PNNL-SA-377341

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WILDFIRE RISK & RESILIENCE @PNNL

Emerging Risk: Adopting Wildfire Mitigation Strategies for Energy Systems

André Coleman, PhD
Chief Scientist

North Central Regional Risk Assessment and Wildfire Workshop
Madison, Wisconsin

August 27, 2025

U.S. DEPARTMENT of ENERGY BATTELLE

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Background

- Over the past decade, utility-caused wildfires have evolved from a regional operational hazard to a national crisis
- On average, utility-caused fires only represent ~3% of wildfire starts
- However, those starts represent 50-500k burned acres/year at a cost of ~$200B/yr for the electricity sector
  - Costs of fire suppression, direct damage, economic losses, health impacts, and long-term recovery amount to $394-893 billion/year

- ***2018 Camp Fire (CA)*** – 153k ac – 18,804 structures – $16.5 billion
  - Caused by a single faulty hook on a transmission tower + extreme weather
- ***2023 Maui Fires (HI)*** – 6k ac – 2,200 structures – $6 billion
  - Caused by downed distribution lines + extreme weather
- ***2024 Smokehouse Creek (TX Panhandle)*** – 1.1M ac – ~500 structures – 12k cattle - ~$1B – High threat to the Texas Pantex Plant (nuclear)
  - Caused by a decayed wood pole + extreme weather

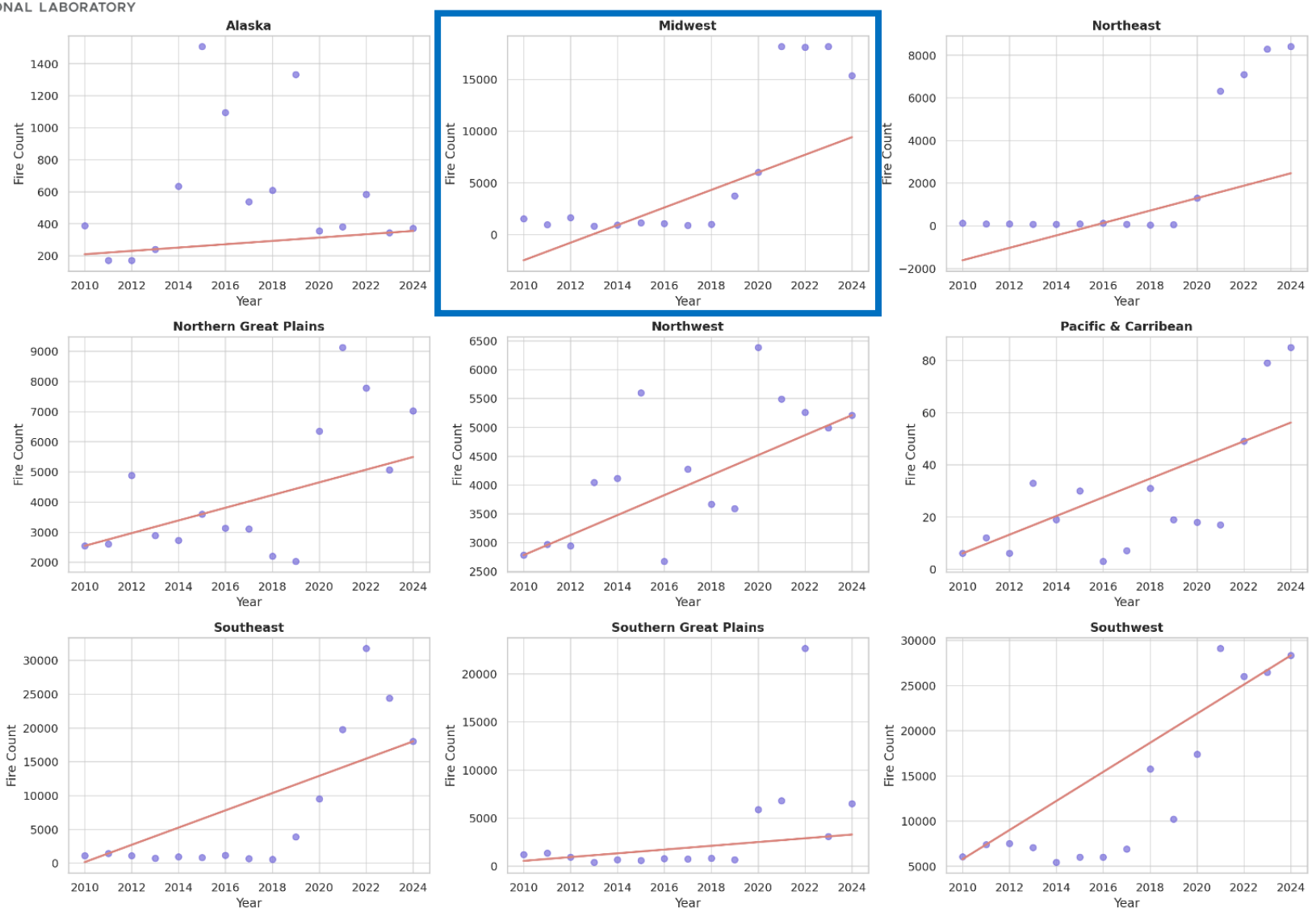

Worn hook

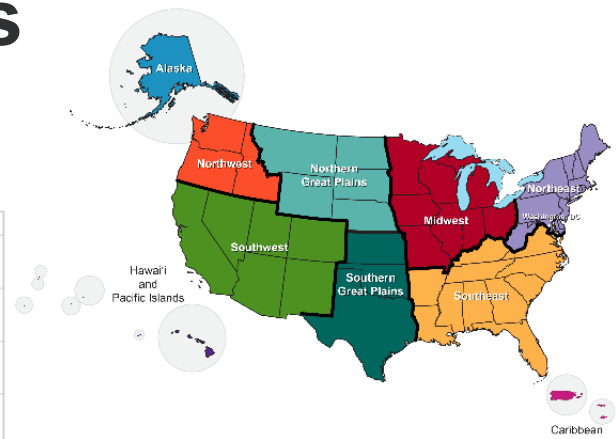

Downed lines


Decayed pole


Vegetation Contact

Long-Term Regional Wildfire Trends
-Annual Total Fire Occurrence





-All regions except Alaska are exhibiting statistical non-stationarity

-Midwest region has seen a 3-4x increase in fire occurrence in the past 5-years

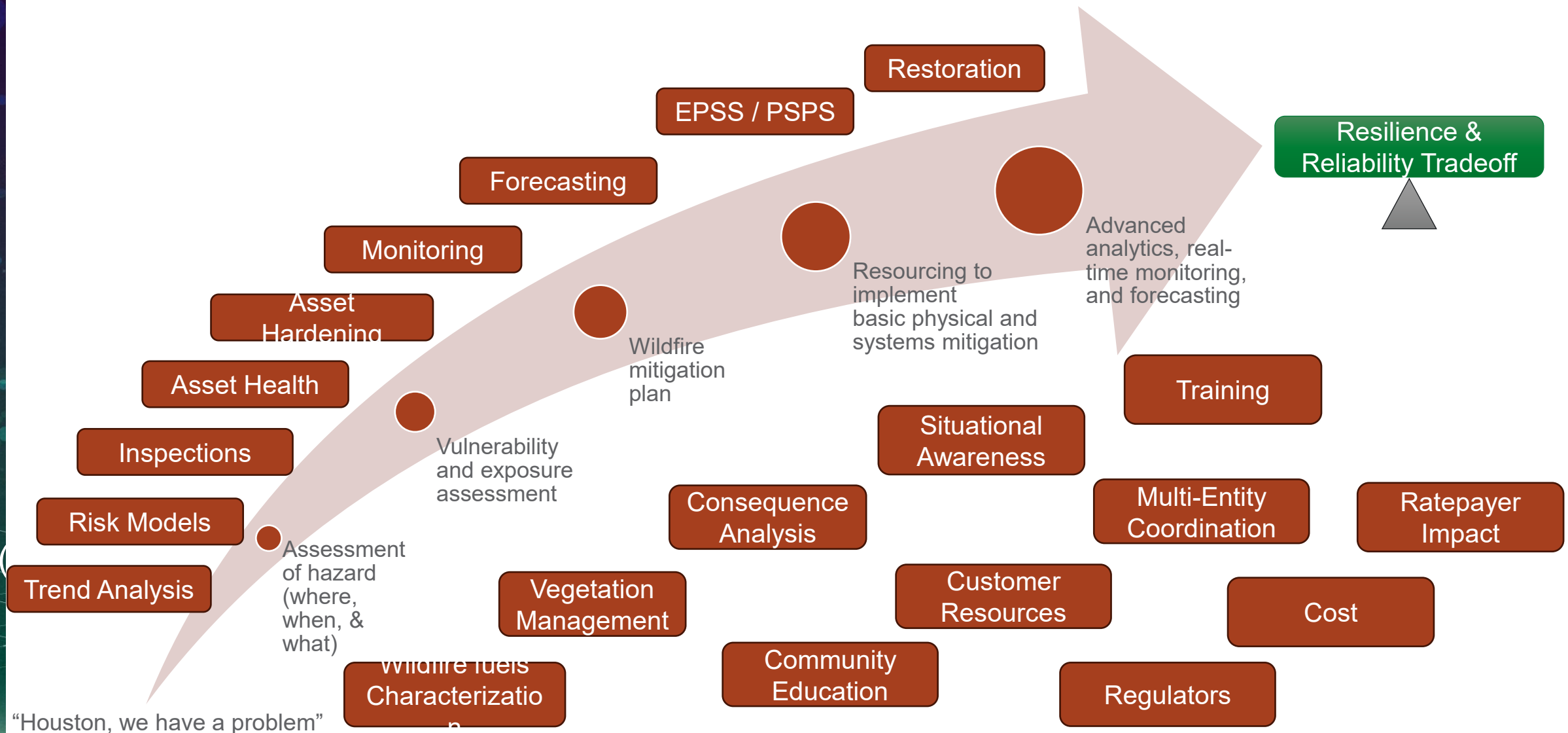
Patchwork of Data, Approaches & Methods for Wildfire Mitigation and Management

- Lack of updated, unifying, data, models, and methods
- Many entities are trying to figure out best practices in a dynamic space - wide assumptions!
- Coordination needed across local, state, Federal, Tribes, industry, private entities, NGOs
- Development of trusted data, methods, models, to build a common understanding and coordinate actions
- Need for trusted and equitable data/methods/model access for up-to-date wildfire risk and event data
  - Small entities at a higher risk

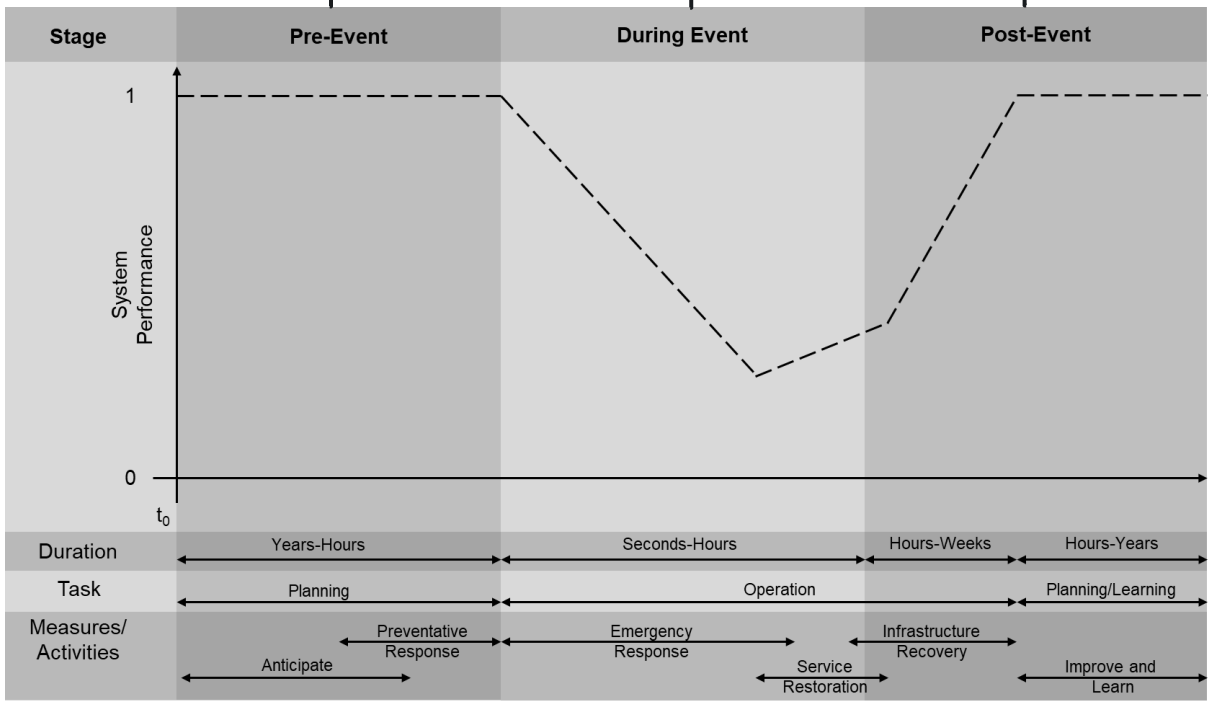
Multi-Dimensional Utility Wildfire Hazard

- Potential ignition due to high temperature, low humidity, wind, and dry fuels
  - Pre-emptive shutdown of power
- Utility-caused ignition
  - Fire impact on surrounding communities, infrastructure, environment, power outage
- Existing fire impacts utility infrastructure
  - Power outages, damage to infrastructure, longer time to restoration
- Downstream power outage impacts
  - Other energy infrastructure (pipelines), industry, health care, communications, economics
- Post-Wildfire
  - Flash flood / debris flow risk
  - Water quality/availability

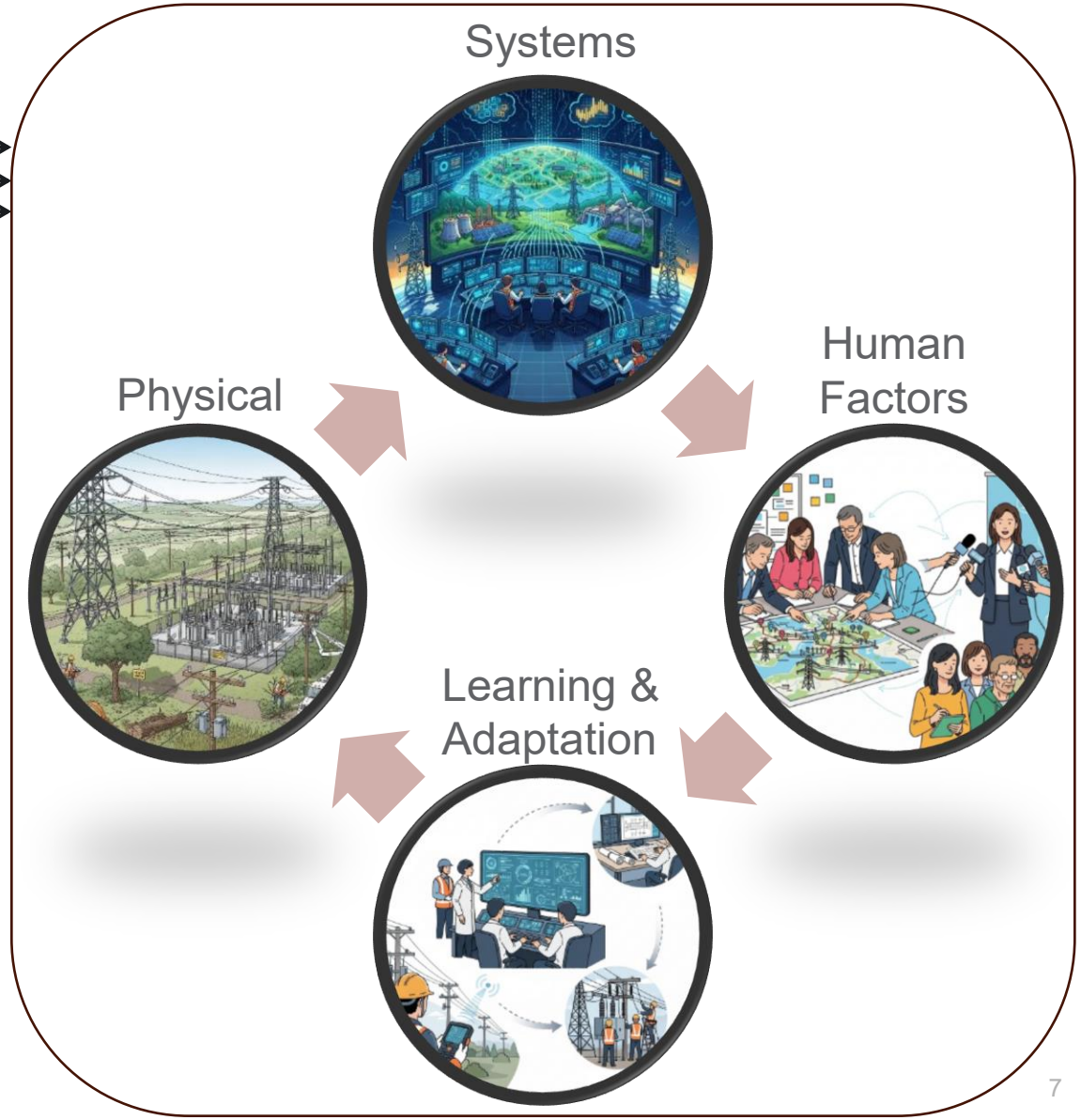
Wildfire Risk Mitigation is a Journey



Mitigating Wildfire Risk for Utilities

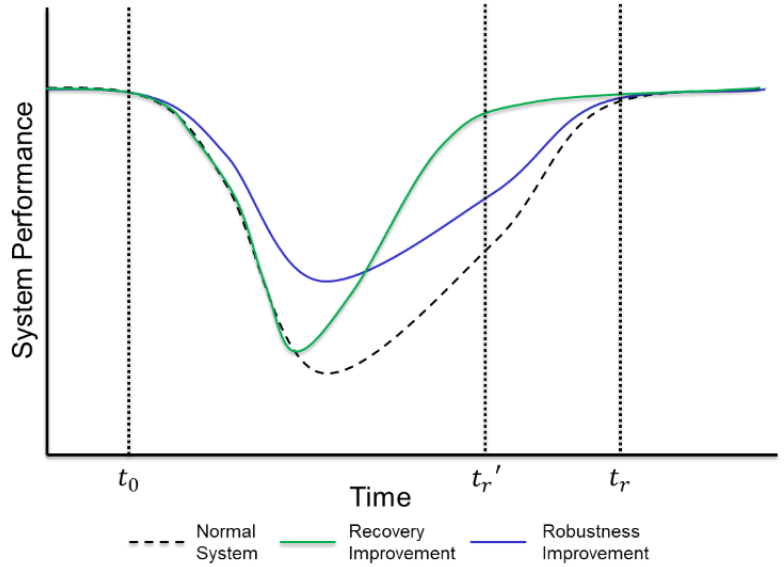


Impact event timeline for risk and resilience mitigation (adapted from Stankovic et al. 2023)



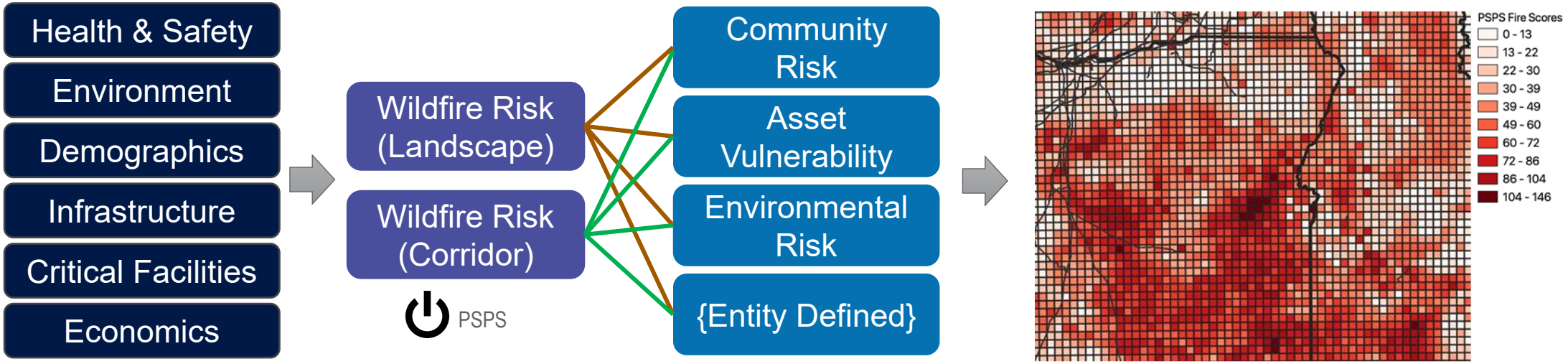
Conceptual Framework for Wildfire Resilience

1. Resilience as robustness (withstanding disruptions)
2. Resilience as graceful extensibility (adaptive capacity in real-time)
3. Resilience as rebound (rapid recovery)
4. Resilience as sustained adaptability (long-term evolution)



Consequence Analysis Modeling -Scale and Entity Relationships Matter

- Multi-criteria decision analysis tool for ranking *wildfire ignition* or *de-energization* in relation to high-value resources and assets
  - Quantitatively score consequences
- Data-driven prioritization tool informs planning, operations, & field operations
- Run at multiple time horizons – pre-season, weekly, monthly, long-term future



User-Defined Weights / Priorities

Fire Modeling Scenarios

Topic-Level Consequence Risk

Compound Consequence Risk Score

Multi-Temporal Wildfire Risk Forecasting

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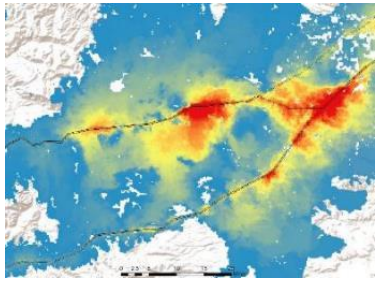
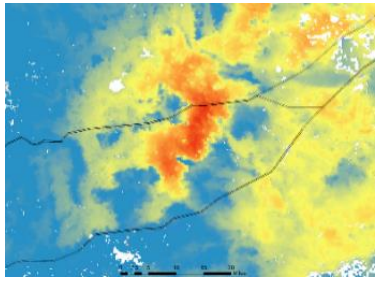
Mitigation Actions

- Vegetation Management
- Community Resiliency
- Infrastructure Hardening
- EPSS/PSPS Planning
- Consequence Analysis

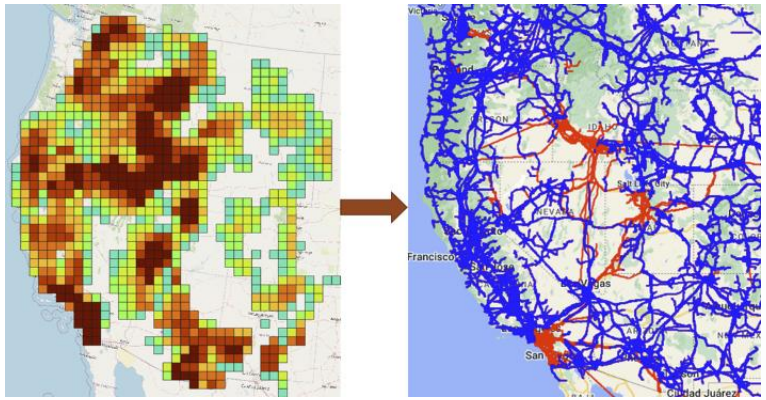
Annual Baseline Fire Risk



Corridor-Only Ignitions



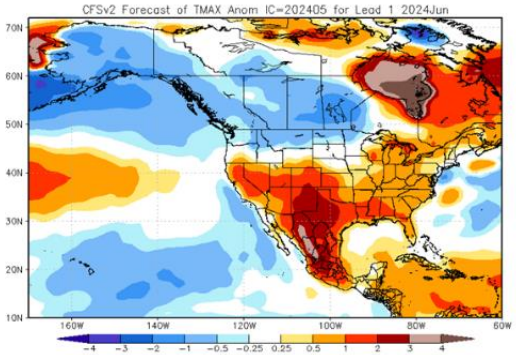
Landscape-Wide Ignitions



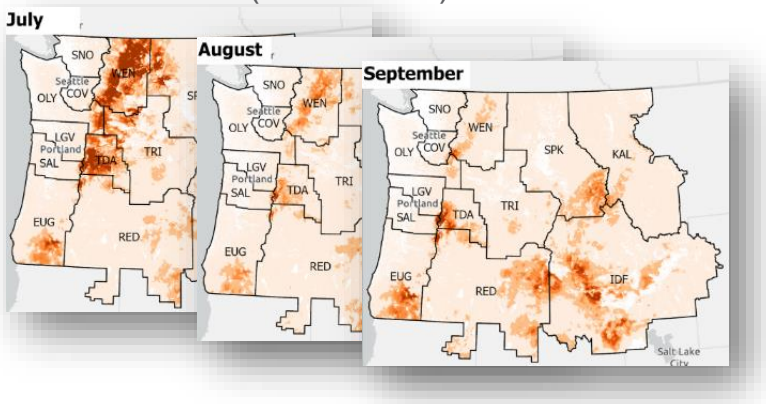
Infrastructure Fragilities - Wildfire Risk Evaluation of the System (WIRES)

Monthly Forecast Wildfire Risk

Medium-Range Ensemble Meteorological Forecasts

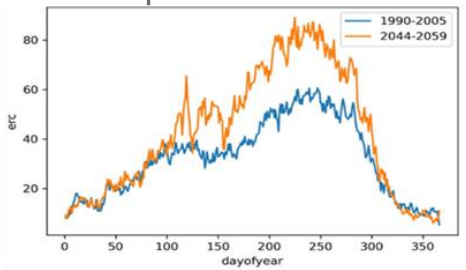


Monthly Wildfire Risk Forecasts (1-7 months)

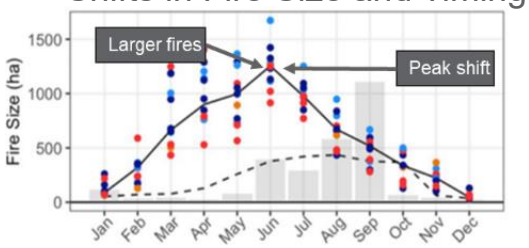


Long-Term Future Wildfire Risk

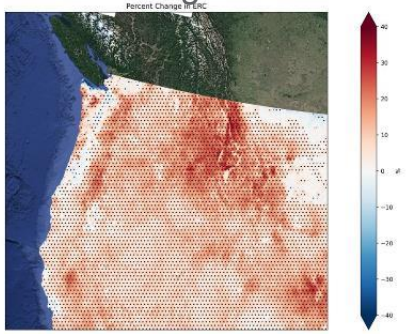
CMIP-5 & CMIP-6 Multiple RCPs / SSPs



Shifts in Fire Size and Timing



% Change in Risk



Conclusion

- To enable effective resilience planning, there is a need to model and **plan at different spatial and temporal horizons** to meet different operational phases

- Evaluating and determining the **reliability and resilience balance** is complex
  - i.e., how do you know if you're doing too much or too little?

- Wildfire **mitigation is a journey** with short-term wins and long-haul actions
  - Recognize that adaptation is mandatory amongst changing conditions
  - Dedicated utility wildfire mitigation teams

- Recognition that most individual entities have **varied approaches** for assessing risk (data sources, models, metrics) and implementing risk mitigation
  - Drive towards standard resiliency frameworks, consistent data sources, and best methods

- Collaboration/Coordination
  - Wildfire risk and mitigation is a multi-entity landscape-scale challenge
  - Need for improved public-private coordination and development of common objectives
  - Communication, partnerships, holistic planning, exercises, and mitigation are critical

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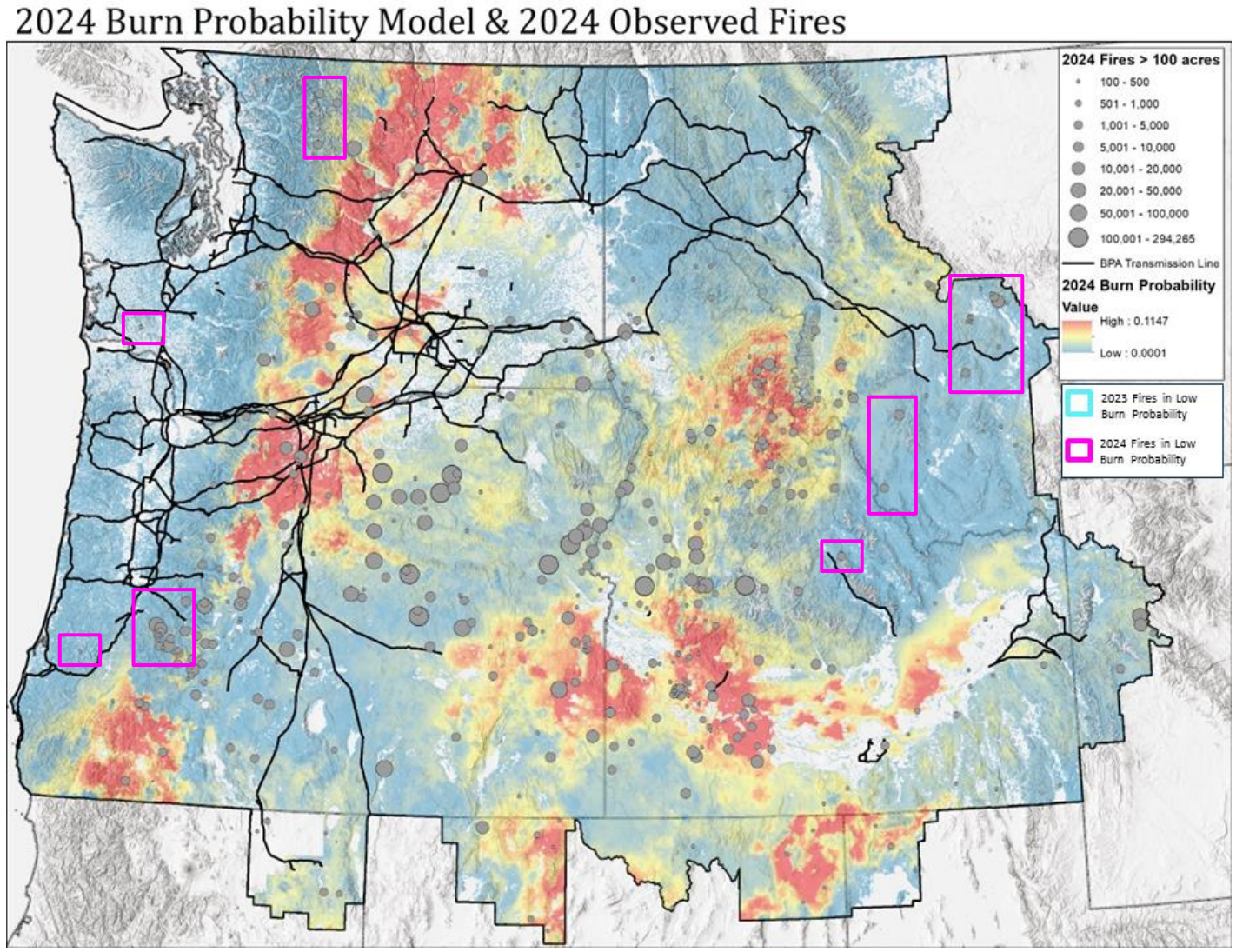
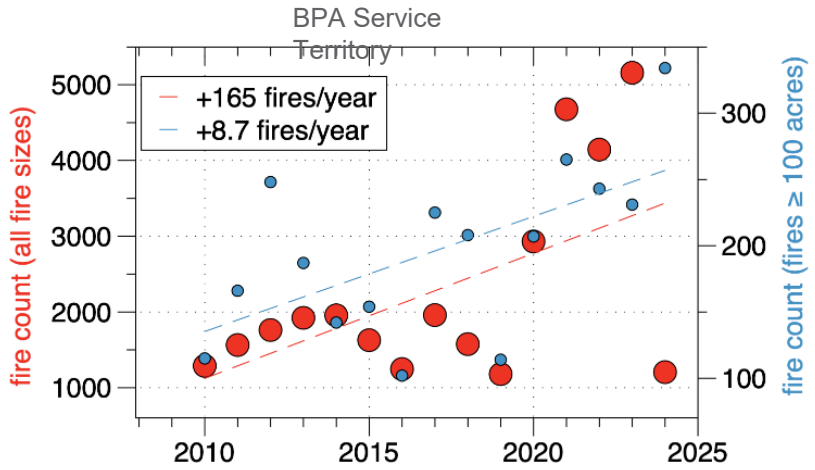
Thank you

Andre Coleman
andre.coleman@pnnl.gov

PNNL Team
Andre Coleman
Jerry Tagestad
Lee Miller
Troy Saltiel
Ilan Gonzalez-Hirshfeld
Kyle Larson
Arielle Catalano
Chris Chini
Jim Yoon
Krystal Ayala
Victoria Sinnott

Emerging Wildfire Risk





- **Emerging Risk:** fires are occurring in areas traditionally considered low-risk
- Concerning because of the high biomass availability

RADR-Fire Lifecycle
-Triple-Line Defense for Wildfire Resiliency

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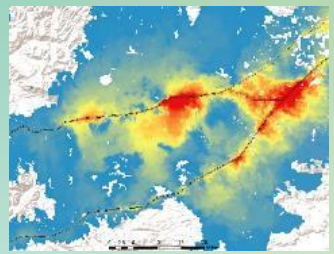
RADR FIRE

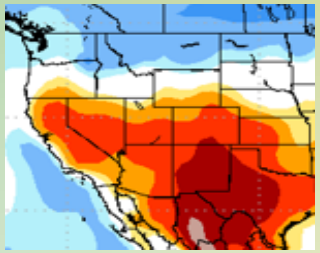
PREVENTION & MITIGATION

Pre-Season Fire Risk



- Vegetation Management
- Infrastructure Hardening
- Community Resiliency
- Consequence Analysis
- Planning, Preparedness, Monitoring, & Policy Actions

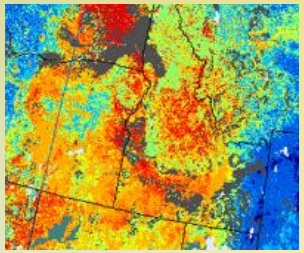
Forecasted Fire Risk



- Planning, Preparedness, Monitoring, & Policy Actions
- Consequence Analysis
- Vegetation Management
- Community Resiliency
- Infrastructure Hardening

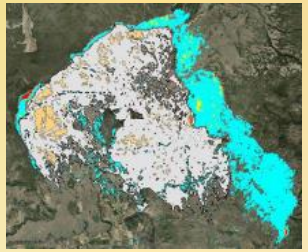
RESPONSE

Current Fire Risk



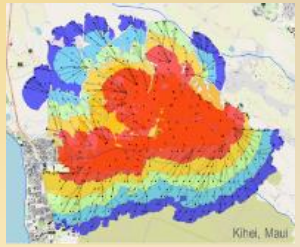
- Monitoring, & Policy Actions
- EPSS PSPS
- Infrastructure & Site Operations
- Consequence Analysis

Active Event Monitoring



- Situational Awareness
- Resourcing & Response
- Infrastructure & Site Operations
- EPSS /PSPS

Forecasted Fire Spread



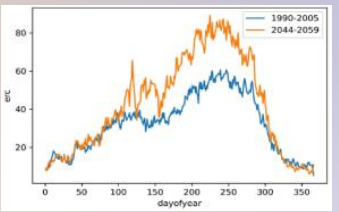
- Resourcing & Response
- Community Protection
- Evacuation
- Infrastructure & Site Operations
- Scenario Analysis

RECOVERY & PREPAREDNESS

Post-Event

- Community Protection
- Infrastructure Protection
- Flood Risk
- Landslide Risk
- Recovery
- Monitoring

Long-Term Future Risk



- Long-Term Planning & Mitigation
- Policy Development
- Strategic Investments

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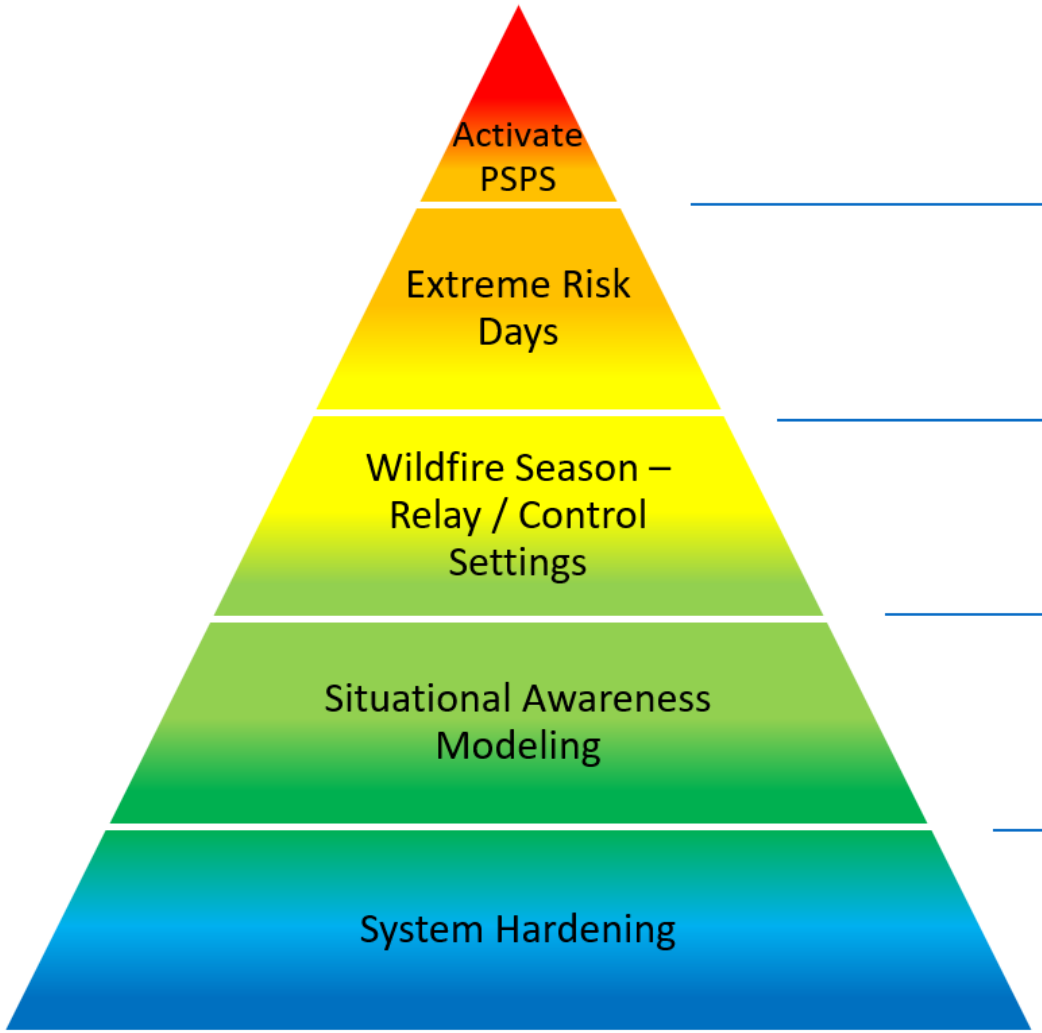
Resiliency Measures



Last resort: Public Safety Power Shutoff (PSPS)

During Extreme Risk Days, activate PSPS decision making team

During wildfire season, utilization of enhanced protection and control settings

During wildfire season, implementation of enhanced weather monitoring/forecasting and asset management tools to understand risk

Year-round system modifications and robust vegetation management program to minimize risk

Example Efforts

Vegetation management

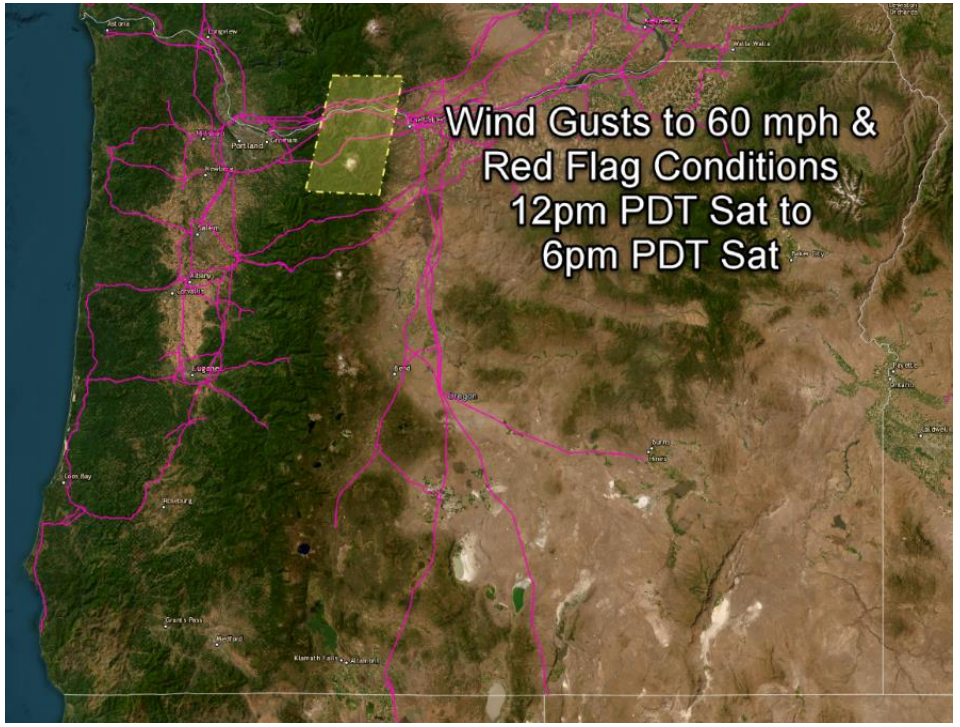


Table-top exercises

Wood pole fire retardants

Edge Cases

- Wildfire near Ashcroft, British Columbia, August 5, 2025 was caused by a fish
- Investigators determined that the fish had likely been scooped up by an osprey from a river 2-miles away
- *Perhaps* because of the excessive heat/exhaustion, the bird had dropped the fish, which hit the conductor
- The line faulted and ignited the dry grass below

Collaboration

- International Wildfire Risk Mitigation Consortium (IWRMC)
- Electric Power Research Institute (EPRI) Wildfire Advisory Group
- CEATI Wildfire Mitigation and Resiliency Working Group
- Utility discussions

- Power Marketing Administrations (WAPA, SWPA, SEPA)
- U.S. Forest Service (USFS)
- DOE: CESER, GRIP, GDO
- National Laboratories (Argonne, PNNL, Sandia)
- Utility discussions

- Oregon Wildfire & Electric Collaborative
- Washington Wildfire Working Group
- Utility and stakeholder discussions

Utility Wildfire Mitigation Plan Database

- PNNL created a database of all known and discrete utility Wildfire Mitigation Plans (WMPs) from across the United States and Canada.
- The purpose of the database is to provide a single consolidated location for access to all WMPs, organized by utility, year, location, and other metadata.
- The database features short citable analyses, map filters, and search functions.

wildfire.pnnl.gov/mitigationplans

409	170	9	18
Number of Wildfire Mitigation Plans	Number of Utilities Represented	Years Represented (2019-2028)	Number of States Represented

NORTH CENTRAL REGIONAL WILDFIRE WORKSHOP

Riaz Mohammed, Xcel Energy
August 27, 2025
Madison, WI

SERVING EIGHT STATES

3.8 million

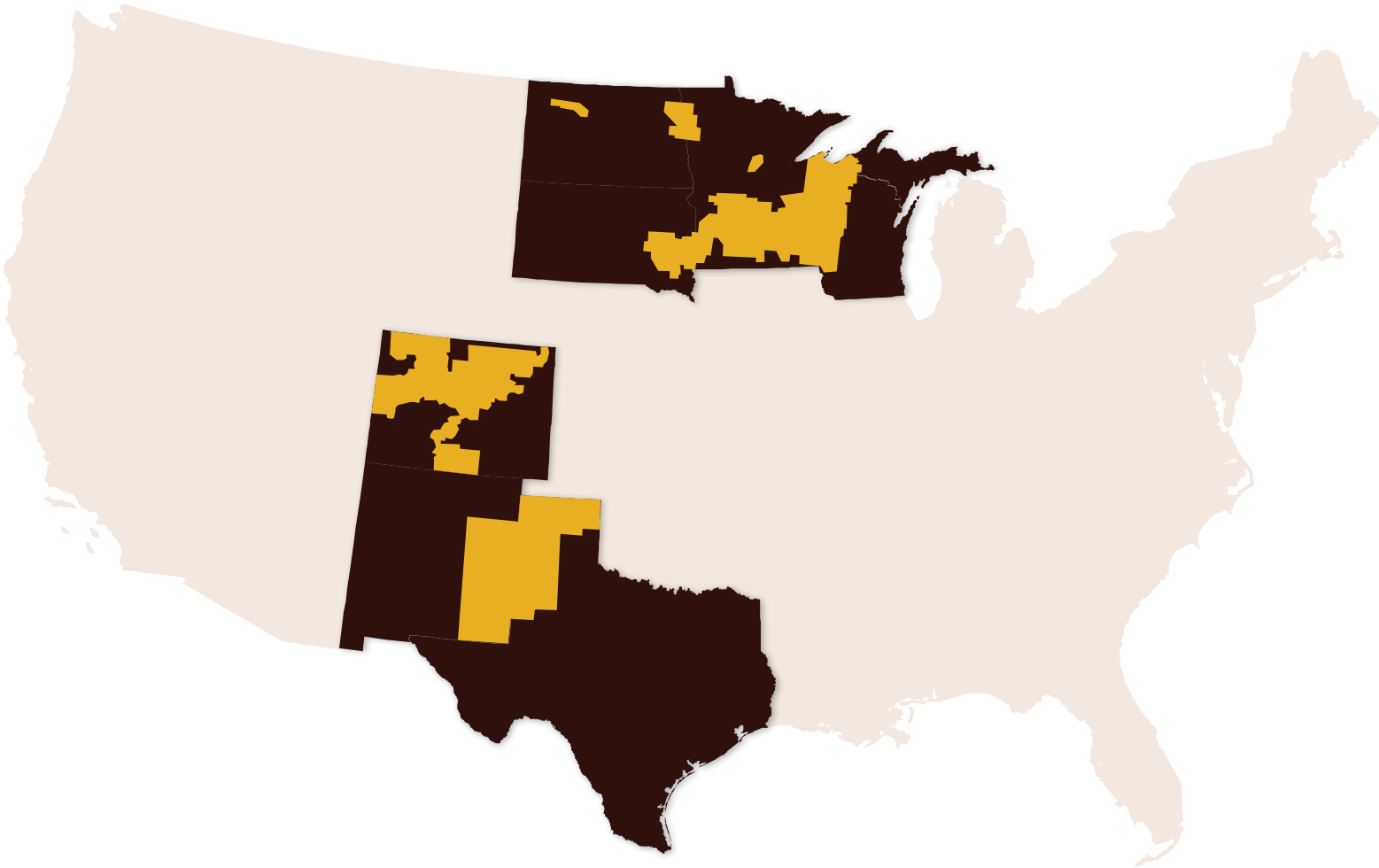
electric customers

2.2 million

natural gas customers

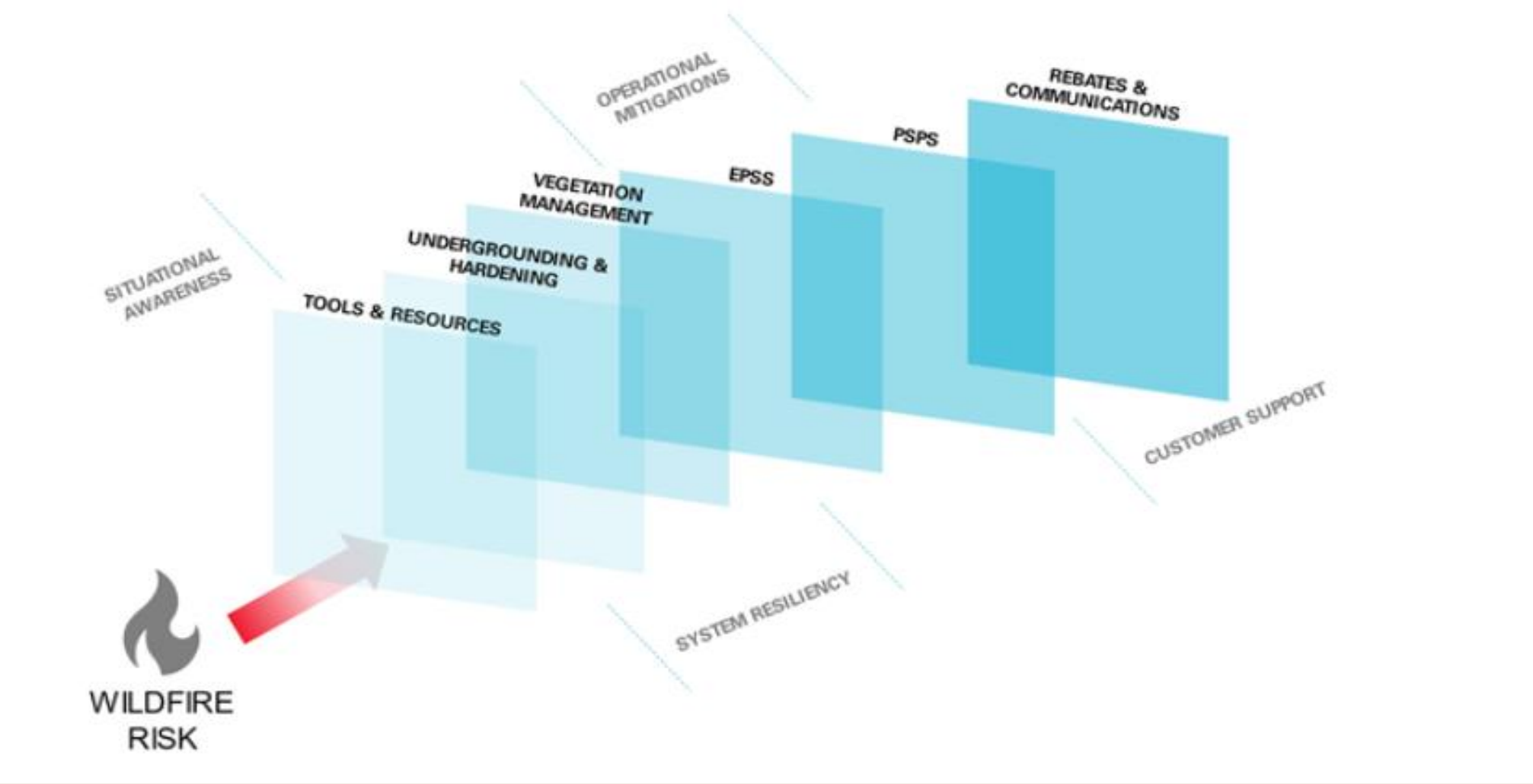
National leader

- Wind energy
- Energy efficiency
- Carbon emissions reductions
- Storm restoration



XCEL ENERGY WILDFIRE MITIGATION PLANS

WILDFIRE MITIGATION PLAN LAYERS OF DEFENSE



WILDFIRE MITIGATION STRATEGIES

#1

Situational Awareness

Risk Tier Maps

Advanced Fire Modeling Software

Weather Stations

Pano AI Cameras

#2

System Resiliency

Asset Inspection, Repair and Replacement

Non-Expulsion Equipment Replacement

System Hardening

#3

Vegetation Management

Conductor Clearance

Defensible Space around Poles and Substations

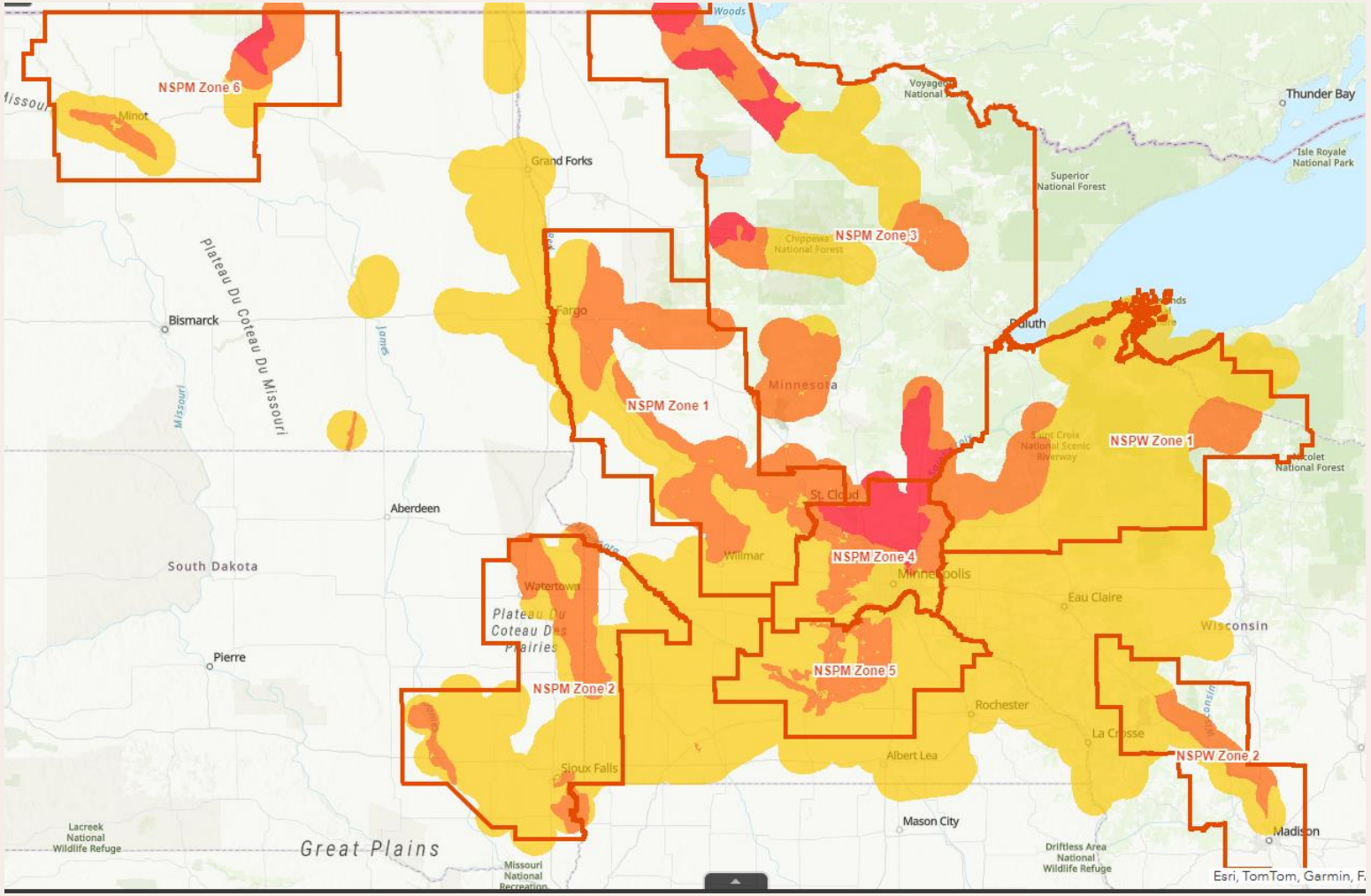
#4

Operational Mitigations

Enhanced Powerline Safety Settings (EPSS)

Public Safety Power Shutoffs (PSPS)

WILDFIRE RISK IN NSPM & NSPW



We use the tier map for asset health, inspection and operational programs.

[View our interactive Wildfire Risk Tier map]

Color	Tier
	Tier 1
	Tier 2
	Tier 3

Tier	Description
Tier 1	Areas with significant human development and/or surfaces resistant to fire.
Tier 2	Areas where wildfire may cause significant damage to human infrastructure due to fuel continuity and terrain.
Tier 3	Areas where wildfire will likely rapidly become large, destructive or catastrophic events due to fuel continuity and population density.

WILDFIRE VEGETATION MANAGEMENT ACTIVITIES

#1 **Wildfire Corridor Maintenance:** Provides physical vegetation clearance around powerlines to prevent encroachment and to mitigate ignition risk.

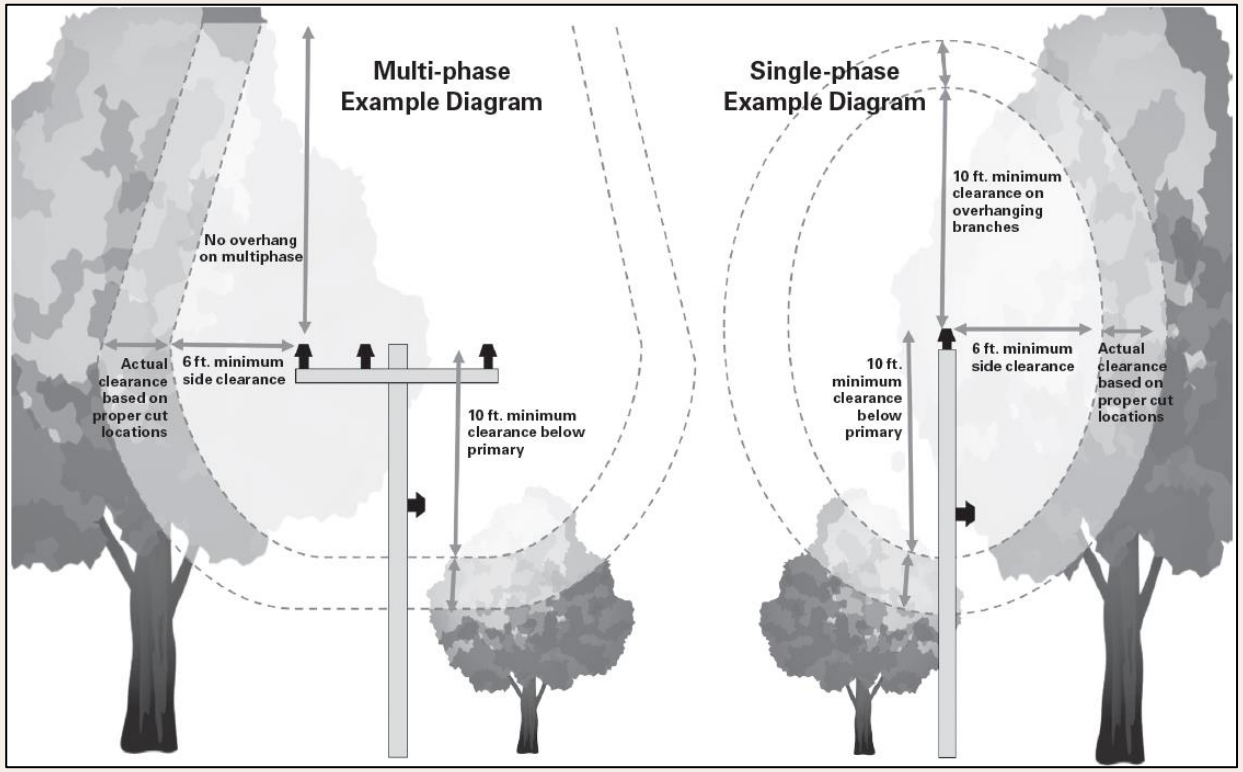
#2 **Wildfire Right of Way Clearance:** Removing trees and incompatible vegetation from utility corridor, thus providing future vegetation encroachment from beneath, accessibility, and sustainability.

#3 **Wildfire Hazard Tree Removal:** Mitigates risk of fall-in trees and ignition risk.

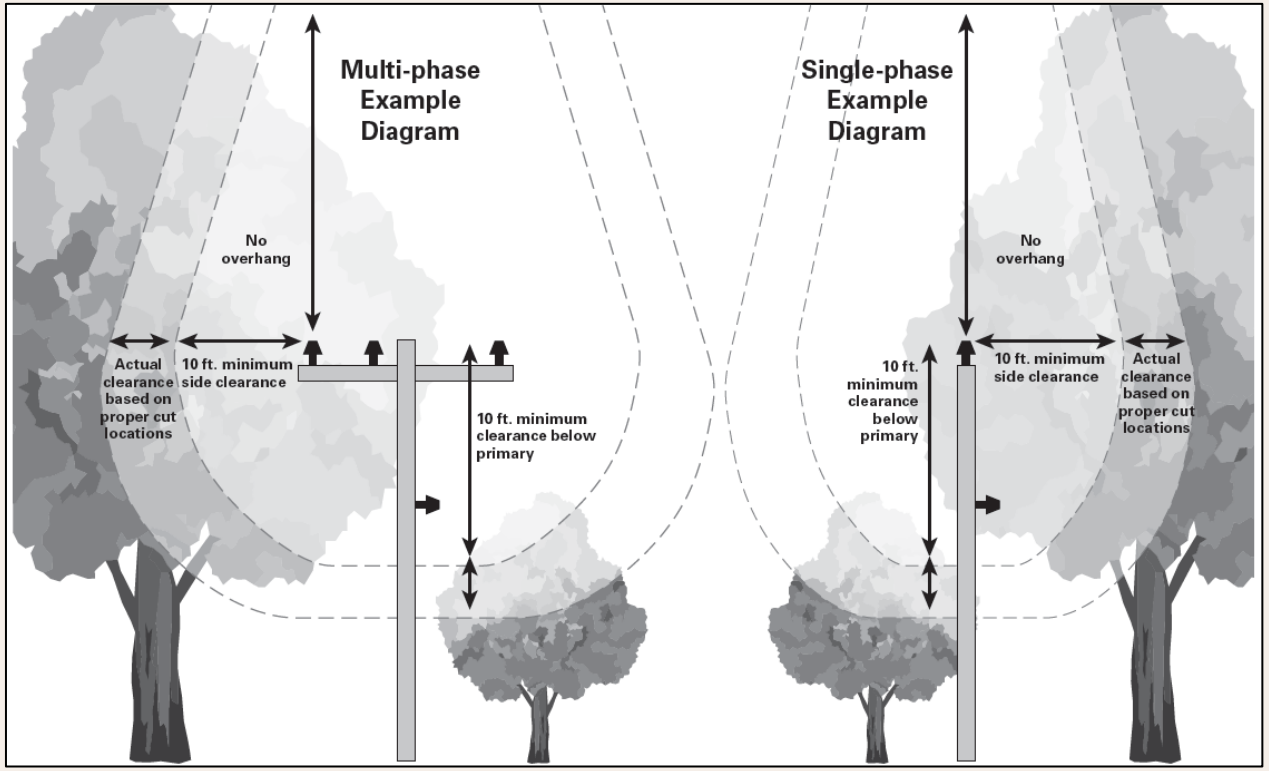
#4 **Wildfire Defensible Space Around Facilities:** Reduces risk of ignition at location of fused cutouts, as well as other selected device types, in our distribution system. Protects transmission assets in the event of a passing wildfire.

#5 **Quality Assurance and Control:** Ensures work is consistent with expectation from VM Standards

DISTRIBUTION VEGETATION MANAGEMENT CLEARANCES



Tier 1 Standard

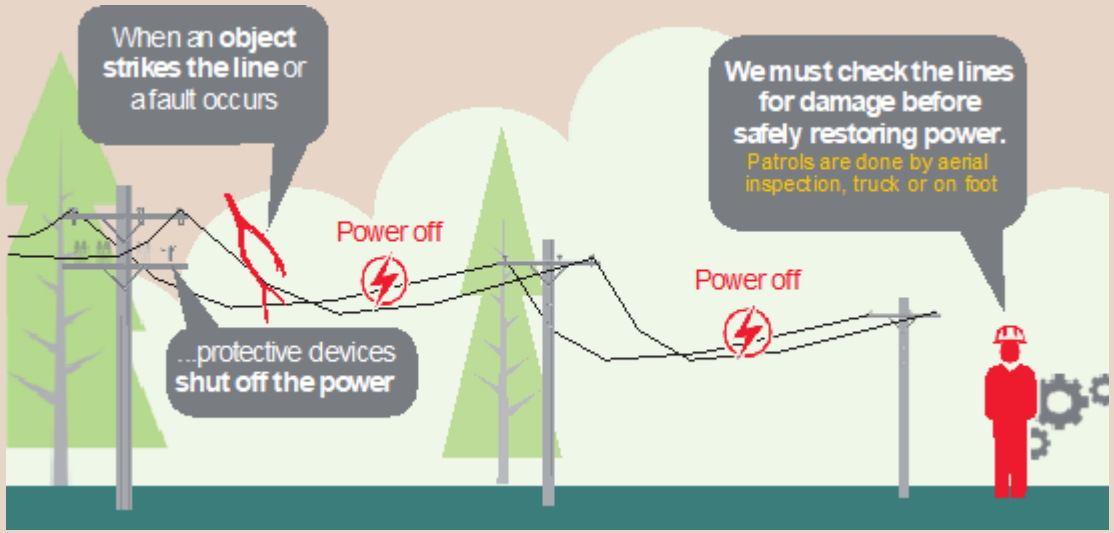


Tiers 2 & 3 Standard

ENHANCED POWERLINE SAFETY SETTINGS (EPSS)

Enhanced Powerline Safety Settings (EPSS) is a proven wildfire mitigation tool.

It allows for power lines to remain in service during periods of elevated wildfire risk, with protection settings enabled.



When EPSS is activated, power lines are more sensitive and can quickly stop the flow of energy if an issue is detected, like a tree branch or other object touching the line. When that occurs, the power will remain off until our crews can inspect the line to make sure it's safe to turn it back on.

It is intended to enhance public safety during heightened risk conditions, but it means power outages are likely to occur more frequently, and if they do, are likely to last longer because crews need to patrol the line before restoring power.

EPSS is used in risk zones identified by risk probability models considering facts like weather, housing density, terrain, miles of overhead lines.

PUBLIC SAFETY POWER SHUTOFFS (PSPS)

During extreme or critical wildfire risk conditions, or if we're working near active wildfires, we may need to temporarily turn off electric service to customers in targeted areas.

This is a risk reduction strategy known as a Public Safety Power Shutoff (PSPS).

Proactively shutting off power is not a step we take lightly. A PSPS is only considered when the following three factors are present:

Extreme Winds: wind speeds greater than or equal to the 99th percentile at specific locations.

Relative Humidity: low relative humidity (30% or lower).

Fuel Moisture: presence of drier fuel sources, calculated by considering day length, hours of rain and daily temperature and humidity ranges.

After a PSPS, restoration efforts can only begin after high winds and elevated wildfire risk have subsided. Power restoration may take multiple hours or days because we must visually inspect lines to ensure they're safe to be re-energized.

PSPS COMMUNICATIONS MILESTONES

POTENTIAL FOR EVENT

Severe weather in the forecast, including high winds and low relative humidity, indicates heightened wildfire risk and the potential need for a PSPS.

48-72 Hours in Advance of PSPS

PRE-EVENT

48-72 Hours in Advance of PSPS

Severe weather forecast persists, and it appears likely that we will need to conduct a PSPS within the next 72 hours.

GO DECISION

Due to weather conditions and increased wildfire risk, we decide that a PSPS event is necessary to prevent possible wildfires.

1-4 Hours in Advance of PSPS

EVENT

Every 24 Hours during PSPS

During a PSPS, we continue to communicate with affected customers, provide updated information to the community and assess risk on the ground.

RESTORATION

Once we have determined that wildfire risk has subsided, and conditions have improved, we will begin the restoration process.

Our crews visually inspect and patrol all power lines to ensure it is safe to turn service back on. Power is restored segment by segment once inspected and cleared.

COMPARING EPSS AND PSPS

EPSS and PSPS are only used when weather conditions, including the temperature, wind speed, relative humidity and available fuel sources, indicate an elevated or extreme risk for wildfire.

ENHANCED POWERLINE SAFETY SETTINGS (EPSS)

EPSS allow power lines to remain in service during periods of high wildfire risk with additional protection settings enabled to enhance public safety.

Customers impacted by EPSS may experience more frequent or longer outages. This is because crews must inspect power lines and the surrounding area to ensure it’s safe to restore service.

PUBLIC SAFETY POWER SHUTOFFS (PSPS)

PSPS is a risk reduction strategy in which we temporarily turn off electricity to customers in targeted areas during extreme or critical wildfire risk conditions.

Proactively shutting off the power is not a step we take lightly. We work closely with our customers and communities to help them prepare and connect them with available resources.

TAKEAWAYS

WMPs are part of the solution to address wildfire risk, but it will take a collective effort of many stakeholders to fully address this issue.

Collaboration and Coordination between all stakeholders before, during, and after a wildfire events is critical.

Be Proactive to the risk posed by wildfire.

Supportive regulatory framework to mitigate wildfire risk.


Credit: *Getty Images*

PNNL/DOE North Central Regional Wildfire Workshop for State Energy Security Planning – Madison, Wisconsin

Escaping the Capability Trap:

Strategic Reframing of Public Safety Power Shutoffs by Electric Utilities for Wildfire Risk Mitigation

Ali Arabnya

QUANTA TECHNOLOGY
A QUANTA SERVICES COMPANY

August 27, 2025

Three Lines of Defense for Wildfire Risk Management

A three-lines-of-defense (3LD) framework for end-to-end wildfire risk management can facilitate an optimal resource allocation for wildfire resilience building by utilities.

Source: Ali Arabnya & Amin Khodaei, "The Economics of Climate Resilience in Power Infrastructure," Wiley-IEEE Press, 2025, available on Amazon.

PSPS Risk

While Public Safety Power Shutoffs (PSPS) can be an effective temporary risk reduction tool, it can pose unintended risks to electric utilities, including:

- ✓ **Operational Risk**
  - Regulatory Risk
  - Reliability Loss
  - Revenue Loss
  - False Negatives
  - Egress/Ingress Risk
- ✓ **Strategic Risk**
  - Capability Trap
  - Adaptation Trap

Picture Credit: Mike Eliason, Santa Barbara County Fire Department, AP / IEEE Spectrum

Strategic PSPS Risks

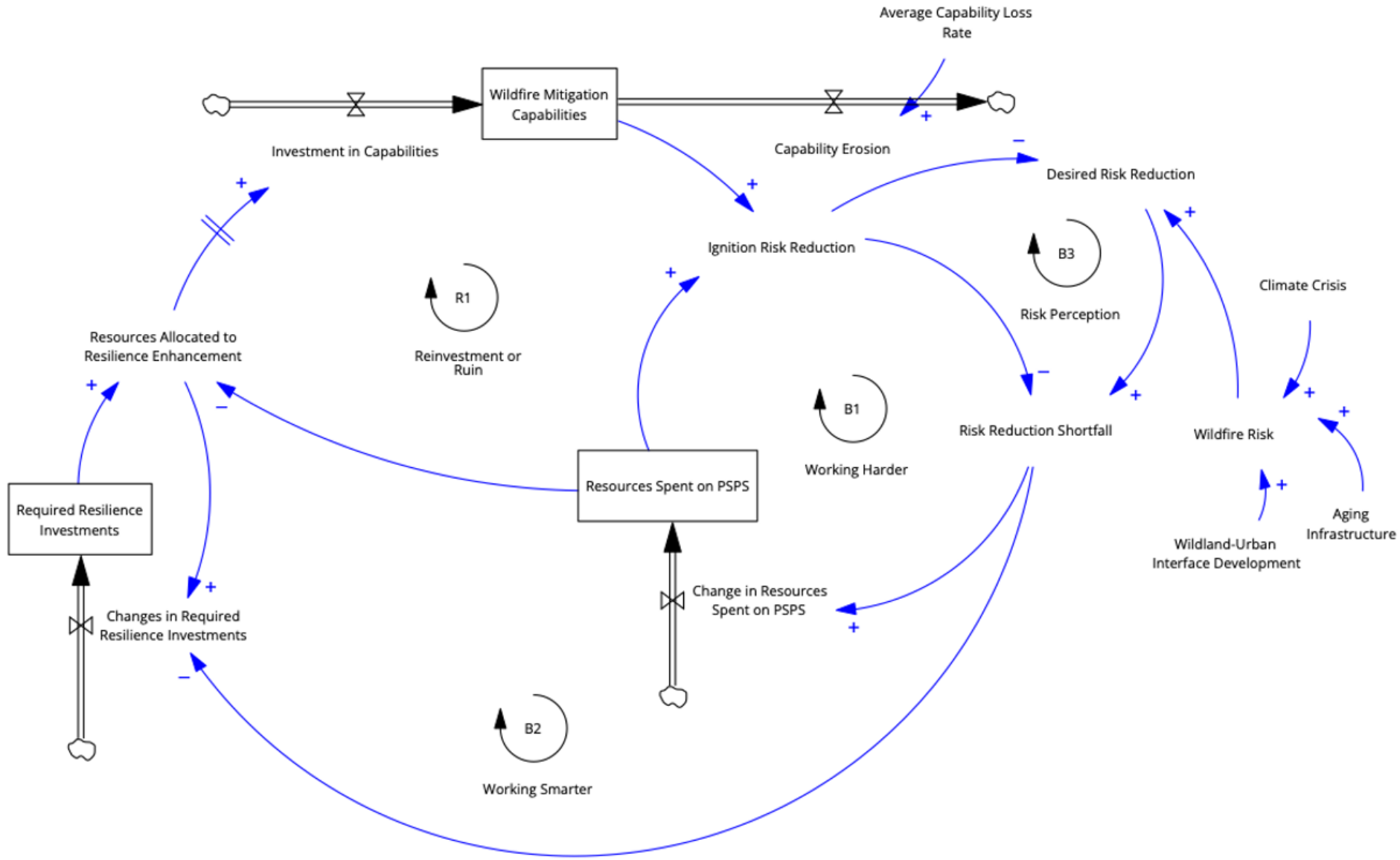
Capability trap occurs when well-intentioned efforts to boost short-term results at the expense of maintaining underlying capabilities risks trapping the organization in a vicious cycle of decline.[1]

Adaptation trap occurs when well-intentioned efforts by organizational leaders to search locally for short-term optimal solutions lead them to create dynamics in the system that cause organizational capabilities to erode.[2]

While PSPS programs are helpful in reducing immediate wildfire risks, their long-term use can unintentionally erode electric utilities' capabilities to manage wildfire risk.

[1]Nelson P Repenning & John D Sterman, "Capability traps and self-confirming attribution errors in the dynamics of process improvement," Administrative Science Quarterly, 2002.
[2]Source: Hazhir Rahmandad & Nelson Repenning, "Capability erosion dynamics," Strategic Management Journal, 2016.

Understanding the Long-term PSPS Dynamics



Strategic Reframing of PSPS

- ✓ Treat PSPS as a managed transition tactic—to convert wildfire problem into outage problem and to expand the window of opportunity to act—not a permanent solution
- ✓ Reallocate capital to high-leverage grid hardening investments
- ✓ Institutionalize high-quality vegetation and asset management programs
- ✓ Use PSPS as a “burning platform” for strategic change management and to boost reinvestment in the aging infrastructure and mobilizing climate resilience investments
- ✓ Align incentives, governance, and strategic communications with stakeholders


Credit: *Getty Images*

Thank you!

aarabnya@quanta-technology.com