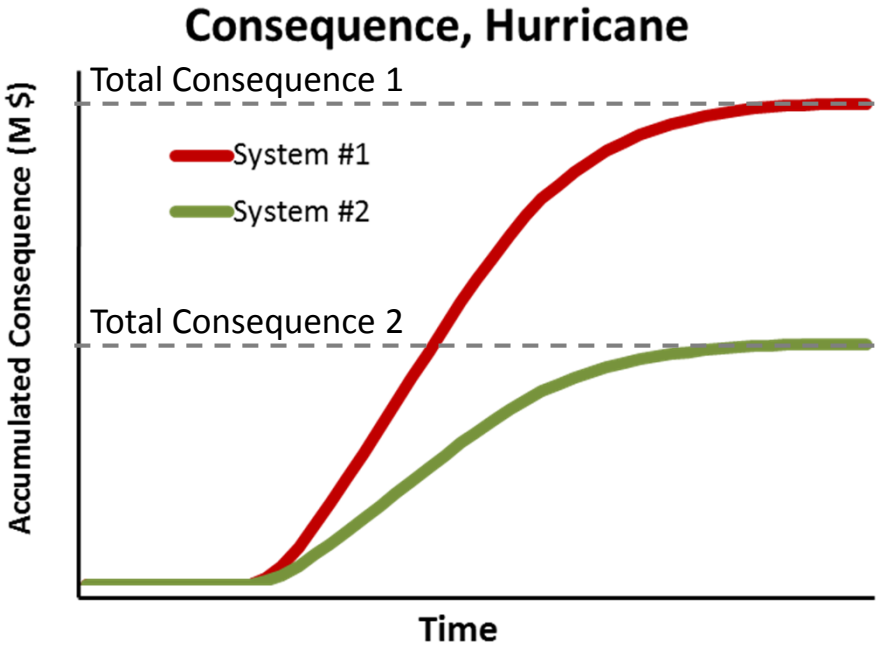


Translation to consequence

Performance Indicators



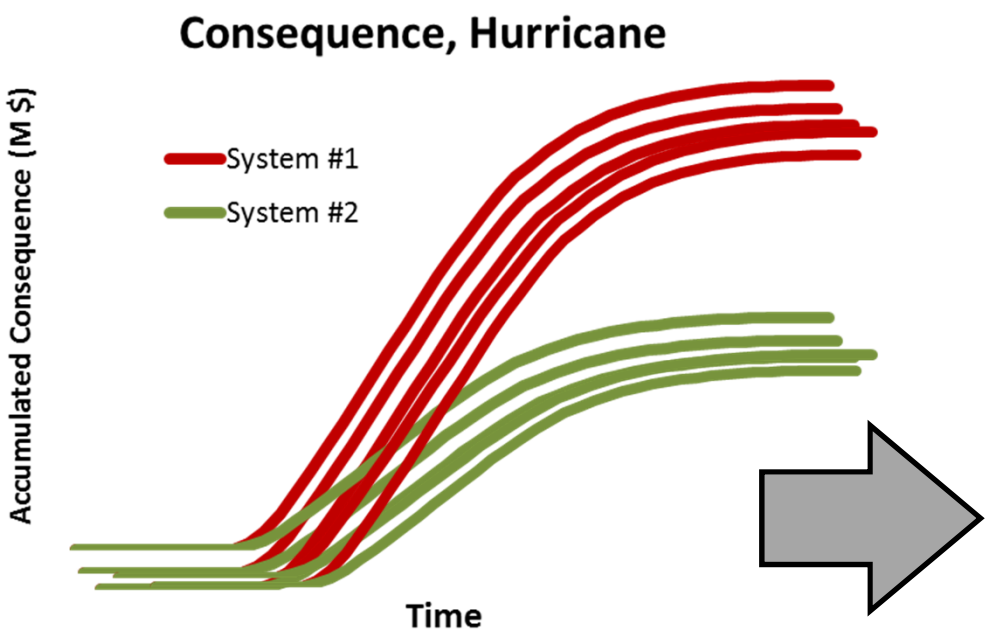


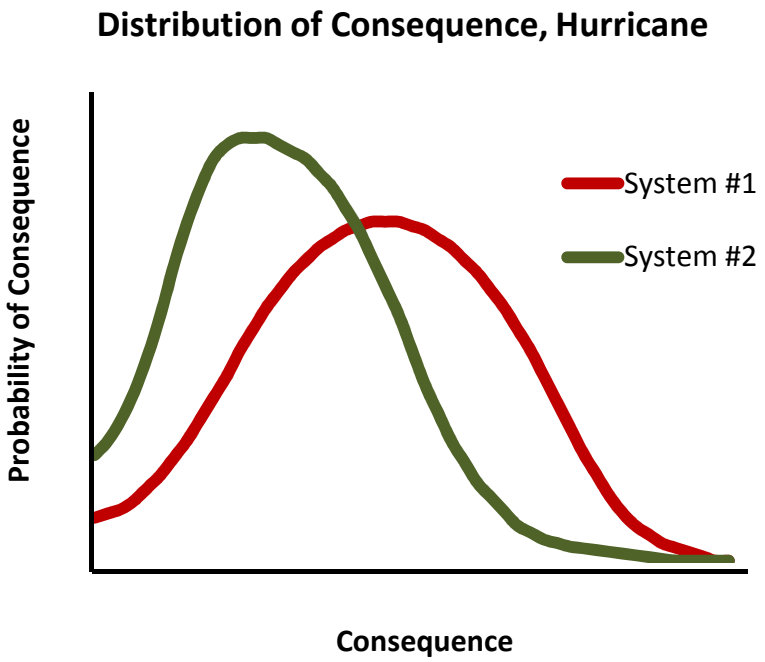


Alternative units:
Safety
Economics
Population affected
Etc…

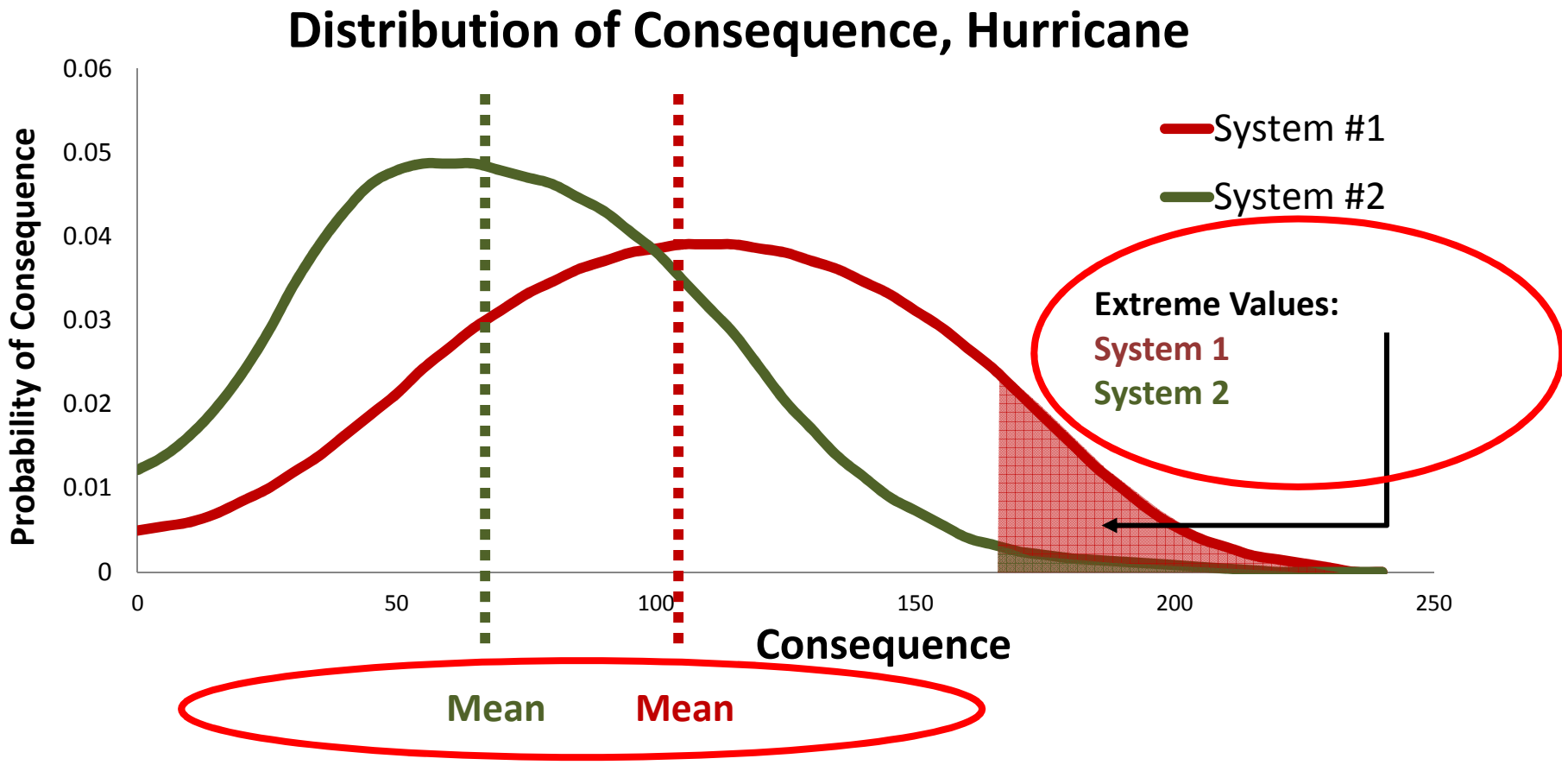
Uncertainty

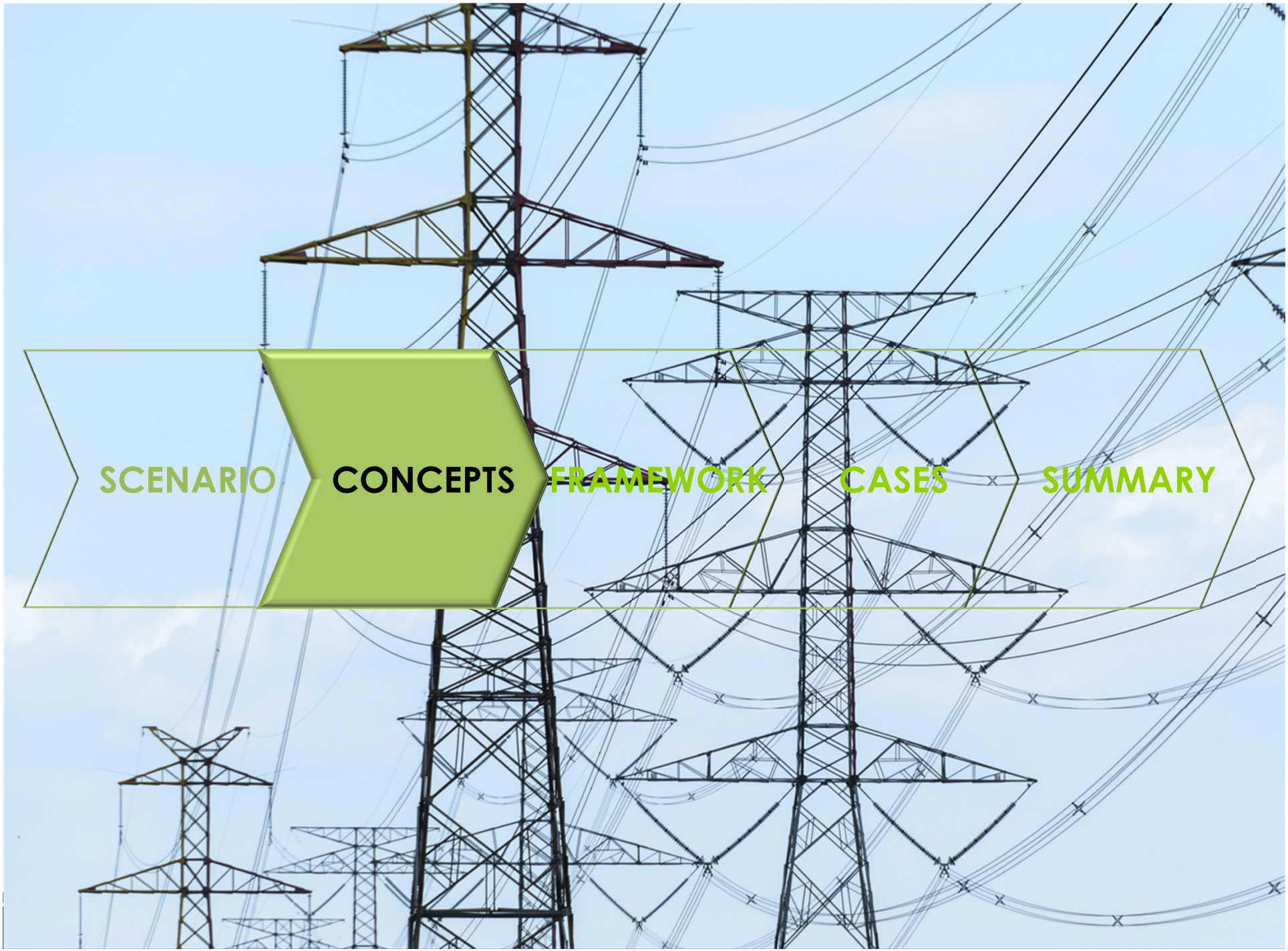
<u>Uncertain</u>:
Disruption impacts
System response
Interdependencies with other systems
Resource availability
Etc…





Enabling Decisions

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Definition of a Metric

- A metric is a measure of something
  - The unit ‘inch’ measures distances
  - ‘Miles per hour’ measures speeds
- Metrics should not be confused with the values that populate them
  - 60 mph is an actual speed, where 60 populates the metric
- We will be making a ‘speedometer’ for resilience

Resilience Complements Reliability

- Reliability is commonly applied to electric power, but is informally applied to oil and gas sectors.
- This work *does not* seek to re-define, displace, or extend existing reliability metrics
- We define resilience to be risk-based, with focus on includes high consequences low probability threats

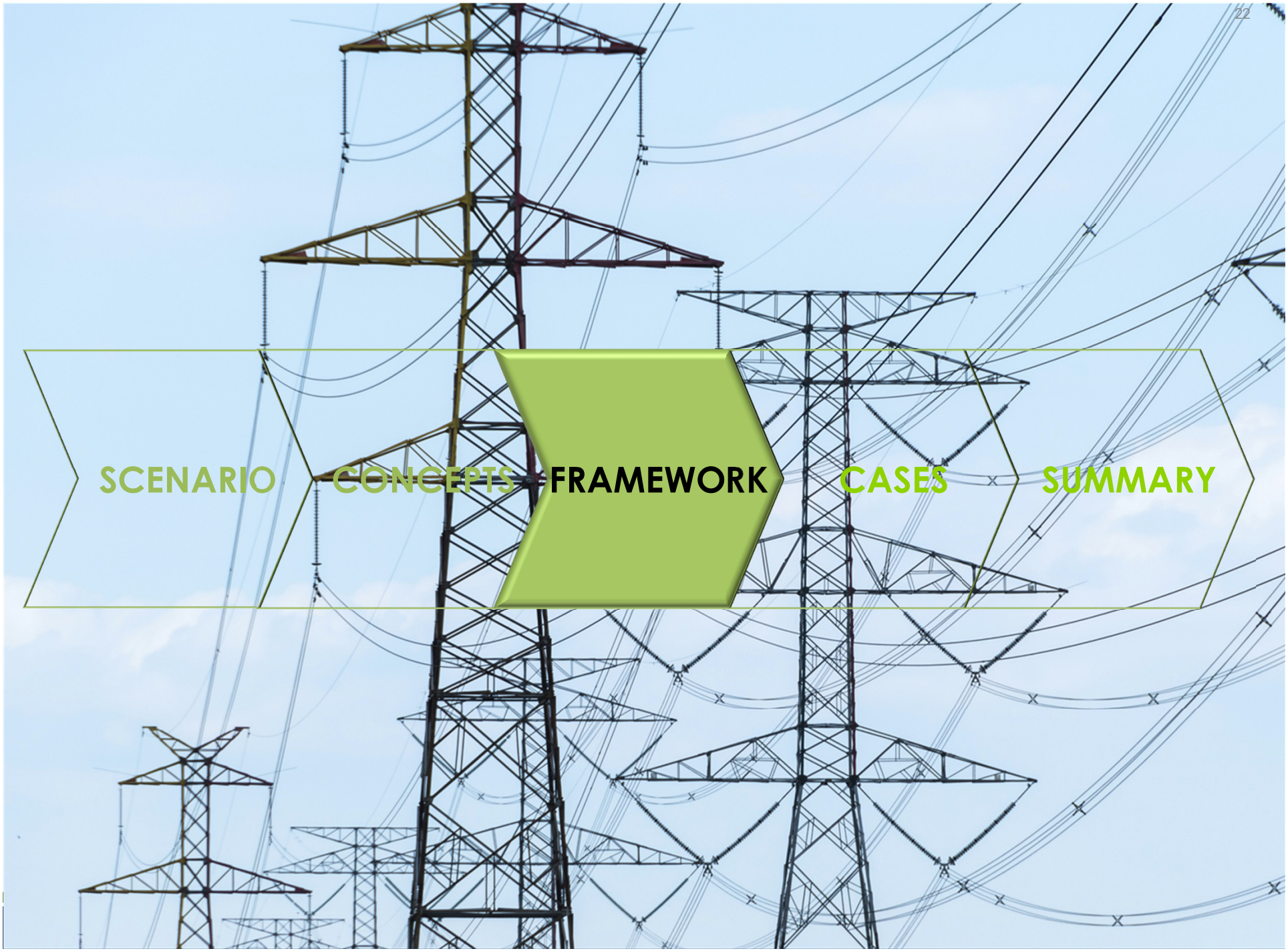
What Resilience Metrics Have to Do

- inform decision making
- provide validity (they properly discriminate)
- are repeatable (robustness to uncertainty)
- are feasible (implementable)
- be useable in a planning or operating context
- allow for uncertainty quantification
- be useable in an analytic context (such as an optimization algorithm)
- the resiliency framework must be scalable

Metrics Inform Better Decision Making

Broad Categories of Decision Making For Energy Infrastructure Systems

1. Policy decisions- how to direct national strategy
2. Planning decisions- whether to inform capital investments
3. Operational decisions- informing real-time decision making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MEASUREMENTS

e.g. voltage, frequency
power flow

INFORMED
DECISION MAKING

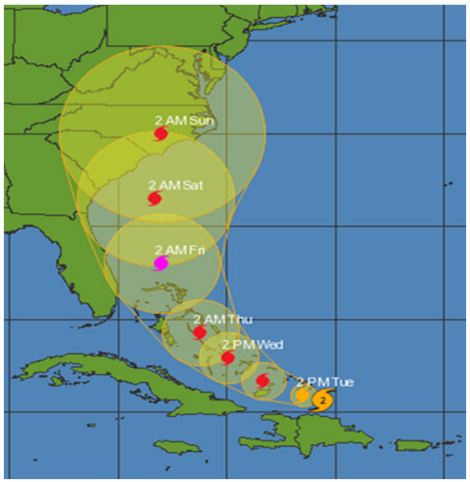
POPULATING RESILIENCE METRICS

From Measurements to Performance Indicators

- Voltage
- Frequency
- Power
- Load Forecasts
- Renewable Gen. Forecasts
- Topology

Forecasts & Measurements

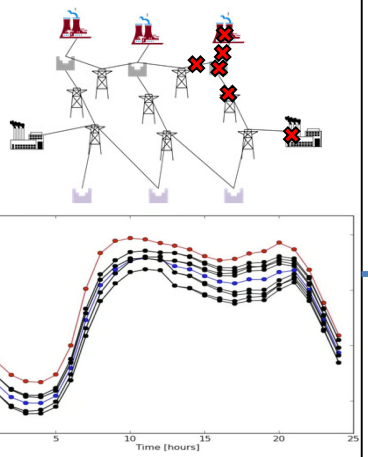
Impending threat



Multiple Models / Algorithms

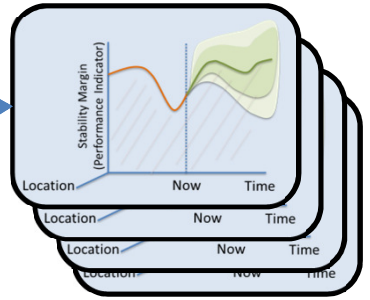
- State Estimation
- Transient Simulation
- Dynamic Simulation
- New Algorithms and Tools

R&D

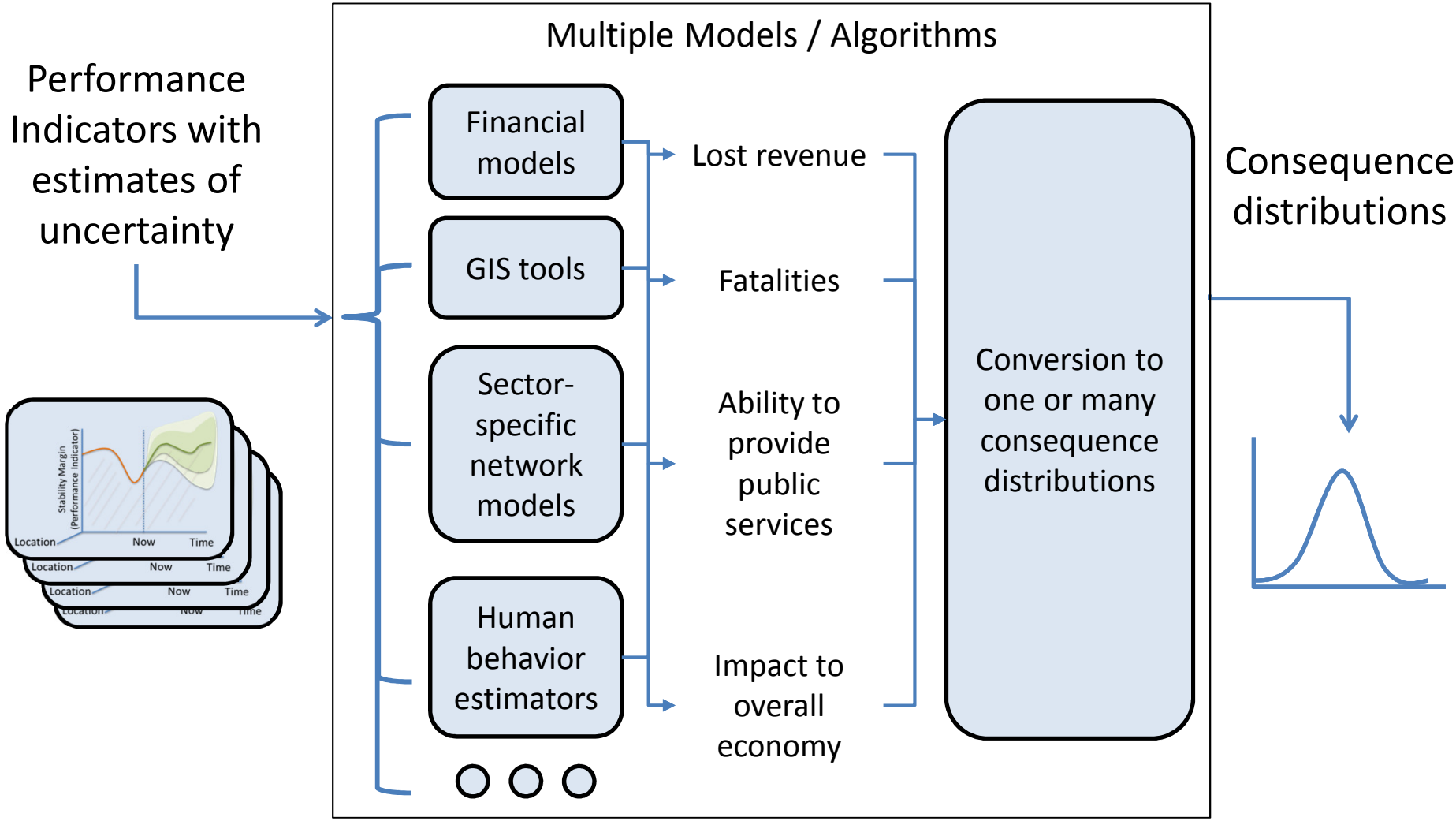


Performance Indicators

- Transfer capability
- Generation shortages
- Stability margins
- ...



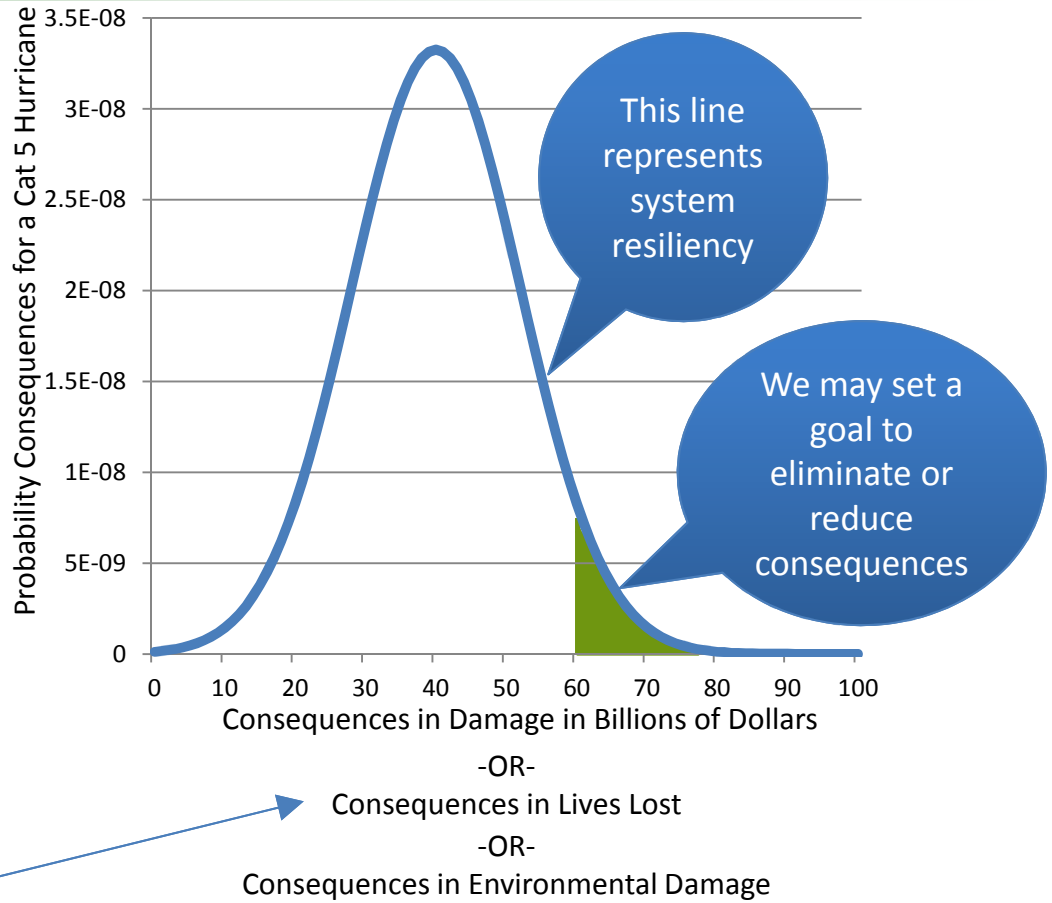
From Performance Indicators to to Consequences



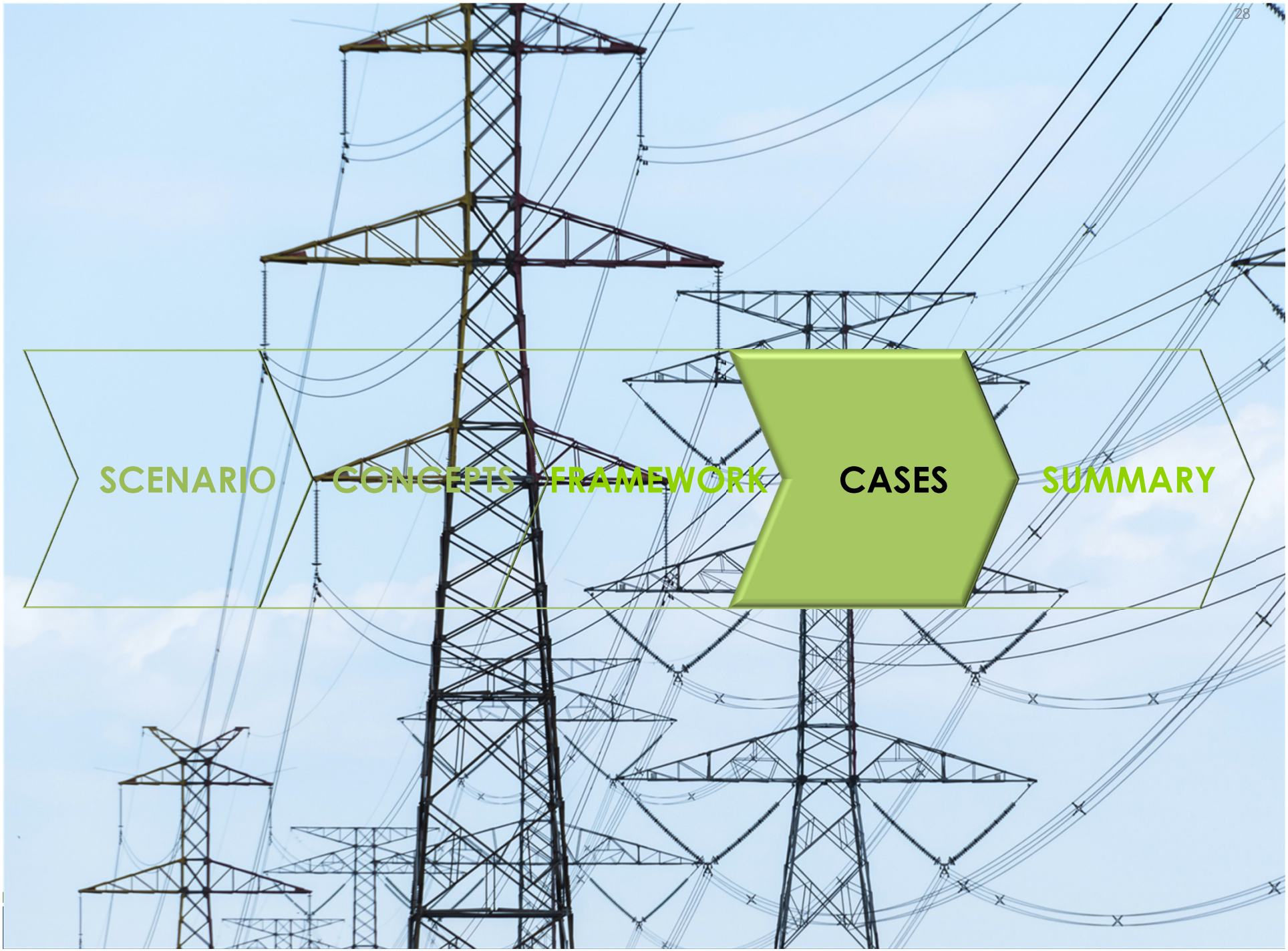
The Form of Resiliency Metrics

- Our proposed resilience metrics take the form of probability density functions

Many PDFs exist for the same system. They reveal resilience for different threats and different consequences



CLOSING THE LOOP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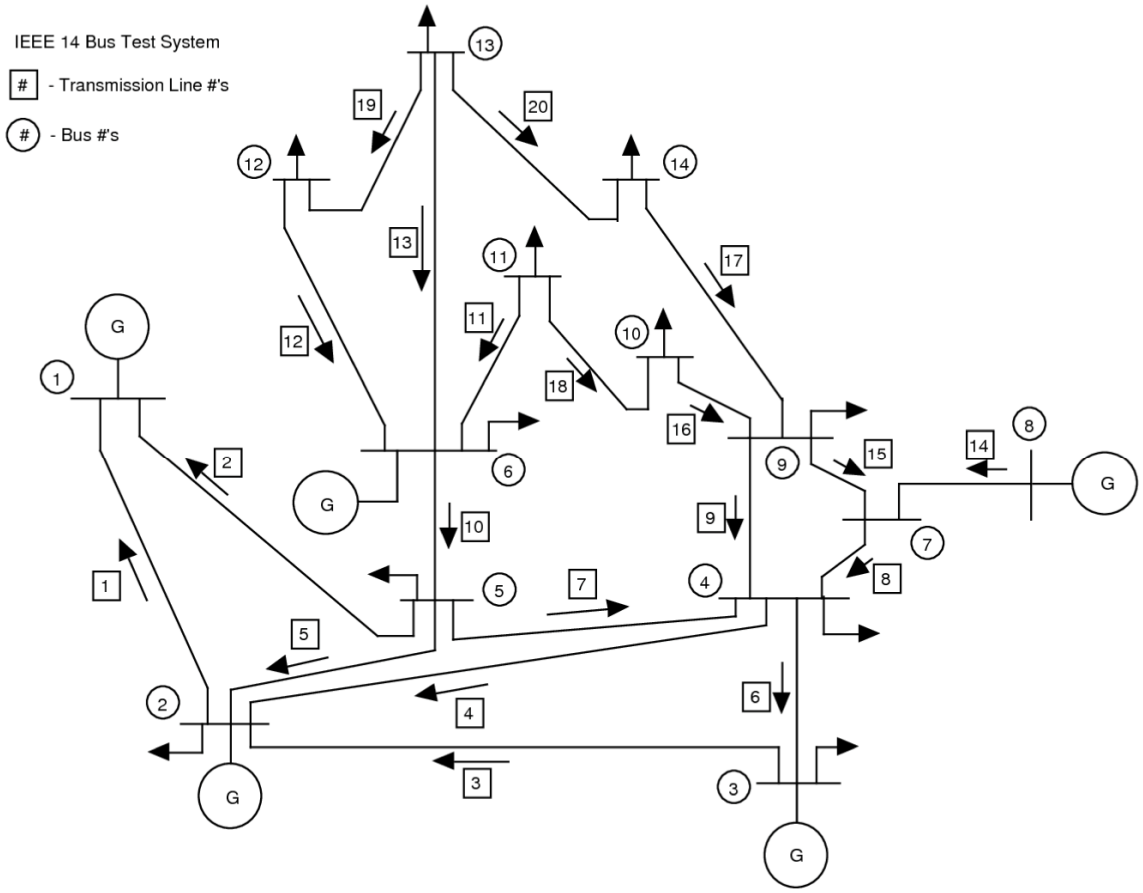
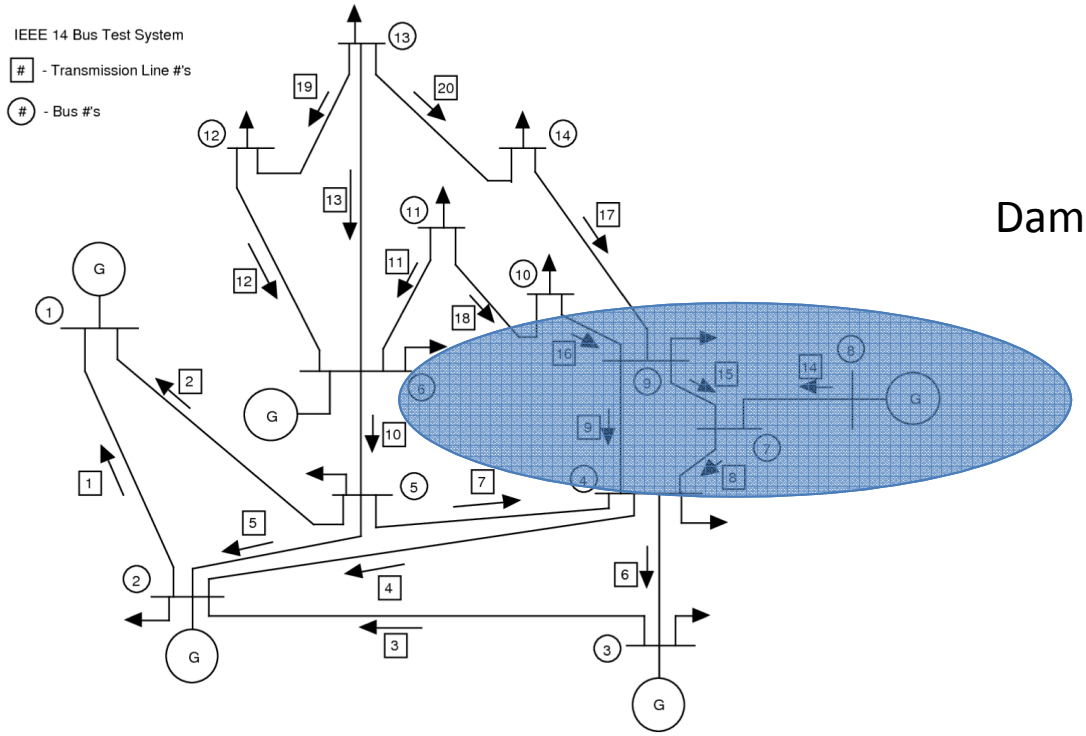
Goal: Deciding between two different system improvements

ELECTRIC POWER USE CASE

Model: IEEE 14 Bus System

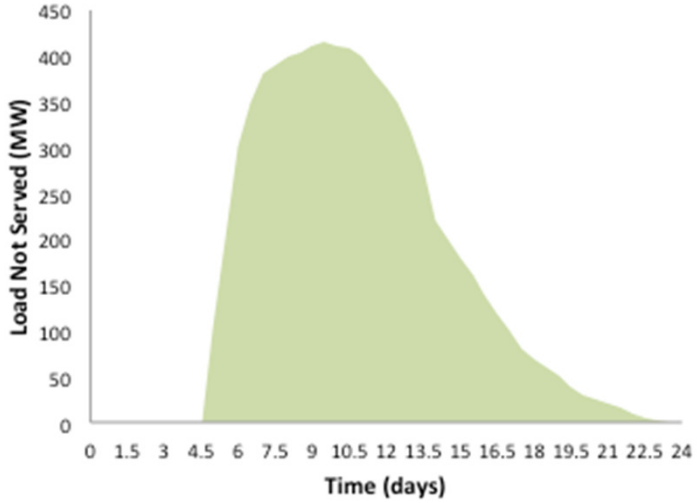


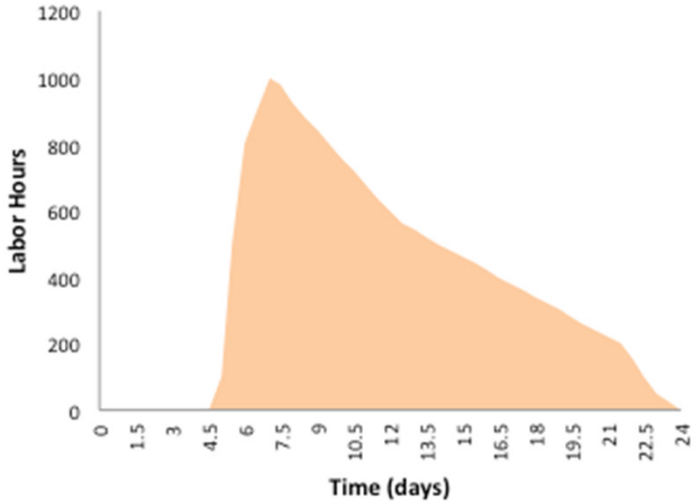
Hurricane



Hurricane winds and flooding disrupt operations

Performance Indicators: Load and Labor

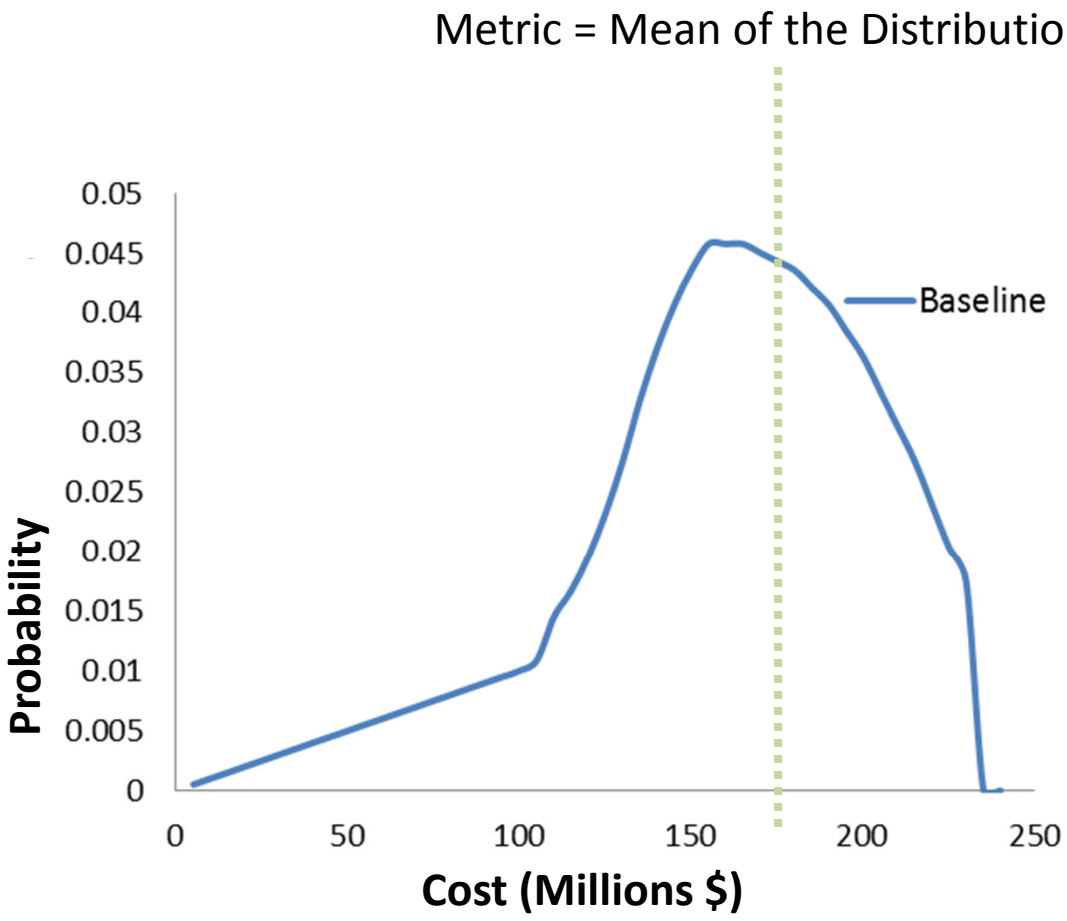




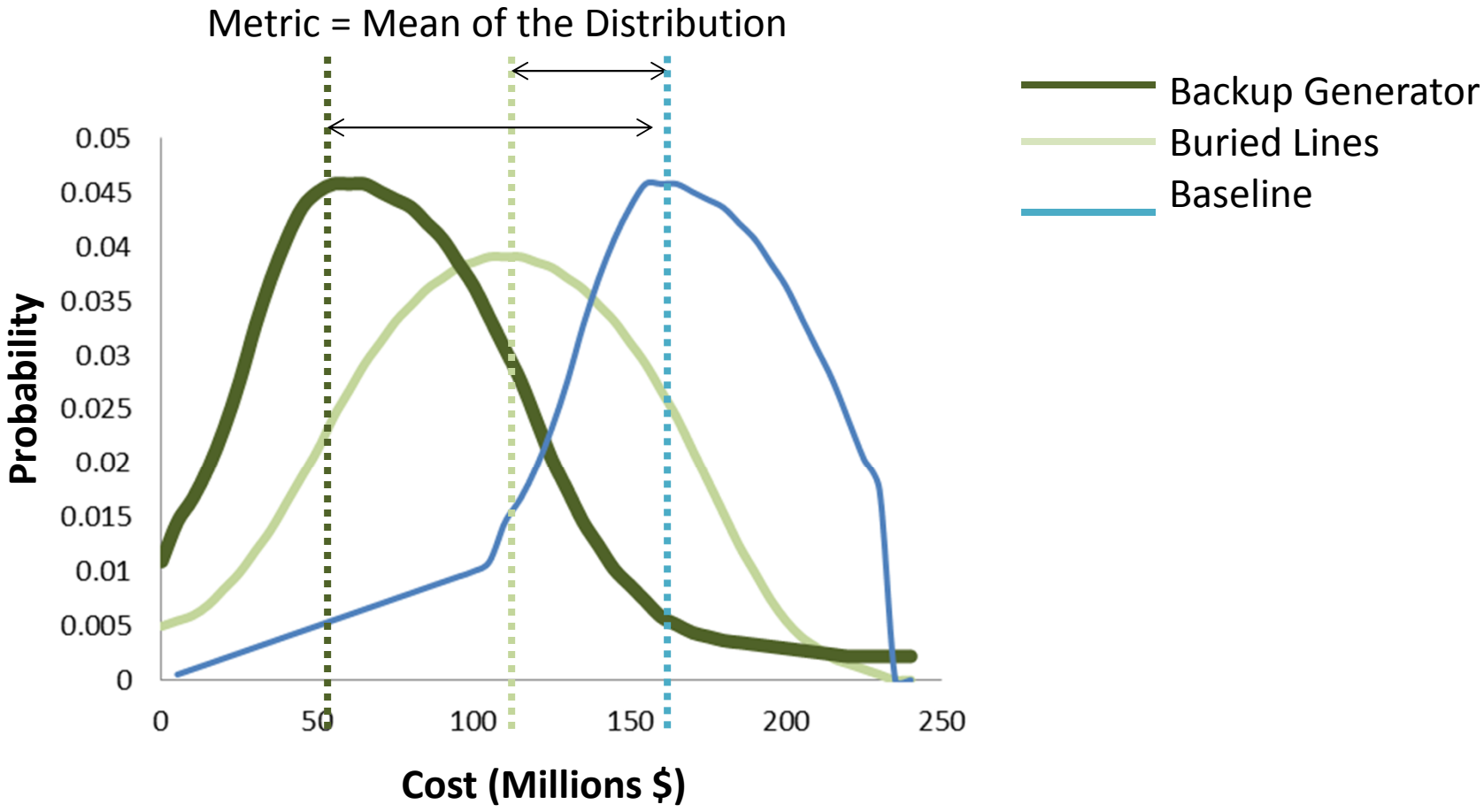
Consequences

Total Cost: $24M

Include Uncertainty: Baseline



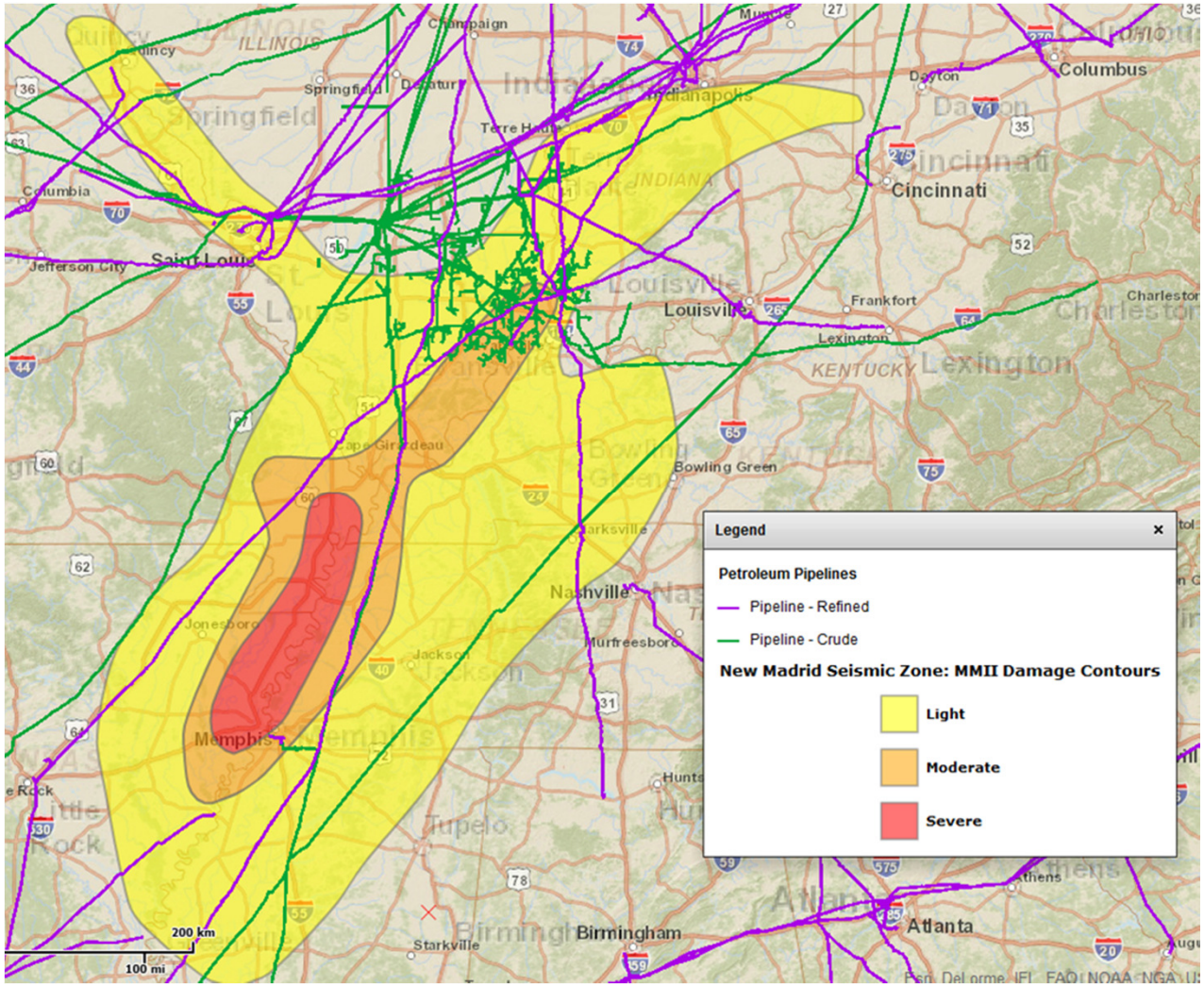
Resilience Comparison: Design Decision



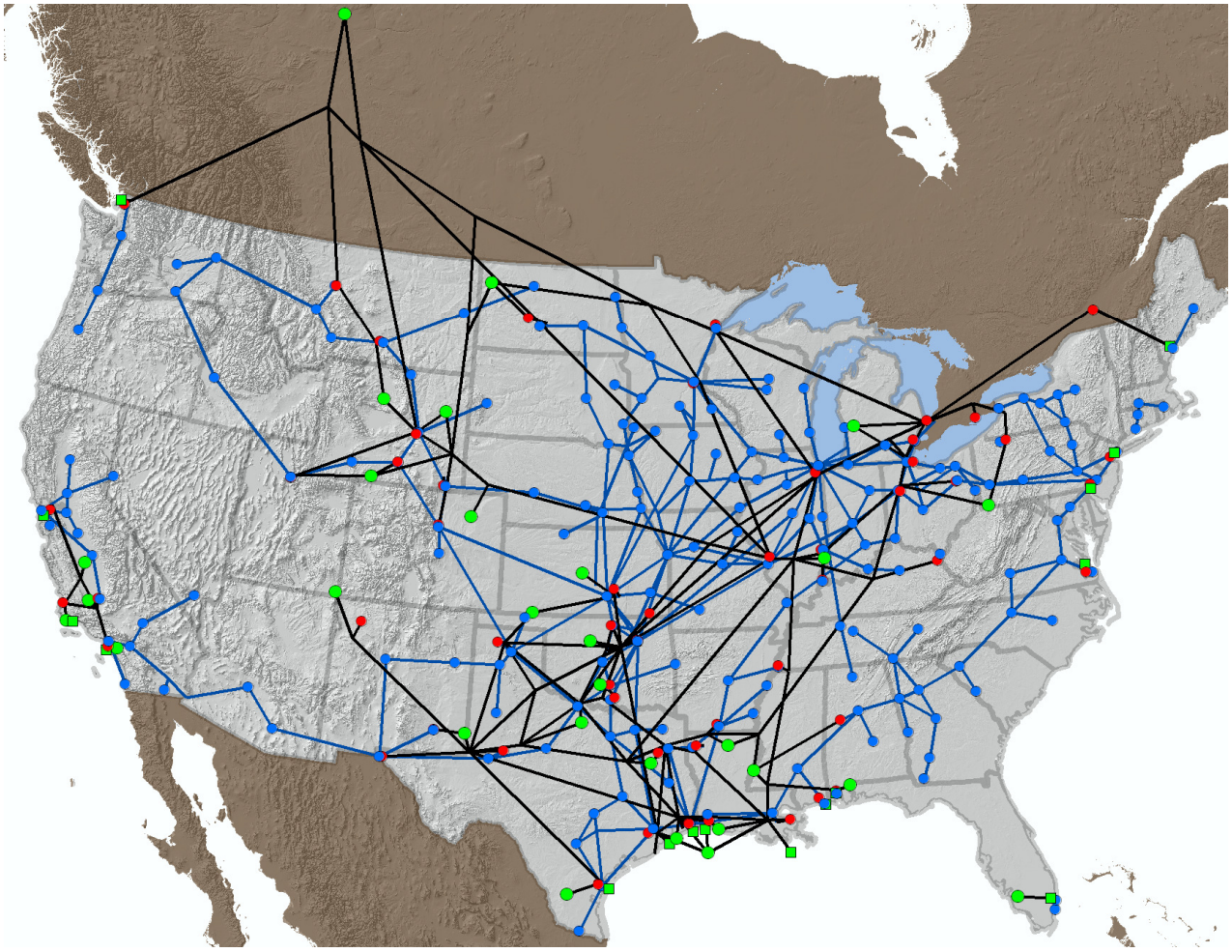
Goal: Reassess system resilience after changes

OIL USE CASE

Oil System Earthquake Example

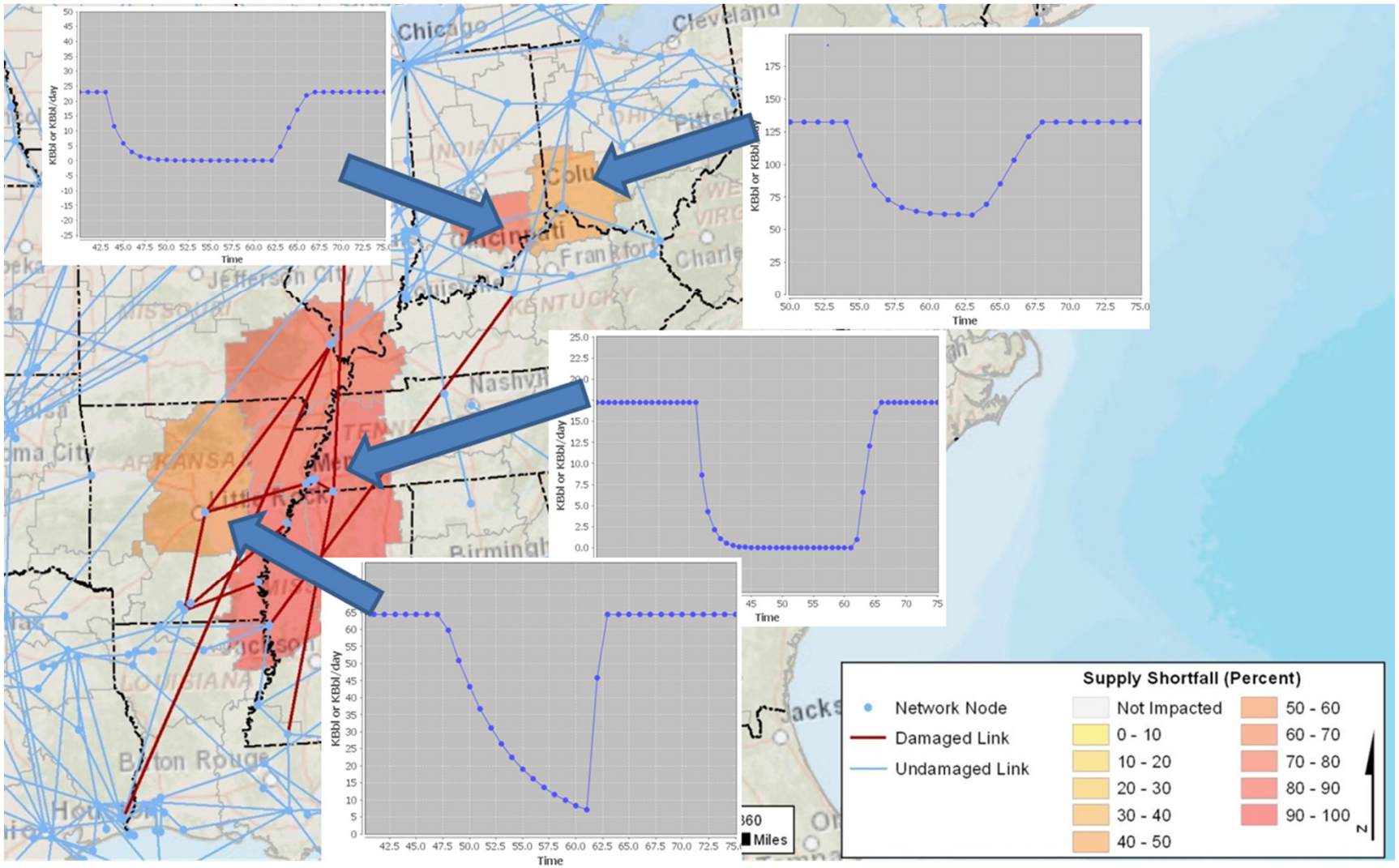


National Transportation Fuel Model Transmission Pipelines, Refineries, and Terminals



The DHS/SNL National Transportation Fuels Model was used for this simulation example

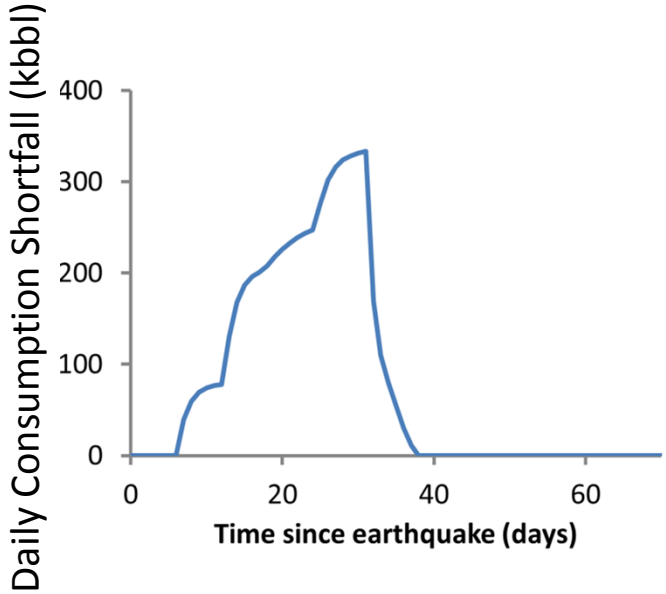
New Madrid Earthquake Performance Indicators

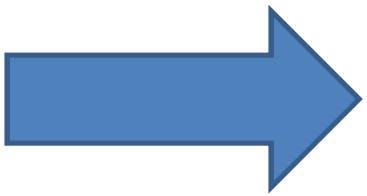


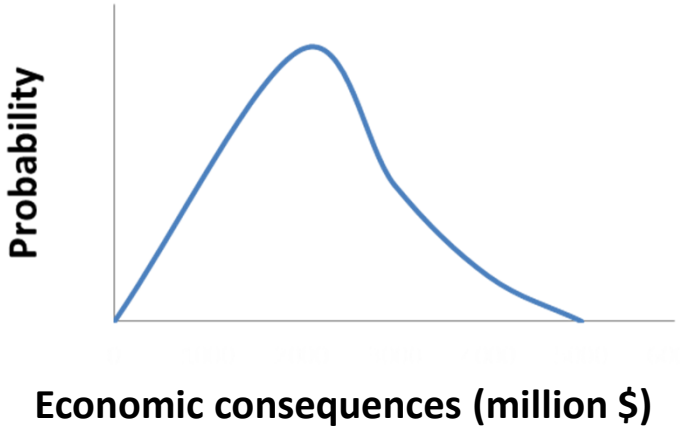
Convert Output to Consequence

Convert using

- Consequence model
- Distribution of outcomes from multiple simulations

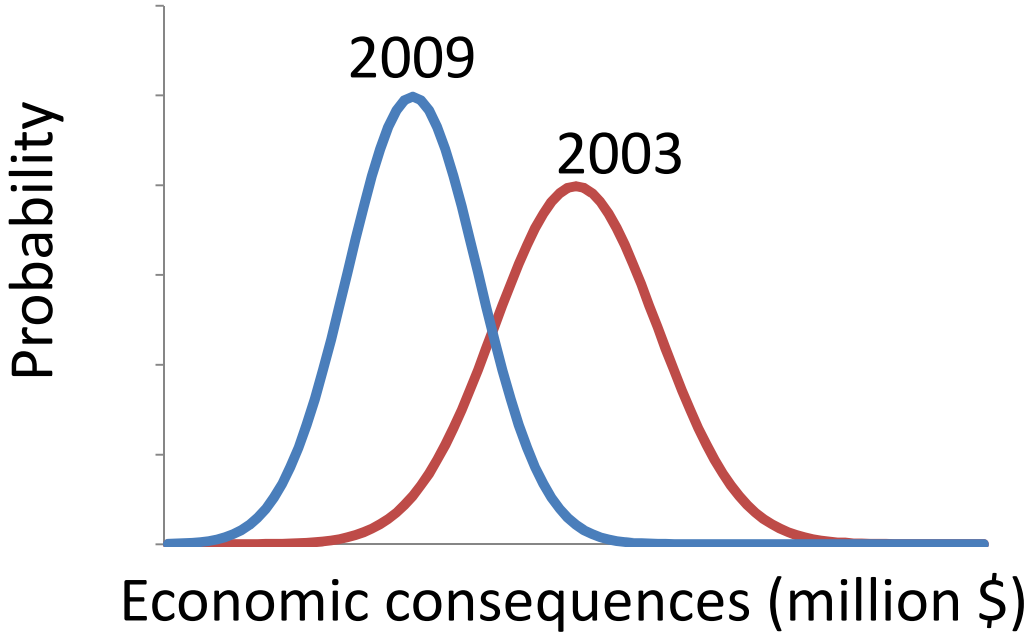






Compare Resilience: Assessment over time

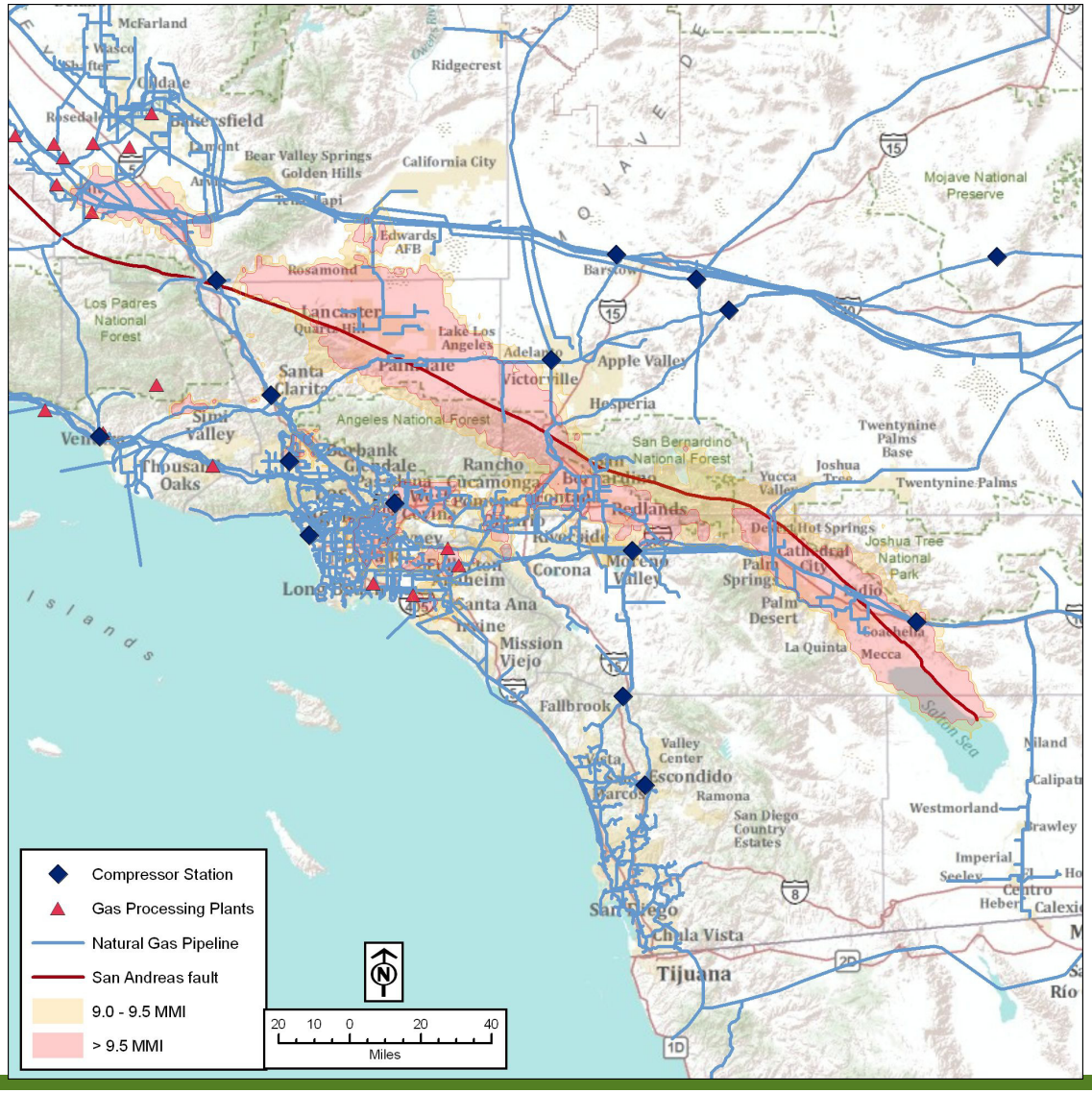
Prior to 2009 Midwest refineries increased use of crude from resulting in increased resilience to a New Madrid earthquake



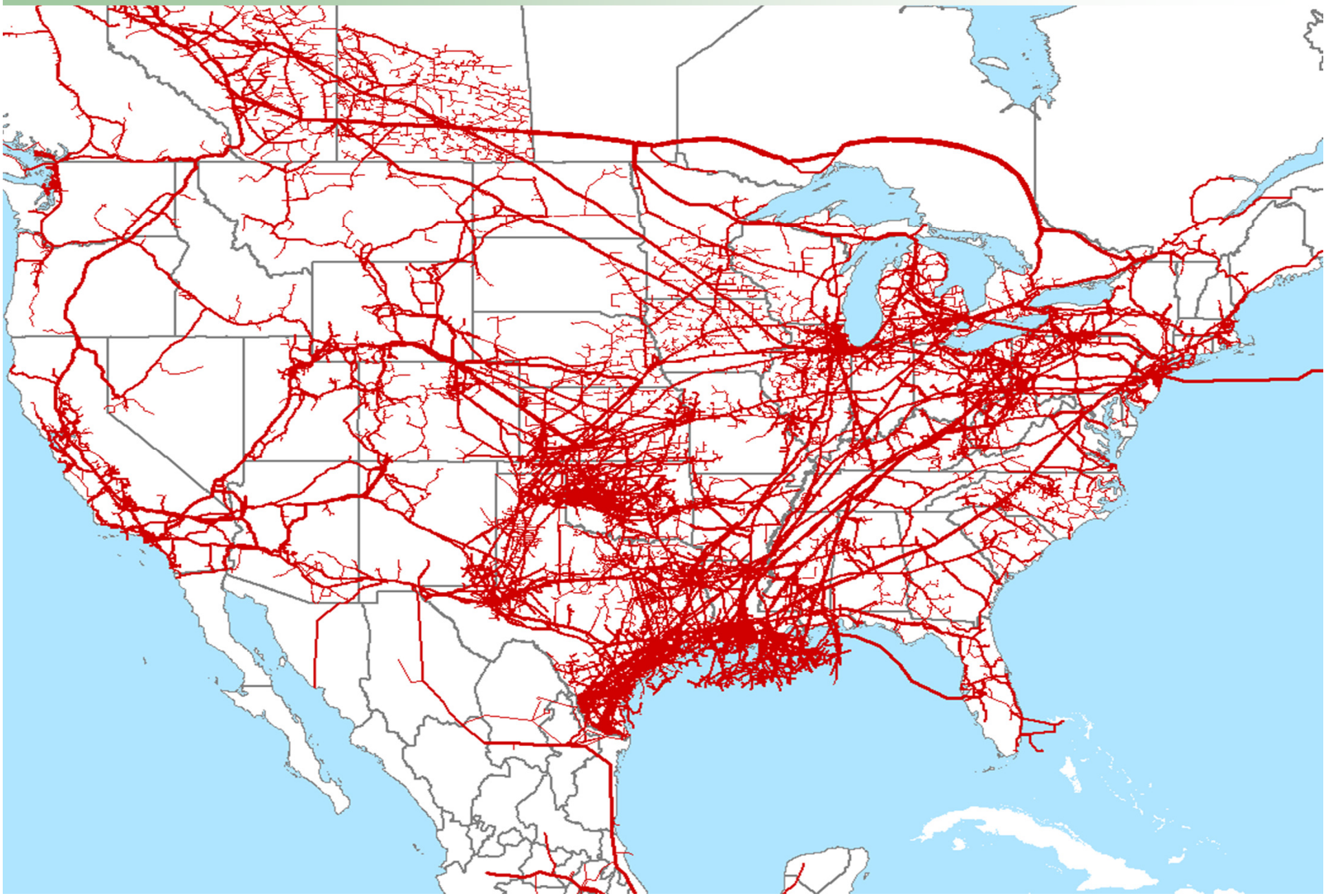
Goal: Select policy for use rules of asset in emergency

NATURAL GAS USE CASE

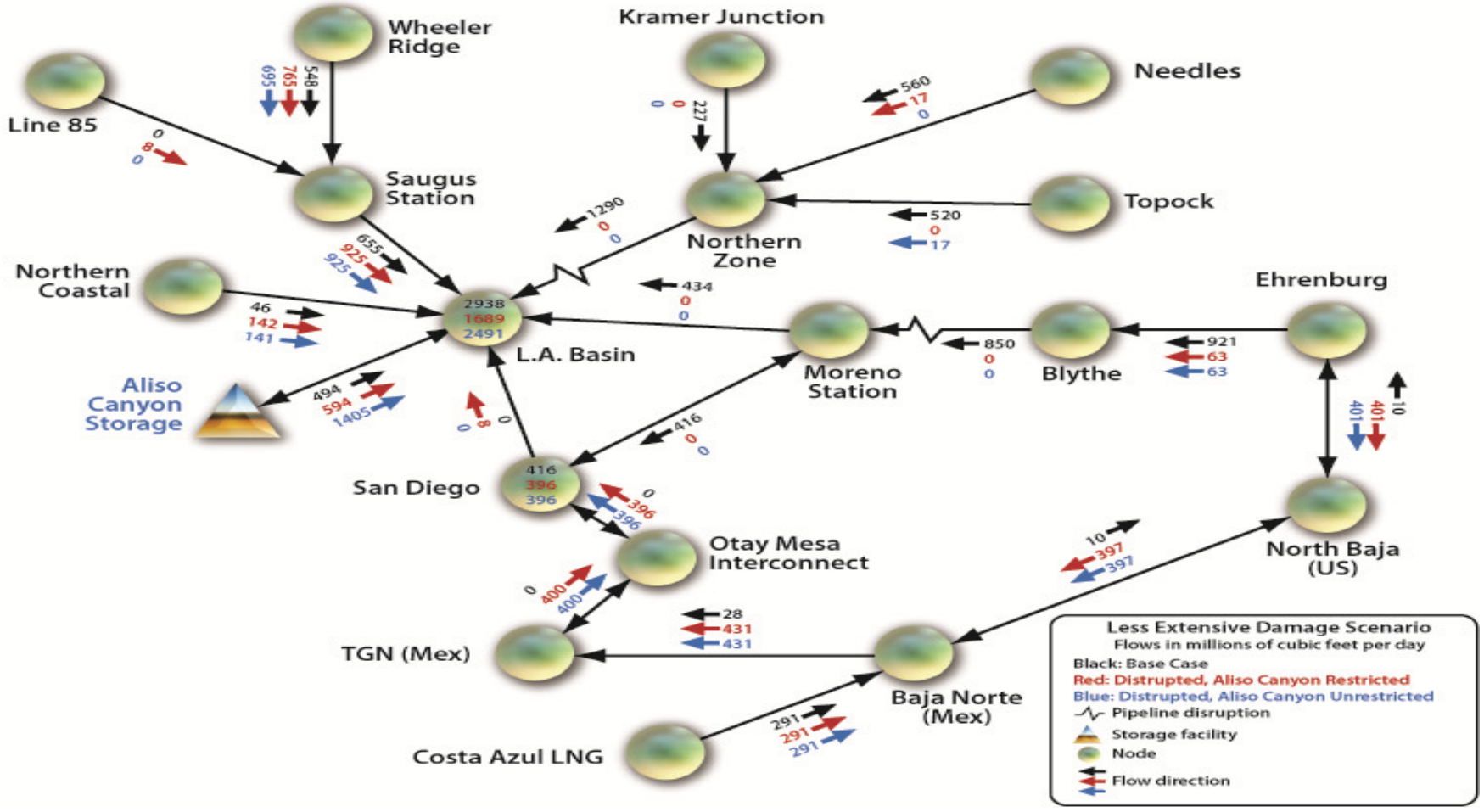
Natural Gas Earthquake Example



North American Natural Gas Network



San Andreas Earthquake Performance Indicators

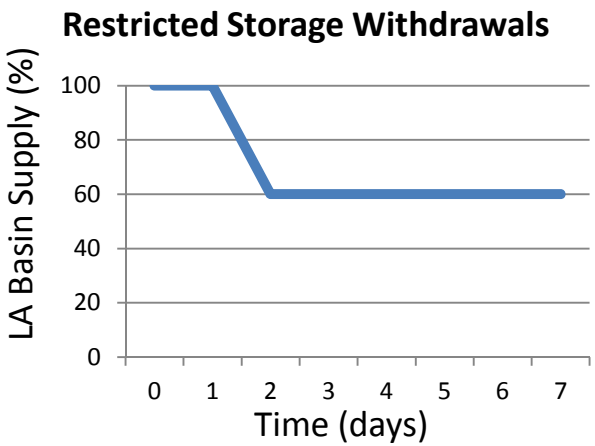


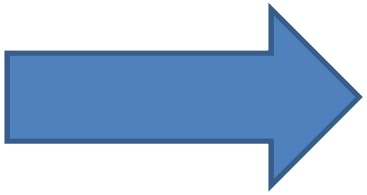
This calculation was performed using the Gas Pipeline Competition Model (GPCM), which was developed by, and licensed from, Robert Brooks Associates Consulting (RBAC).

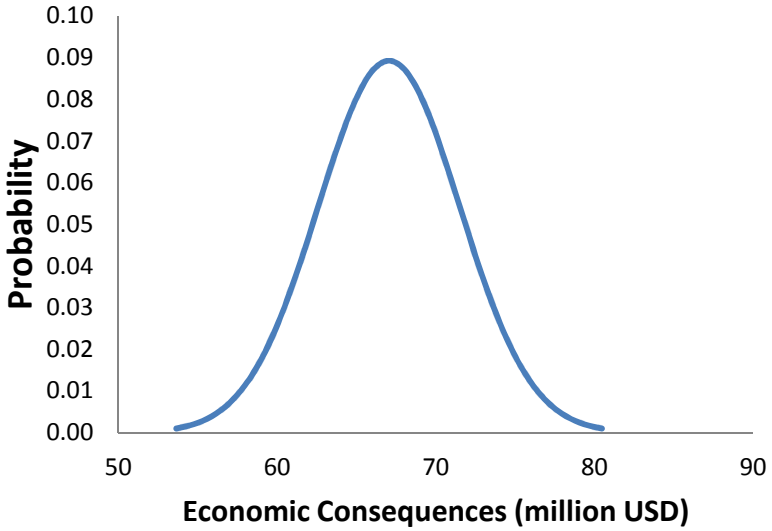
Convert Output to Consequence

Convert using

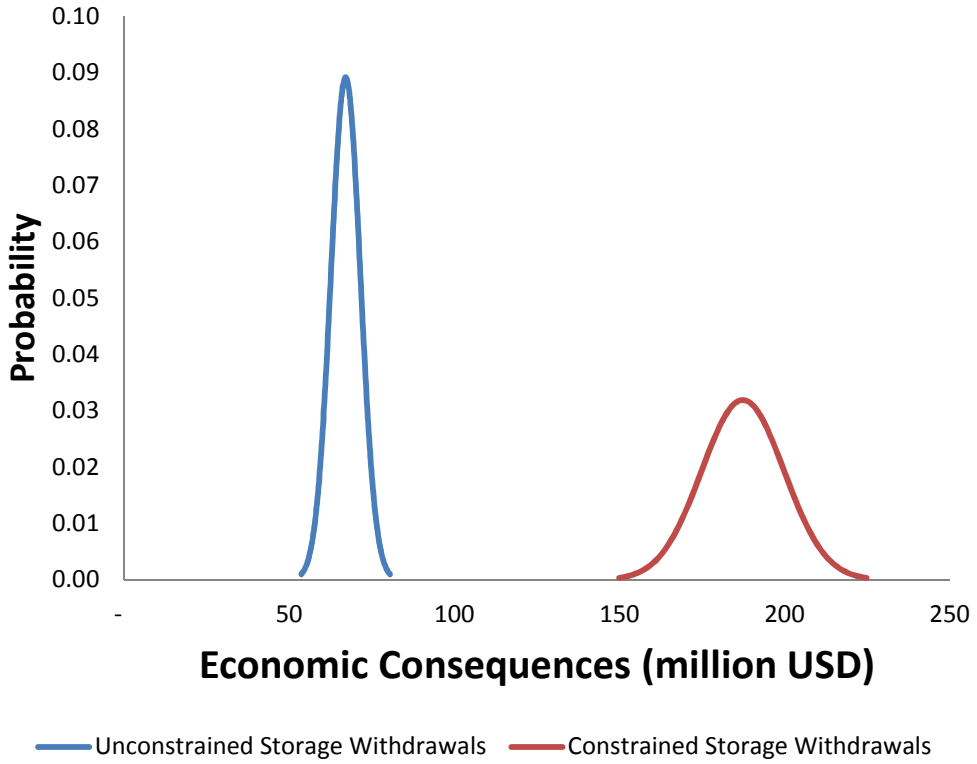
- Consequence model
- Distribution of outcomes from multiple simulations

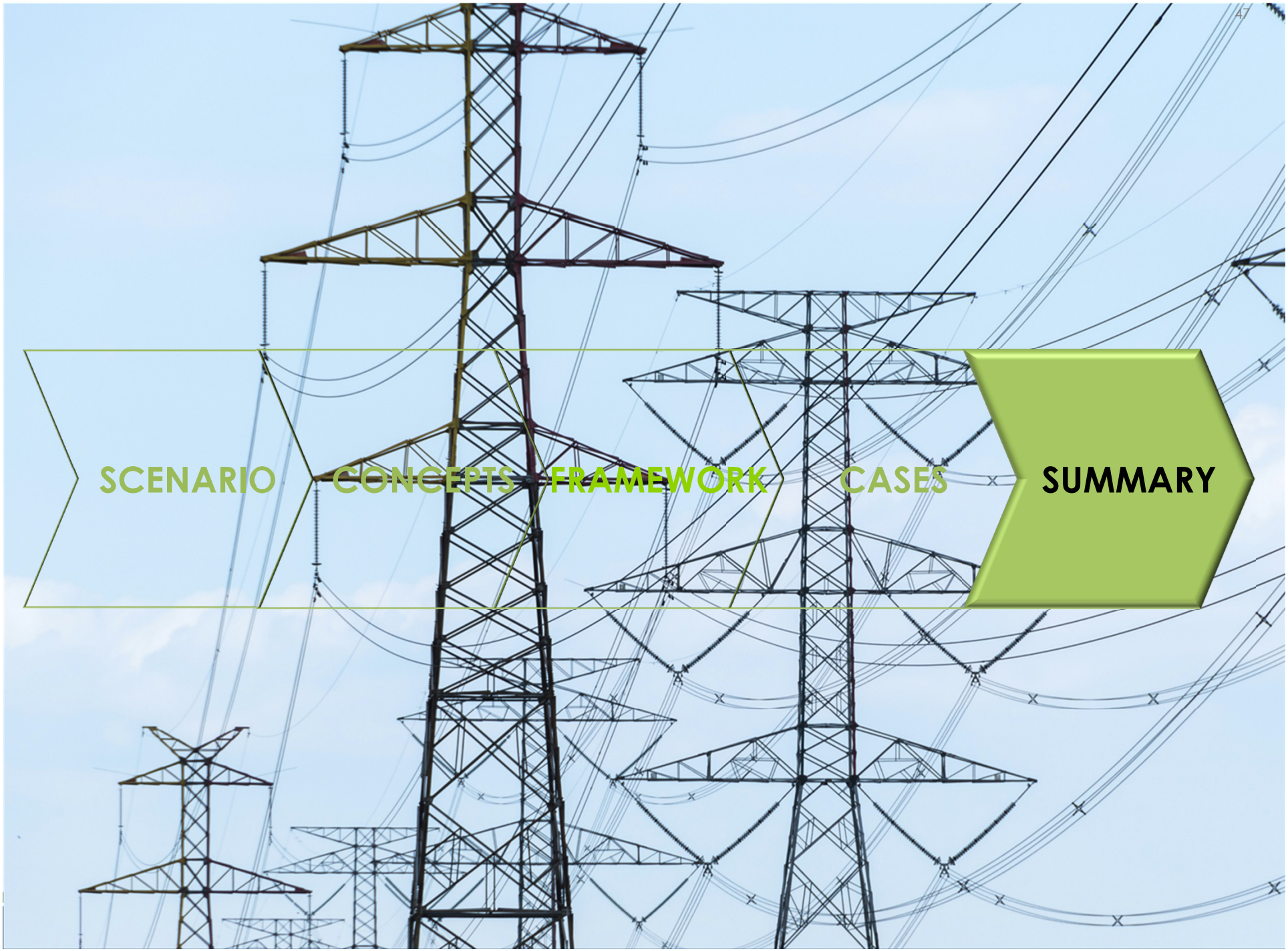






Compare Resilience: Policy Options

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Challenges

- Strategic
  - Stakeholder engagement
- Interdependencies
  - Common models, knowledge sharing
- R&D
  - Decision support tools, consequence estimation

Energy Resilience is a National Priority

- Energy resilience metrics are needed to make measure baselines and create goals
- Metrics should allow depth of application, but should simplify when desired
- R&D will be needed for advanced decision support
- Success will depend on a multi-disciplinary team