Power System Resilience

Supply and Climate Resilience

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COLLABORATION

EPRI's collaborative platform is unrivaled. Our R&D:

- Leverages members research dollars
- Connects members to a global network of peers
- Accelerates deployment of technology
- Mitigates the risk and uncertainty of going it alone
- Positions members as a leader in addressing industrywide challenges

CREDIBILITY

EPRI's independent research is guided by our mission to benefit the public. We offer:

- Objective solutions
- A proven track record
- Scientifically based research that can be trusted

EXPERTISE

For 50 years, EPRI has been applying R&D to help solve real challenges. With EPRI, you can:

- Reduce expenses and increase productivity
- Be more resilient today and better prepared for tomorrow
- Access an industry repository of collective experiences, technical expertise, and training resources
- Extend staff and make your teams more robust and more confident
- Benchmark, learn and share best practices
- Increase awareness of challenges that others are facing and alternate solutions to challenges you might be facing
- Save time and money troubleshooting problems EPRI and its stakeholders have seen before

Who We Are

EPRI is a non-profit organization that performs research to advance safe, reliable, and environmentally responsible energy for the public benefit.

Our Members

EPRI members represent 90% of the electricity generated and delivered in the United States, with international participation extending to 45 countries.

Portfolio Spans the Entire Electricity Sector

Generation

- Advanced Coal Plants, Carbon Capture & Storage
- Combustion Turbines/Combined Cycles
- Environmental Controls & Combustion Performance
- Materials & Chemistry
- Major Component Reliability
- Operations & Maintenance
- Plant Water Management
- Renewables

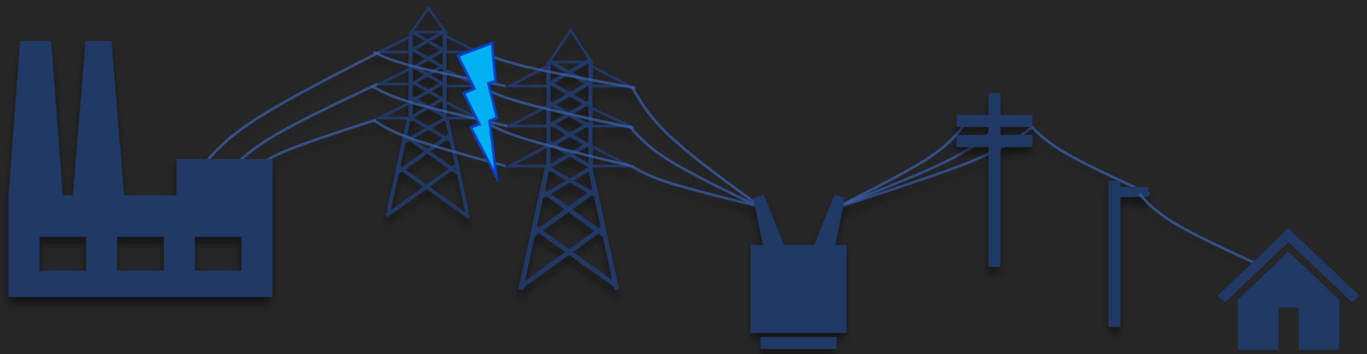
Nuclear

- Advanced Nuclear Tech.
- Chemistry, Low-Level Waste and Radiation Management
- Equipment Reliability
- Fuel Reliability
- Long-Term Operations
- Material Degradation/Aging
- Nondestructive Evaluation & Material Characterization
- Risk & Safety Management
- Used Fuel and High-Level Waste Management

Power Delivery & Utilization

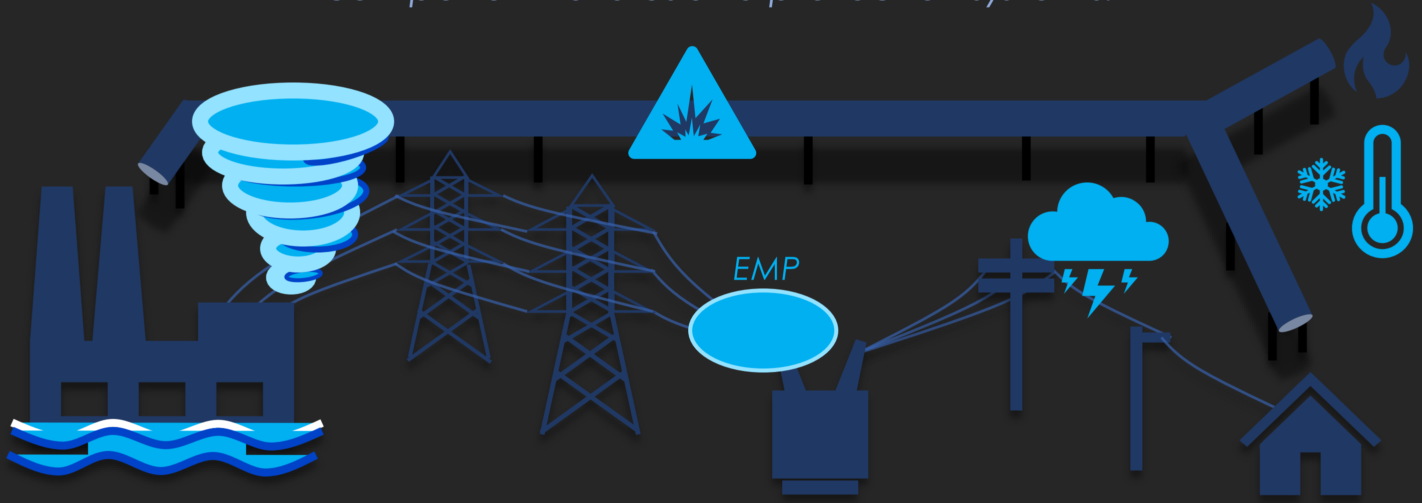
- Transmission and Substations
- Transmission Operations and Planning
- Distribution
- Energy Systems and Climate Analysis
- Electrification and Customer Solutions
- Information, Communications and Cyber Security (ICCS)
- Occupational Health and Safety
- Air, Water and Ecosystems

What is Power System Resilience?



Existing criteria based on "traditional" failures

Traditional failures based on standard set of events, based on power system component failures and protection systems.



Criteria based on "externally driven extreme" events

Externally-driven events are those that are less known and typically events unrelated to the power system (e.g. N-k), but which affect the power system.

Reliability
Limit customer outages

Restoration/ Recovery
Restoring grid components following customer outage

Definitions, metrics, criteria, solutions (influence but can be distinct)

Resilience
Anticipate, absorb, adapt to, and/or rapidly recover

Resilience Across Power Systems

Power System Resilience

Supply Resilience

Events
- Extreme weather (i.e., extreme cold)
- Natural disasters (hurricanes, floods)

Strategy
- Generator hardening
- Fuel supply assurance
- Local supply: DER and microgrids

Incentives
- Opportunities for market incentives, or products, interdependencies with other infrastructure
- Cost based recovery

Transmission, Substation and Distribution Infrastructure Resilience

Events
- EMP, GMD events
- Natural disasters & extreme weather
- Manmade threats

Strategy
- Line hardening, network redundancy
- Strategies for reliable network architecture & communications
- Local supply: DER and microgrids

Incentives
- Side payments from operators
- Cost based recovery through LSE

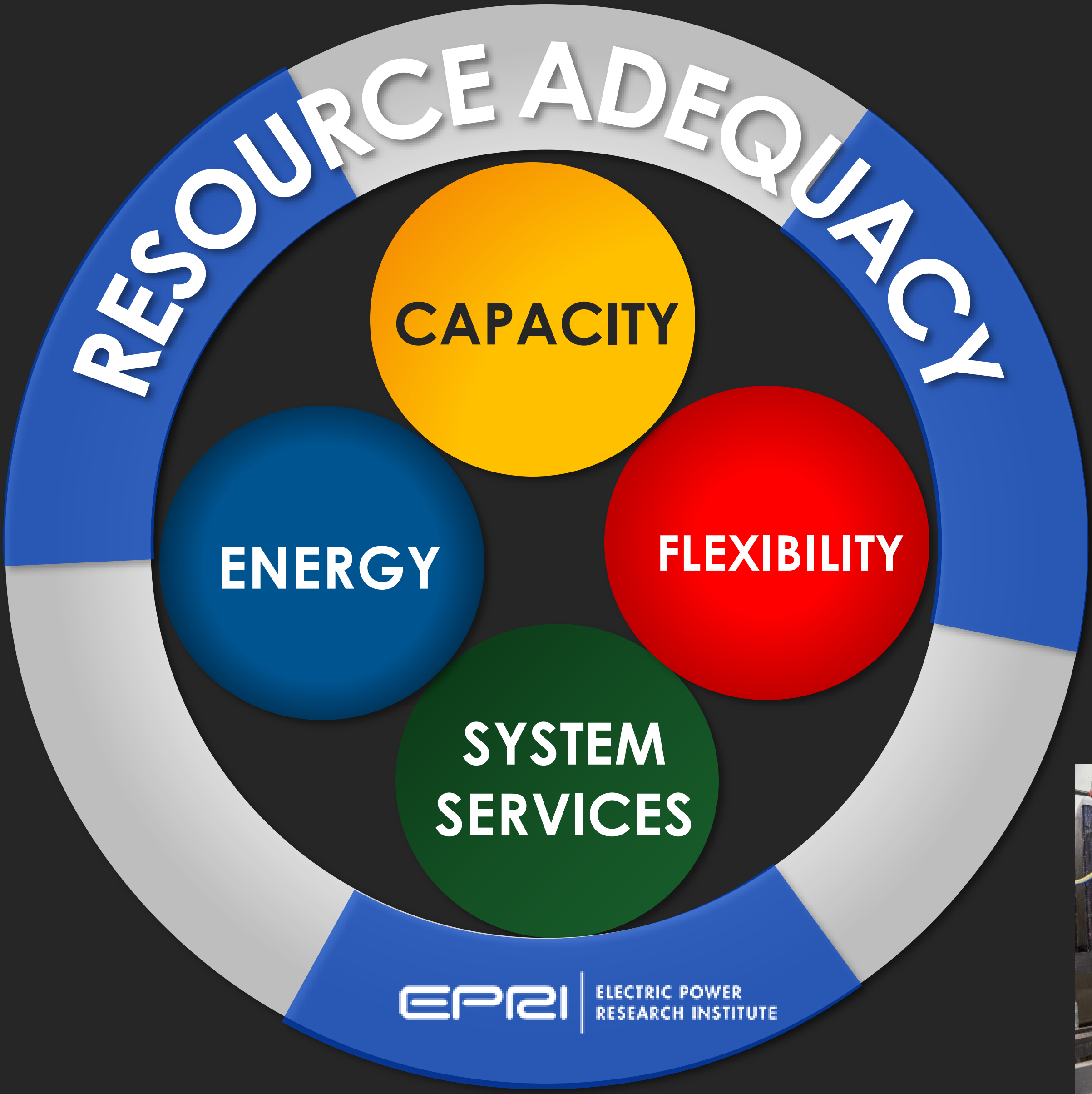
Communications Resilience

Events
- Cyber attacks
- Natural disasters

Strategy
- Enhanced cyber security
- Strategies for reliable network architecture & communications

Incentives
- Cost based recovery through LSE
- New technology and devices (IoT, microgrids)

Supply Resilience Driven by Adequacy



An adequate supply fleet is not just the installed MW in the ground. The capacity must have energy to sustain during critical time periods, flexibility to accommodate condition changes, and sufficient reliability services to provide when necessary

Supply Resilience: Common Mode Events

- Definition: Events when two or more resources simultaneously become unavailable or are output limited
  - Cases with a single external event (e.g., gas pipeline failure)
  - Cases with a combination of factors (e.g., decline in renewable output due to weather and gas pipeline unavailability)
- Outages have been assumed to be independent and uncorrelated
  - Given increases in common mode events, this assumption is no longer valid
  - Planners might need to consider the impact of multiple events

Projecting Event Probabilities

- Climate change is resulting in more frequent extreme weather events
- Historical probabilities do not capture these extremes, making forecasting or projecting future disruptive events difficult

Type of Extreme Weather	Frequency	Intensity	Geographic Extent
Extreme Heat Events	↑	↑	↑
Drought	↑	↑	↑
Wildfires	↑	↑	↑
Extreme Precipitation/ Flooding	↑	↑	↑
Hurricanes/ Tropical Storms	↔	↑	↑
Cold Events	↑	↓	
Heavy Snow Events	↔	↔	
Severe Weather (e.g., tornados, hail)	↔	↔	

Historical probabilities for the frequency, intensity, geographic scope, and duration of weather events need to be adjusted upwards to take recent climate trends into account

Climate Resilience in Transmission Operations & Planning

What needs to be assessed?

Long-term consequences that manifest as sustained impact on the power system as well as acute event that create large impacts that are beyond typical design consideration

How can we consider climate impacts?

Climate data needs to be included in the study process. Needs to be localized to the system under consideration and geographically correlated to the local infrastructure

System adaption and prioritization

Need to establish project value across multiple areas of system impact; operations, planning, recovery and restoration and make investment decisions based on the impacts observed

Identified gaps and areas for improvement

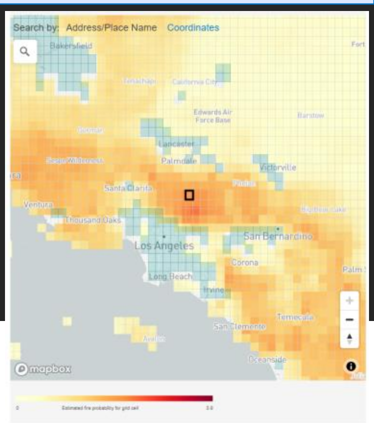
Still an evolving area of research. Requires creating a more integrative planning process that allows a longer-term assessment of the system from both an operations and planning perspective.

Capturing Future Climate Threats as an Electrical Consequence

1 Review & Interpret Climate Projections for Location and Variables of Interest

Use global, regional, national, and other existing detailed local climate datasets

Ex: Characterize change in wildfire probability in Los Angeles County

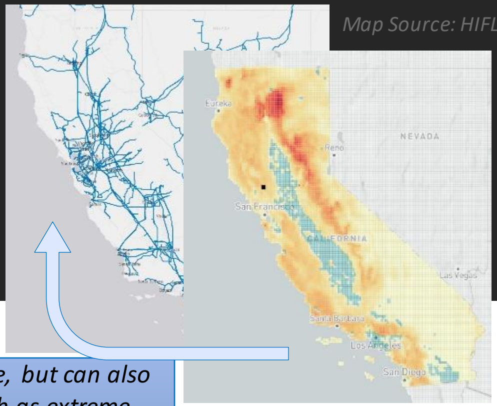


Map Source: Cal-Adapt

2 Map Climate Impacts Geographically to Identify Highly Impacted Electrical Equipment

Assess locationally-specific climate vulnerabilities

Capture and evaluate projected changes across utility service territory



Map Source: HIFLD

Map Source: Cal-Adapt

Example shown for wildfire, but can also consider other threats such as extreme heat and sea level rise / storm surge inundation

3 Translate Climate Impacts into Electrical Consequence and Define Events

Generate extreme contingency events

Define electrical consequence based on anticipated climate impacts

```
CONTINGENCY '2 STATION
WILDFIRE OUTAGE'
DISCONNECT BUS FROM BUS 12345
DISCONNECT BUS FROM BUS 23456
END
CONTINGENCY '3 STATION
WILDFIRE OUTAGE'
DISCONNECT BUS FROM BUS 34567
DISCONNECT BUS FROM BUS 45678
DISCONNECT BUS FROM BUS 57890
END
END
```

Climate Data Informs HILF Event Definition for Transmission Resilience Analysis

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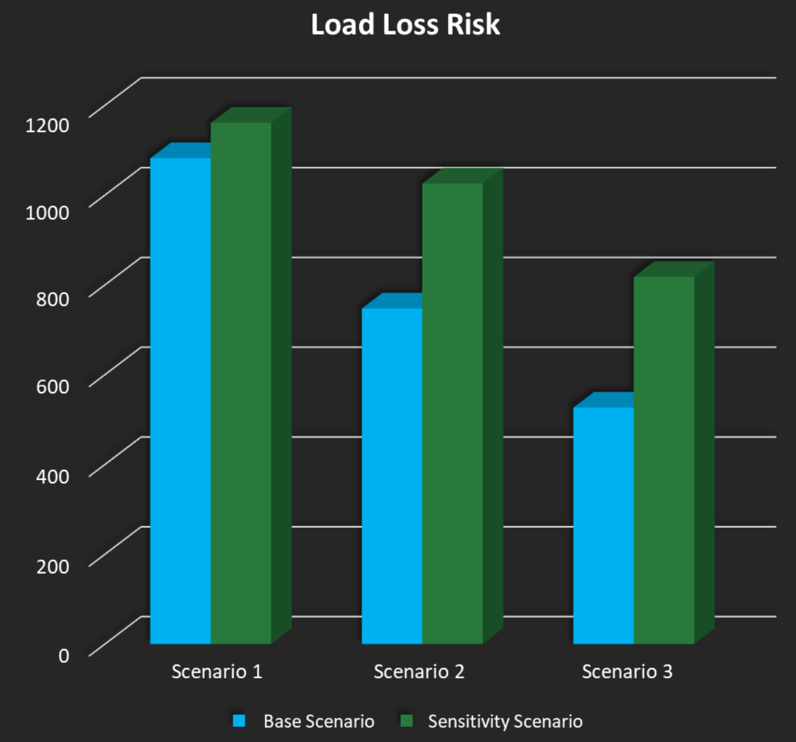
Example Assessment: 2030 LADWP System

▪ Studied Scenarios

Scenario 1	Scenario 2	Scenario 3
• Full retirement of the once-through cooling (OTC) generation units in the LA Basin	• **630 MW** of additional firm generation in-Basin compared to Scenario 1	• **870 MW** of additional firm generation in-Basin compared to Scenario 1

Weighed multiple possible future configuration of the LADWP system and compared the resilience of the network in response to a set of defined events

- Example shown here is a significant wildfire event impacting transmission, interconnection, and generation
- Sensitivity case examines the failure to complete schedule upgrades on the system by 2030



As less generation is available locally, the system is exposed to more risk of load loss

EPRI Resource Adequacy Initiative

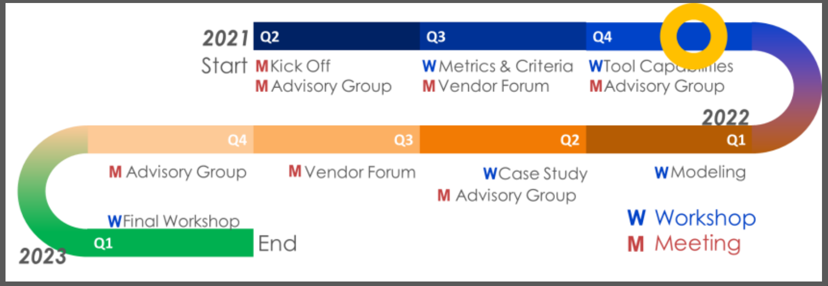
Scope and Deliverables

RA Process	Models and Data	Analysis Tools
▪ Recommended Metrics and Criteria ▪ Future Scenario Database and Tool	▪ Emerging Resource & Demand Side Models ▪ Model Data Development Tools	▪ Existing RA Tool Capabilities ▪ New Algorithms and open-source code

Case Studies — Evaluation of existing and development of new capabilities based on 4-6 regional RA case studies covering differing RA issues and tools.

Tech Transfer — Reports and workshops to be conducted to disseminate results and to promote broad adoption in commercial tools.

Schedule



27+ Participants

Southern California Edison, CPS Energy, Duke Energy, AECI (Associated Electric Cooperative Inc.), Hawaiian Electric, American Electric Power, LCRA, conEdison, Ameren, TVA, Austin Energy, NY Power Authority, LADWP (Los Angeles Department of Water & Power), Arkansas Electric Cooperative Corporation, Southern Company, SRP, NERC (North American Electric Reliability Corporation), MISO, SPP (Southwest Power Pool), aps, ISO new england, pjm, Entergy, evergy, New York ISO (Independent System Operator), Manitoba Hydro, NPCC, Inc.

Collaboration & Partners

External Advisory: NARUC, RROs, DOE, ESIG, ENTSO-E, EEI, ISO/RTOs, G-PST, et. al.

R&D Partners: Vendors, Nat. Labs, Consultants, Universities

CLIMATE READi
RESILIENCE AND ADAPTATION INITIATIVE

Workstream 1	Workstream 2	Workstream 3
Physical Climate Data & Guidance	**Energy System & Asset Vulnerability Assessment**	**Resilience / Adaptation Planning & Prioritization**
• Identify climate hazards and data required for different applications • Evaluate data availability, suitability, and methods for downscaling & localizing climate information • Address data gaps	• Evaluate vulnerability at the component, system, and market levels from planning to operations • Identify mitigation options from system to customer level • Enhance criteria for planning and operations to account for event probability and uncertainty	• Assess power system and societal impacts: resilience metrics and value measures • Create guidance for optimal investment priorities • Develop cost-benefit analysis, risk mitigation, and adaptation strategies

EPRI Climate Resilience and Adaptation Initiative (READi)

- **COMPREHENSIVE:** Develop a *Common Framework* addressing the entirety of the power system, planning through operations
- **CONSISTENT:** Provide an informed approach to climate risk assessment and strategic resilience planning that can be replicated
- **COLLABORATIVE:** Drive stakeholder alignment on adaptation strategies for efficient and effective investment

Deliverables: Common Framework "Guidebooks"

- Climate data assessment and application guidance
- Vulnerability assessment
- Risk mitigation investment
- Recovery planning
- Hardening technologies
- Adaptation strategies
- Research priorities

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