# A recording of the June 15, 2022 Intro to Resiliency Planning Workshop is Available at:

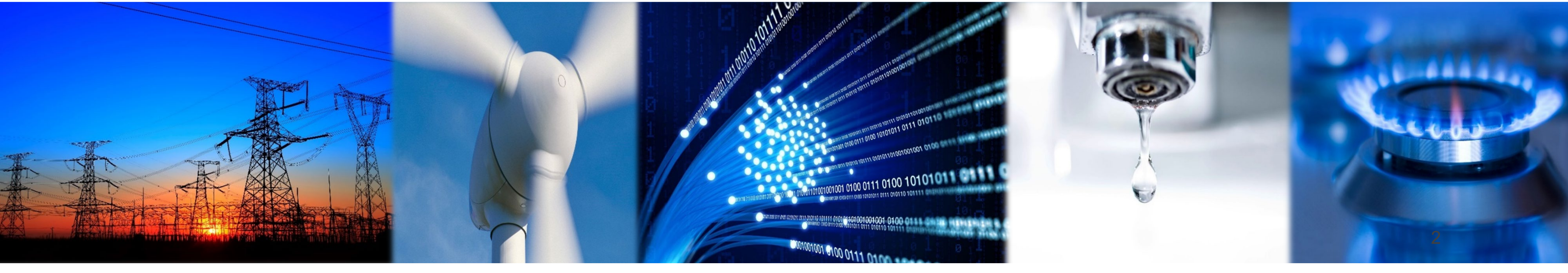
https://oregonpuc.granicus.com/MediaPlayer.php?view_id=2&clip_id=967

Oregon Public Utility Commission

# UM 2225 Investigation Into Clean Energy Plans

## Introduction to Resilience Workshop

June 15, 2022



# Logistics

## Thank you for joining us today!

- For discussion and comments, use "Raise Hand“ button to get in the queue; if joined by phone press *9
- Include your affiliation in your Zoom name
- Say your name and affiliation before speaking
- Engage with the main dialogue
- Move around and take care of yourself as needed

# Meeting Protocols

Oregon Public Utility Commission

## Introductions in the chat

- Name
- Organization
- Biggest goal for how resilience shows up in Clean Energy Plans

Honor the agenda and strive to stay on topic

Provide a balance of speaking time

Listen to understand and ask questions to clarify

Stay engaged and be open about your perspective and experience

Address issues and questions - focus on substance of comments without attacking others

Bring concerns and ideas up for discussion at the earliest point in the process

# Meeting Context

According to HB 2021 Clean Energy Plans are required to include:

"a risk-based examination of resiliency opportunities that includes costs, consequences, outcomes and benefits based on reasonable and prudent industry resiliency standards and guidelines established by the Public Utility Commission."

# Meeting Objectives

- Learn about initial research into industry standards and practices from national labs.
- Questions to ask yourself during presentation:
  - What is missing?
  - What areas should be further expanded or discussed?
  - What outcomes are we trying to avoid with the resiliency analysis?

**Agenda *Pacific Time**

Welcome (1:00pm)

Landscape research on resilience and planning (1:10 – 3:20 pm)

BREAK (3:20 – 3:30 pm)

Wrap up discussion (3:30 - 4:00 pm)

# Landscape Research

- Oregon context
- Resilience and reliability vs resilience
- Metrics and risk spend efficiency
- Metrics from industry organizations
- State and utility examples
- Valuation and cost-benefit analysis
- Community resilience

# Break!

Back at 3:30p (Pacific)

# Wrap Up

## Initial research

- What is missing?
- What areas should be further expanded or discussed?

## Bringing it back to Clean Energy Plans

- What outcomes are we trying to avoid with the resiliency analysis?

# Thank you!!

## Questions/ideas:

Heide Caswell
503-400-0619
heide.caswell@puc.oregon.gov

Caroline Moore
caroline.f.moore@puc.oregon.gov
503-480-9427

# Considerations for Resilience Guidelines for Clean Energy Plans

**Juliet Homer[1], Karyn Boenker[1], Kostas Oikonomou[1], Hope Corsair[2], Alice Lippert[3], and Rebecca Tapio[1]**

[1]Pacific Northwest National Laboratory, [2] Oak Ridge National Laboratory, [3]Argonne National Laboratory

UM 2225 – Planning for Resilience Workshop #1

6/15/2022

# Grid Modernization Laboratory Consortium Technical Assistance Project Team

- **Juliet Homer** – Pacific Northwest National Laboratory
- **Karyn Boenker** - Pacific Northwest National Laboratory
- **Kostas Oikonomou** - Pacific Northwest National Laboratory
- **Rebecca Tapio** - Pacific Northwest National Laboratory
- **Alice Lippert** – Argonne National Laboratory
- Todd Levin – Argonne National Laboratory
- **Hope Corsair** – Oak Ridge National Laboratory
- Larry Markel – Oak Ridge National Laboratory

# Goals of meeting

- Level set with current information, research, and practices on resilience and planning
- Discuss other resources, areas of focus, and approaches to consider
- Discuss what the most meaningful final product will look like

We will have time for questions, suggestions, and discussion as we go along

We hope this session provides an opportunity for participants to share perspectives as well as provide suggestions to the GMLC team

What do you think is important? What is your perspective on the issues being presented?

We provide national perspectives and examples. Oregon will find what is right for Oregon.

# Agenda

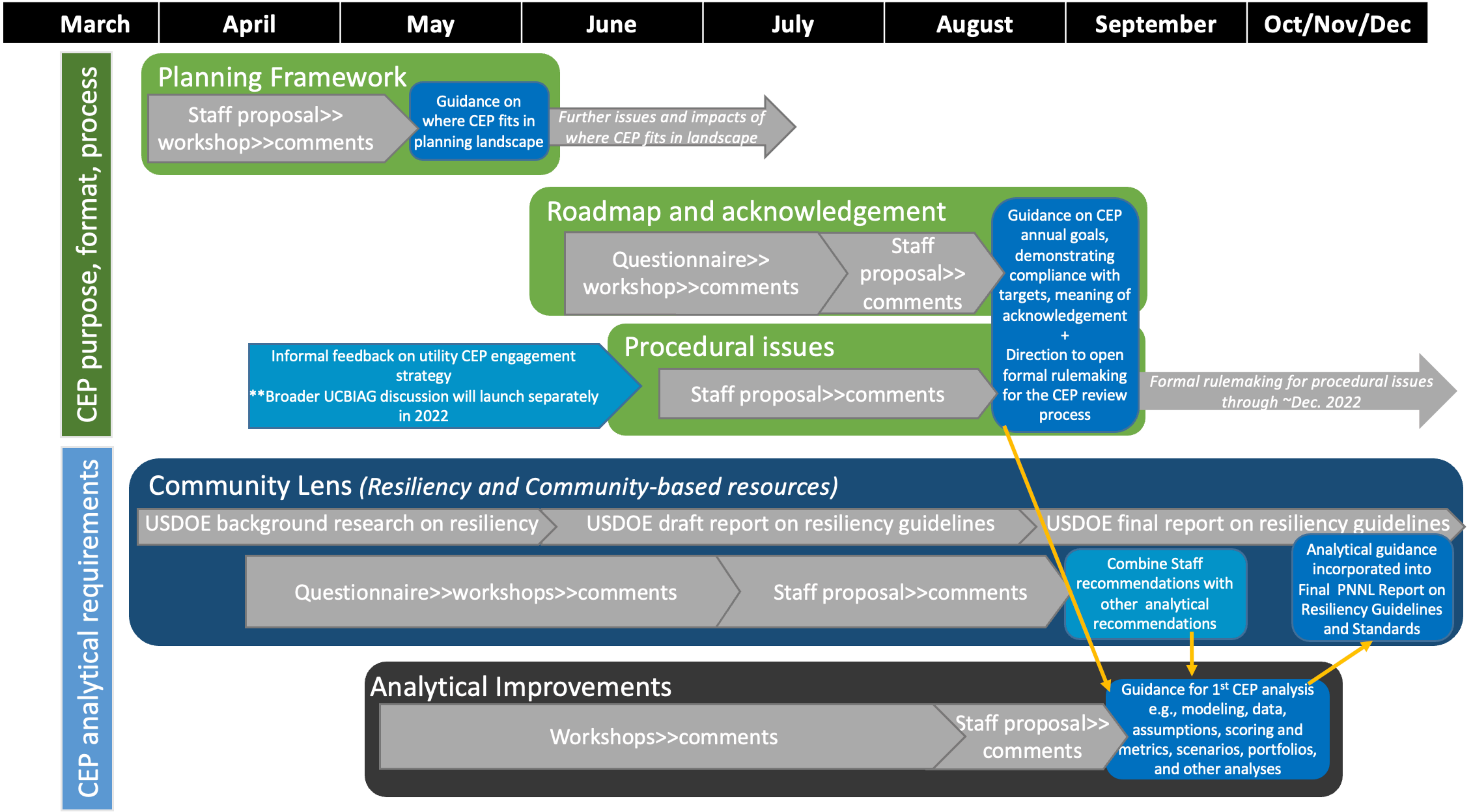
- Oregon context – Karyn Boenker (5 minutes)
- Resilience context – Alice Lippert (20 minutes + 10 minutes discussion)
  - Resilience definitions
  - Resilience vs. reliability
  - Metrics from industry organizations
- Community-focused resilience – Hope Corsair (15 minutes + 10 minutes discussion)
- Valuation and benefit-cost analysis – Rebecca Tapio (5 minutes + 5 minutes discussion)
- BREAK 10 minutes
- Resilience metrics – Kostas Oikonomou (15 minutes + 10 minutes discussion)
  - Metrics context
  - Risk spend efficiency
  - Power grid investments with potential resilience benefits
- State and utility examples – Juliet Homer (15 minutes + 5 minutes discussion)
- Wrap-up and next steps – Juliet Homer (2 minutes)

# Resilience – Oregon Context

- Oregon HB 2021, Section 4 – Clean Energy Plans must:
  - "Include a risk-based examination of resiliency opportunities that includes costs, consequences, outcomes, and benefits based on *reasonable and prudent industry resiliency standards and guidelines* established by the Public Utility Commission."

- Oregon's HB 2021 includes the following contextual definitions for resilience:
  - **"Energy resilience"** means the ability of energy systems, from production through delivery to end-users, to withstand and restore energy delivery rapidly following non-routine disruptions of severe impact or duration.
  - **"Community energy resilience"** means the ability of a specific community to maintain the availability of energy needed to support the provision of energy-dependent critical public services to the community following non-routine disruptions of severe impact or duration to the state's broader energy systems.
  - **"Community energy resilience project"** means a community renewable energy project that includes utilizing one or more renewable energy systems to support the energy resilience of structures or facilities that are essential to the public welfare.
  - Mitigative actions create "stability, local jobs, economic development, or direct energy cost savings for families and small businesses."

# HB 2021, Section 4 - Clean Energy Plan (CEP) Work Plan



# Resilience – Oregon DOE (ODOE) Parallel

## HB 2021 (2021): Clean Energy Targets

- Must "Include a risk-based examination of resiliency opportunities that includes costs, consequences, outcomes, and benefits based on *reasonable and prudent industry resiliency standards and guidelines* established by the Public Utility Commission."
- CEP approval will depend on; GHG impact, tech/econ feasibility, reliability/resilience, federal incentives, costs/risks.
- **Includes $50M for ODOE to provide in grants for community renewable energy projects outside of Portland and allows for "green tariffs" to create cleaner energy options.**
    - Eligible projects include renewable energy generation systems like solar or wind, and energy storage systems, electric vehicle charging stations, or microgrid technologies paired with new or existing renewable energy systems.

## ODOE's Community Renewable Energy Grant Program

| Project | Maximum Award | Maximum Percent of Eligible Project Costs |
|---|---|---|
| Planning a community renewable energy project | $100,000 | 100% |
| Planning a community energy resilience project | $100,000 | 100% |
| Constructing a community renewable energy project | $1,000,000 | 50% |
| Constructing a community energy resilience project | $1,000,000 | 100% |

***Currently, $12 Million in funding is available with applications due July 8, 2022. Program lasts through 2024. More information here.***

# Resilience Context - Alice Lippert

- Resilience definitions
- Reliability vs. resilience
- Metrics from industry organizations
- Limitations of traditional reliability metrics

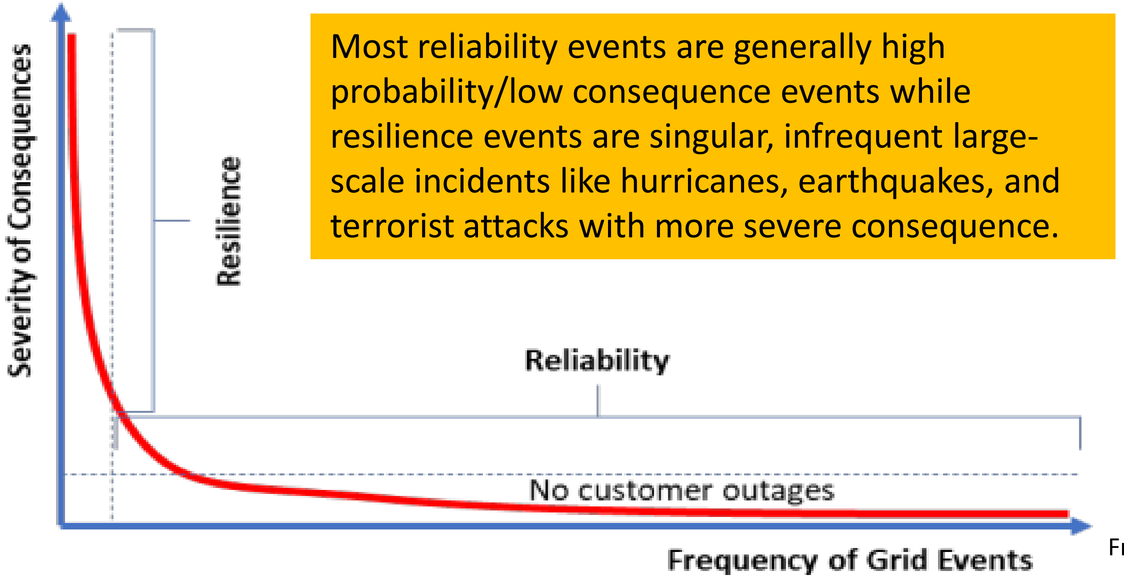
# Resilience – Definitions

- National Infrastructure Advisory Council (NIAC) definition:
  - "Infrastructure resilience is the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a resilient infrastructure or enterprise depends upon its ability to anticipate, absorb, adapt to and/or rapidly recover from a potentially disruptive event." In 2010, a framework construct was developed based on risk management practices of the electric utility industry and included the four elements of resilience: robustness, resourcefulness, rapid recovery, and adaptability. (NIAC 2009, 2010)
- National Association of Regulatory Utility Commissioners (NARUC):
  - "Robustness and recovery characteristics of utility infrastructure and operations, which avoid or minimize interruptions of service during an extraordinary and hazardous event." (NARUC 2013)
- FERC definition:
  - "The ability to withstand and reduce the magnitude and/or duration of disruptive events, which includes the capability to anticipate, absorb, adapt to, and/or rapidly recover from such an event." (FERC 2018)
- Electric Power Research Institute (EPRI):
  - "Resilience includes the ability to harden the system against – and quickly recover from – high-impact, low-frequency events…. Enhanced resilience of the power system will be based on three elements:
    - Damage prevention: the application of engineering designs and advance technologies that harden the power system to limit damage
    - System recovery: the use of tools and technologies to restore service as soon as practicable
    - Survivability: the use of innovative technologies to aid consumers, communities, and institutions in continuing some level of normal function without complete access to their normal power sources."

From LBNL Future Electric Utility Regulation 2019: Utility Investments in Resilience of Electric Systems

# Resilience vs. Reliability

- FERC and NERC
  - *The concept that "resilience is a time-based component of reliability" is widely accepted in the electric industry and was promoted by NERC to FERC in their response to Docket No AD18-7-000 (NERC 2018). NERC notes that their definition of "adequate level of reliability or 'ALR' includes resilience as a time-based component of reliability"*
- DOE GMLC
  - Resilience: The ability of the system to prepare for and adapt to changing conditions and withstand and recover rapidly from disruptions, including the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents (DOE 2017).
  - Reliability: The ability of the system or its components to withstand instability, uncontrolled events, cascading failures, or unanticipated loss of system components (DOE 2017).
- The Hawaii Resilience Working Group Report for Integrated Planning (HRWG 2020)




Most reliability events are generally high probability/low consequence events while resilience events are singular, infrequent large-scale incidents like hurricanes, earthquakes, and terrorist attacks with more severe consequence.

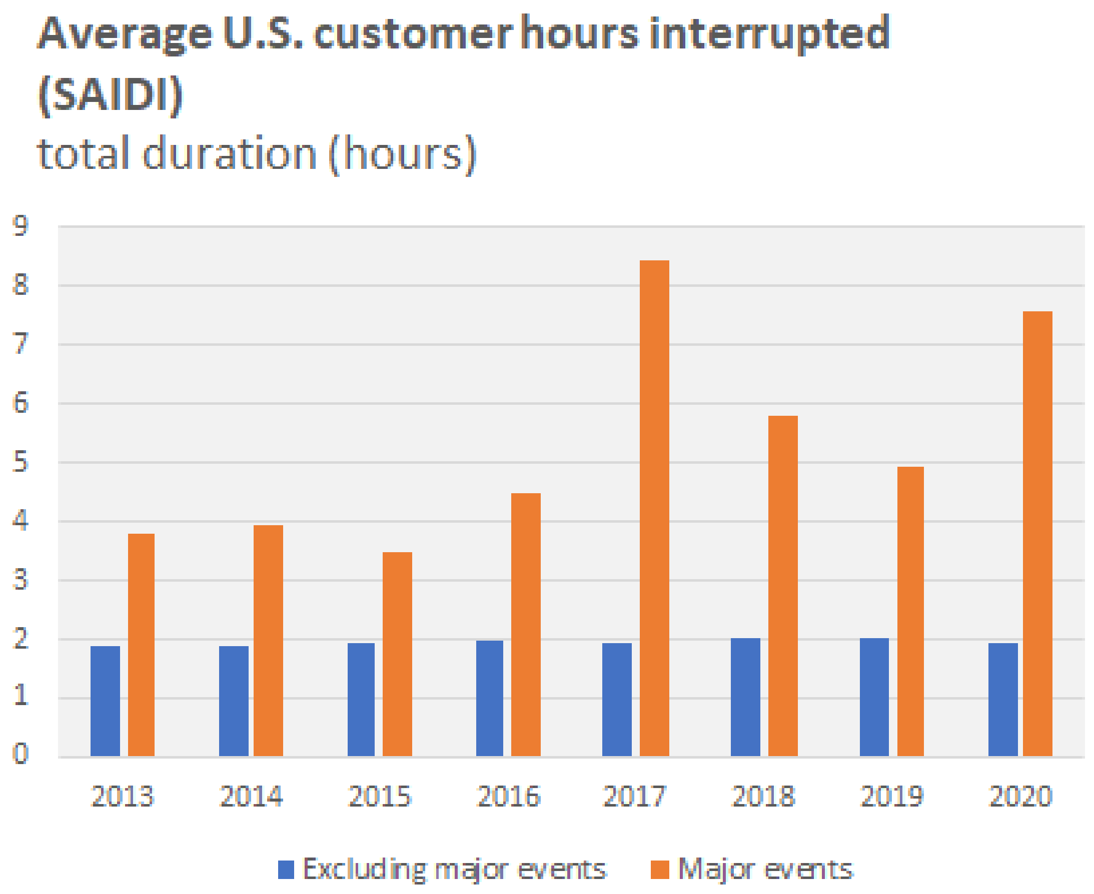
From [Hawaii Resilience Working Group 2020]

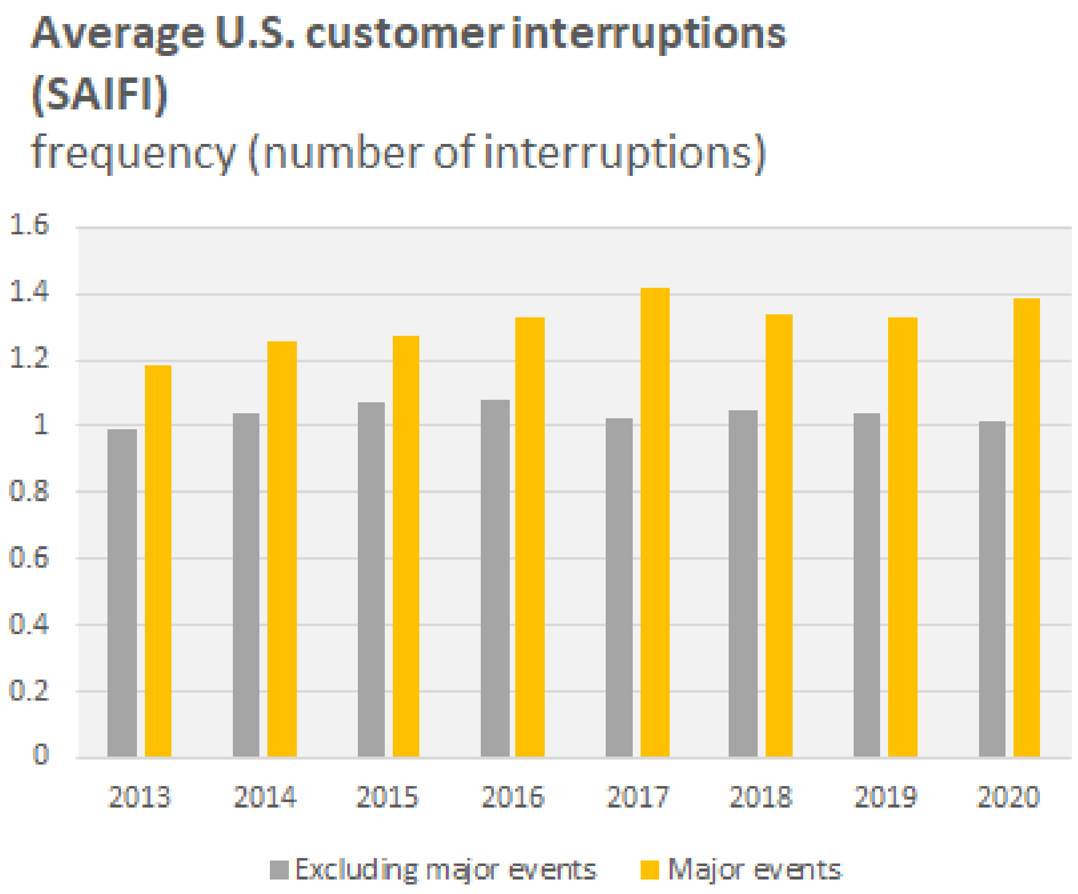
# Metrics from Industry Organizations

- Standards and metrics of bulk power system (generation and transmission) are used by FERC and NERC, whereas state regulatory agencies oversee the reliability of the distribution level.

- Distribution reliability metrics (indices based on averages and therefore don't point to customers who regularly experience longer-duration outages)
  - SAIDI - System Average Interruption Duration Index
  - SAIFI - System Average Interruption Frequency Index
  - CAIDI - Customer Average Interruption Duration Index
  - CAIFI - Customer Average Interruption Frequency Index
  - MAIFI - Momentary Average Interruption Frequency Index
- Metrics that point to specific customer segments that may be experiencing a larger share of outages:
  - CEMI - Customers Experiencing Multiple Interruptions
  - CELID - Customers Experiencing Long Interruption Duration
- DTE example

# Average US Electricity Customer Interruptions in 2013 to 2020, Energy Information Administration




https://www.eia.gov/electricity/annual/html/epa_11_01.html

# Limitations of traditional reliability metrics

- NARUC notes that current metrics and standards do not completely address long-term outages, also known as dark or black sky events. (NARUC 2022)
- NARUC stated that using the standard set of metrics that apply duration and frequency metrics to resilience "often undervalue the impact of large-scale events and focus on normal operating conditions and they price lost load at a flat rate, when in fact the value of lost load compounds the longer it's lost." (NARUC 2013)
- NARUC noted the best investments for large-scale events will not be evaluated if large-scale events are ignored.
  - *"NARUC has stated that adapting metrics such as, SAIDI, CAIDI, SAIFI, etc., as well as other methods and calculations for non-blue sky events to address areas that can help utilities offer smarter resilience proposals and help regulators make better-informed prudence decisions that support those investments." (NARUC 2013).*
- The measures of reliability based on historical outage data like SAIFI and SAIDI are of limited usefulness for measuring resilience, as the IEEE Standards Association states in the LBNL report (Schwartz 2019):
  - *"Although classic reliability indices include the effects of routine weather, they exclude so-called black sky conditions, which represent catastrophic storms and other low-frequency or unusual events that can have a high impact on the functioning of the grid. As a result, reliability measurements do not give us statistical insights on how power systems or networks perform during major outage events."*

# Community Resilience – Hope Corsair

- Community resilience definitions and core elements
- Identification of vulnerable populations
- Community resilience programs example: Xcel's Resilient Minneapolis Project

# Core common elements of community resilience

- Resilience is effective if communities are resilient, not if the grid is resilient.
- Communications and communications planning are critical above all
  - Communication plans should be coordinated with government and other service providers to ensure consistent messaging. Coordination with civic groups would also be useful.
  - Communication plans should include a variety of means of outreach in order to reach subcommunities:
    - Low literacy and people unlikely to read a flier included with a bill
    - Low internet use and people unlikely to read an email from the utility
    - Non-native English speakers
  - Be creative in assessing how subcommunities can be reached, including through church or civic leaders, social media influencers, children at schools, etc.
  - Particular effort should target those who may be resistant to authority or official messaging, including immigrant communities, communities of color, or other identifiable demographics associated with distrust of authority.

From Patel et al. 2017: [What Do We Mean by 'Community Resilience'? A Systematic Literature Review of How It Is Defined in the Literature](), Esmaliann et al. 2021: [Determinants of Risk Disparity Due to Infrastructure Service Losses in Disasters: A Household Service Gap Model.]()

# Core common elements of community resilience

- Patel et al. (2017) reviewed 80 relevant papers and concluded that there was no evidence of a common, agreed-upon definition of community resilience. However, there is evidence of nine core elements of community resilience that were common among the definitions.
  - **Local Knowledge**: “The effects of a disaster, whether short-term or long-term, could be mitigated if a community understands its existing vulnerabilities.”
  - **Community Networks and Relationships**: “Positive effects on a community and its members can occur during a crisis when its members are well connected and form a cohesive whole.”
  - **Communication**: Effective communication includes common meanings for all to understand and community-provided opportunities for open dialogue.
  - **Health:** “Understanding and addressing health vulnerabilities can build resilience before a disaster and mitigate long-term issues after a disaster.”
  - **Governance/Leadership**: “Governance and leadership shape how communities handle crises.”
  - **Resources**: “It is important to have resources widely available and distributed in the community.”
  - **Economic Investment**: “If not addressed, the direct and indirect economic costs of a disaster can plague an affected community long after it has occurred.”
  - **Preparedness**: “The outputs of the planning, mitigation measures, and overall preparedness were intended to enable a sustainable response and recovery by the community, and to reduce the likelihood of harm to community members.”
  - **Mental Outlook**: “Important in shaping the willingness and ability of community members to continue on in the face of uncertainty.”

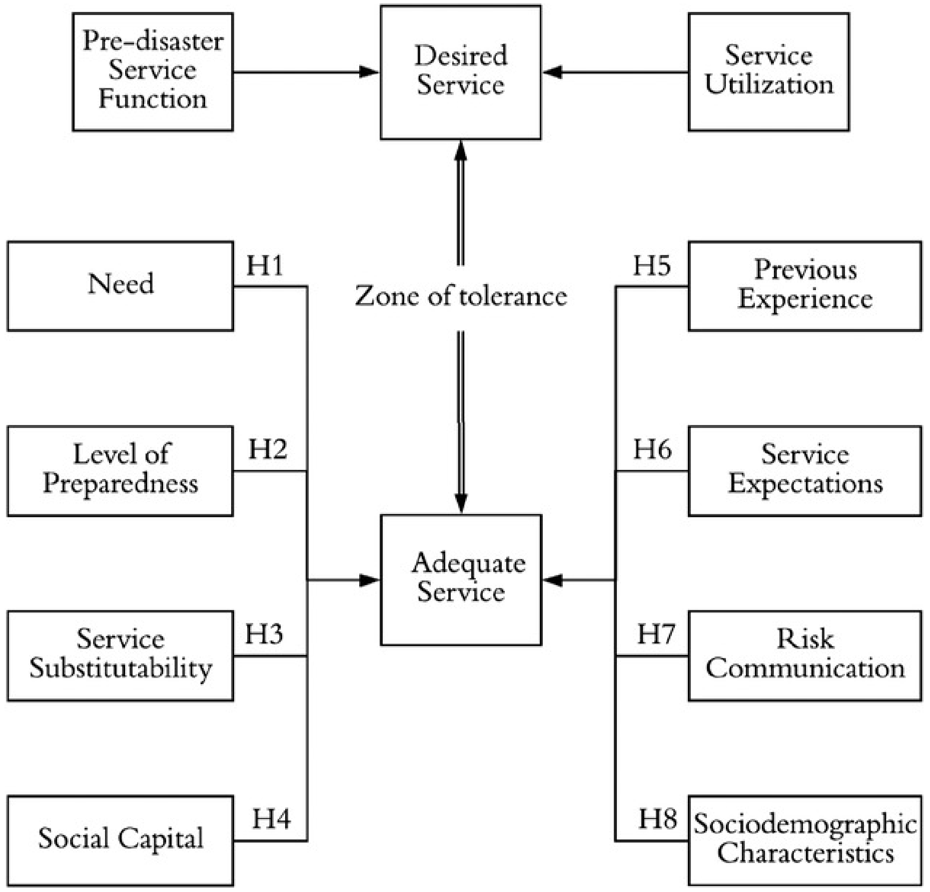
From Patel et al. 2017: What Do We Mean by ‘Community Resilience’? A Systematic Literature Review of How It Is Defined in the Literature

# Identification of vulnerable populations

- Community and household resilience are functions of both the disaster event and the vulnerability of the people in question
- A wide array of characteristics may be used to identify vulnerable populations at the household or community level
  - Customers who qualify for utility bill assistance
  - Zip codes or census blocks where income is particularly low
  - Customers with small children (perhaps identified as those with a child enrolled in elementary school), disabled household members, or the elderly
  - Communities of color or immigrant communities
  - Areas that have been hard hit by disasters in the past (disaster-prone areas)
  - Areas specifically identified by a local, state, or federal government

# Community Resilience – threat, susceptibility, and hardship model: the Zone of Tolerance

- Esmaliann et al. (2021) assesses and identifies factors affecting risk disparity due to infrastructure service disruptions in extreme weather events.
- They propose a **model** that characterizes societal risks at the household level
- The concept of "zone of tolerance" for the service disruptions identified to account for different capabilities of the households to endure the adverse impacts.
  - Sociodemographic characteristics, such as race and residence type, are shown to influence the zone of tolerance, and hence the level of hardship experienced by the affected households.
  - Findings highlight the importance of integrating social dimensions into the resilience planning of infrastructure systems.
  - The proposed model and results enable human-centric hazards mitigation and resilience planning to effectively reduce the risk disparity of vulnerable populations to service disruptions in disasters.




From Esmalian et al. 2021. [Determinants of Risk Disparity Due to Infrastructure Service Losses in Disasters: A Household Service Gap Model]

# Community Resilience – threat, susceptibility, and hardship model: the Zone of Tolerance

- Empirical results: Hurricane Harvey
  - Surveys in Harris County, TX, 2017
  - Duration of outage not significantly different for vulnerable populations than everyone else
    - Thus “hardship” differences are a function of population characteristics, not the disruptive event!
  - Sociodemographics correlated to self-described hardship: expected and unexpected results
    - Greatest hardship, smallest zone of tolerance: low household income, small children in the home, racial/ethnic minority households
    - Some surprises: households with seniors or disability (same as comparators), households with chronic illness (better than comparators!)
    - Factors increasing tolerance: communication, **social capital**, preparedness, substitutable services, **previous experience**

From Esmalian et al. 2021. [Determinants of Risk Disparity Due to Infrastructure Service Losses in Disasters: A Household Service Gap Model]

# Community Resilience – threat, susceptibility, and hardship model: the Zone of Tolerance

- Oregon implications
  - Resilience is specific to location, type of event, & population
  - Event type and preparedness & previous experience
    - Little or no previous experience with very rare or “unprecedented” events
    - Easier to prepare for frequent & forecast hurricanes than major earthquake or previously rare wildfires
  - Communication & preparedness
    - Information to community from trusted *and* trustworthy sources
    - Information from community *to authorities*
  - Social capital & survivability
    - Investment in civic organizations worthwhile?

- “…Risk-based examination of resiliency opportunities that includes costs, consequences, outcomes, and benefits based on *reasonable and prudent industry resiliency standards and guidelines* established by the Public Utility Commission."
  - Risk: community & households
  - Consequences & outcomes: non-economic are important!
  - Industry standards: here’s an example

From Esmalian et al. 2021. Determinants of Risk Disparity Due to Infrastructure Service Losses in Disasters: A Household Service Gap Model

# Xcel's proposed Resilient Minneapolis Project

- Project is proposed as part of the Xcel Energy's 2022 -2032 Integrated Distribution Plan
- Three Minneapolis project locations proposed in partnership with Black, Indigenous, and People of Color (BIPOC)-led partner organizations
- At each site, Xcel plans to work with partners to install rooftop solar, battery storage systems, microgrid controls, and necessary distribution system modifications to integrate these technologies.
- Xcel developed a request for applications and developed evaluation criteria
  - Four minimum criteria that all projects must meet (geographic location, safety, regulatory compliance, and physical site requirements)
  - Eight scoring criteria, with definitions, scores, and weights assigned to each:
    a) Scope of benefits
    b) Geographic location preference
    c) Impact on distribution infrastructure
    d) Maturity of proposed technology and innovation of application of technology
    e) Project timing
    f) Experience of project lead
    g) Strength of project team
    h) Additional resources leveraged



From Xcel Energy 2021: Integrated Distribution Plan 2022-2031

# Resilient Minneapolis Projects

| | Units | North Minneapolis Community Resiliency Hub | Sabathani Community Center | Minneapolis American Indian Center | Aggregate |
|---|---|---|---|---|---|
| **COSTS** | | | | | |
| **Capital** | | | | | |
| **Total Capital Cost** | $ | $3,911,367 | $2,644,276 | $2,383,235 | $8,938,878 |
| **O&M** | | | | | |
| Annual O&M Cost | $ | $23,861 | $19,091 | $19,091 | |
| NPV of Annual O&M Costs (10 years) | $ | $172,662 | $138,146 | $138,146 | $448,953 |
| | | | | | |
| **Total Capital and O&M** | $ | **$4,084,029** | **$2,782,421** | **$2,521,381** | **$9,387,831** |
| | | | | | |
| **BENEFITS** | | | | | |
| **Resilience/Value of Lost Load** | $ | $575,076 | $575,076 | $460,060 | $1,610,212 |
| **Bulk System Capacity Value** | $ | $111,344 | $54,384 | $65,643 | $231,371 |
| **Generation & Carbon Emissions** | | $133,138 | $25,417 | $22,997 | $181,551 |
| **Arbitrage** | $ | $62,174 | $3,173 | $12,417 | $77,764 |
| | | | | | |
| **Lifetime Benefit** | $ | **$881,732** | **$658,050** | **$561,117** | **$2,100,899** |
| | | | | | |
| | | | | | |
| **BENEFIT:COST RATIO** | | **0.22** | **0.24** | **0.22** | **0.22** |

"Some of these benefits are **quantifiable** in dollar terms…others are **non-quantified** but no less important. We urge the Commission to consider the non-quantified benefits as well, even though they are not part of the benefit:cost ratio presented.... Since all costs are quantified, but only a subset of benefits are quantified, the benefit-to-cost ratios presented.. reflect an incomplete picture of the overall benefit of the RMP projects to our communities and customers." (emphasis added)

From Xcel Energy 2021: Integrated Distribution Plan 2022-2031

# Cost-benefit analysis – Rebecca Tapio

- Use of cost-benefit analysis
- Considerations of measurement
- Benefit categories

# Cost-benefit analysis

- Utilities and regulators routinely use CBA to guide investment decisions for grid improvements.
- Deep uncertainty around frequency, severity, and nature of future threats.
- The costs of resilience are identifiable, but the benefits are harder to quantify because the definition of resilience is broad.
- Examples: Avoided customer interruption costs, impacts to critical facilities, utility costs; non-interruption-related societal benefits like safety, ecosystem benefits, and avoided emissions and aesthetic costs/property damage

**Table 1**. Resilience categories, definitions, examples, and benefits (Zamuda et al. 2019)

| Category of Resilience Measure | Definition | Examples | Benefits |
|---|---|---|---|
| System hardening | -Prevent damage to the electricity system and protect it from extreme weather hazards | -Targeted undergrounding<br>-Floodwalls<br>-Vegetation management<br>-Siting, design and construction<br>-Wetlands restoration | Reduced frequency of interruptions and costs of repairing damaged electricity assets |
| Physical changes to prevent service interruptions (despite damage) | -Allow the grid to continue to deliver electricity to customers despite damage to its infrastructure | -Microgrids and distributed energy resources<br>-Improved system redundancy<br>-Advanced grid design<br>-Remote communications, monitoring and control technologies<br>-Community energy storage<br>-Demand-side management | Could reduce the frequency/duration of interruptions or if system enhancements required a brief period to allow for power delivery from different source/along different route |
| Measures to improve recovery time and/or process | -Enable utilities to recover from system damage and interruptions more quickly or more efficiently | -Mutual aid agreements<br>-Damage prediction and response<br>-Increased labor force<br>-Ensuring availability of standby equipment for response | Reduce the duration of interruptions |

From Zamuda et al., 2019: Monetization methods for evaluating investments in electricity system resilience to extreme weather and climate change

| Benefit Type | Benefit Amount | Source |
|---|---|---|
| **Avoided Legal Liabilities** | $87,100 per mile - reduced litigation from fewer contact fatalities and serious accidents | PSI (2006) |
| **Avoided Vegetation Management Costs** | $3000 - $12,000 per mile for distribution; $300 - $9000 per mile for transmission | PUCT (2009) |
| **Avoided Revenue Loss** | $0.09-$0.32 per kWh (Range of System Average Rates Across U.S.; average SAR = $0.13) | EIA (2019) |
| **Avoided Short-Duration Customer Interruption Costs: Medium/Large C&I (>50,000 annual kWh)** | $12-$37 per unserved kWh (interruptions lasting 30 minutes - 16 hours) | Sullivan et al. (2015) |
| **Avoided Short-Duration Customer Interruption Costs: Small C&I (<50,000 annual kWh)** | $214-$474 per unserved kWh (interruptions lasting 30 min - 16 h) | |
| **Avoided Short-Duration Customer Interruption Costs: Residential Customers** | $1.3-$5.9 per unserved kWh (interruptions lasting 30 min - 16 h) | |
| **Avoided Long-Duration Customer Interruption Costs** | $1.20/kWh (for high priority services) to $0.35 (for low priority services)<br>(interruptions lasting 24 h; Allegheny County, PA) | Baik, et al., (2018) |
| | $190M-$380 M (24 -h interruption)<br>$4.4B-$8.8B (7-week interruption)<br>(downtown San Francisco) | Sullivan and Schellenberg (2013) |
| **Safety: Avoided Injuries and Fatalities** | Fatality: $7.4 million ($2006) Injury: up to $7.4 million ($2006) | EPA (2019)<br>Rice et al. (1989) |
| **Avoided Aesthetic Costs** | Avoided loss in property values due to overhead electricity being undergrounded: 5-20 percent increase in property value | Des Rosiers (2002); Sims and Dent (2005); Larsen (2016a) (2016b) |
| **Ecosystem Benefits** | Depends on ecosystem, location and other factors | |
| **Avoided Emissions** | $5800 per ton - $SO_2$ from coal plants | NAS (2012) |
| | $1600 per ton - NOx from coal plants | |
| | $460 per ton - PM-10 from coal plants | |

From Zamuda et al., 2019: Monetization methods for evaluating investments in electricity system resilience to extreme weather and climate change

# Electric Grid Investments with Potential Resilience Benefits: Costs and Benefits

Table 7. Costs

| Type | Impact | Utility System | Host Customer | Community | Society[28] |
|---|---|---|---|---|---|
| Project Implementation | Installation, Operation, and Maintenance | X | X | X | |
| | Transaction | X | X | X | |
| | Interconnection | X | X | X | |
| | Financial Incentives | X | | | X |
| | Program Administration | X | | | |
| | Utility Performance Incentives | X | | | |

Table 8. Benefits

| Type | Impact | Utility System | Host Customer | Community | Society[31] |
|---|---|---|---|---|---|
| Generation, Transmission & Distribution: Energy and Capacity | Reducing Emergency Staff Deployment Costs | X | | | |
| | Avoiding Energy Infrastructure Damages | X | | | |
| Non-Energy: Economic[32] | Avoiding Damages to Goods and Infrastructure | | X | X | X |
| | Avoiding Lower Revenues from Lower Production and Fewer Sales of Goods and Services | | X | | X |
| | Reducing Emergency Staff Deployment Costs | | X | X | |
| | Avoiding Departure of Customers Important to the Community | | | X | |
| | Avoiding Lost Economic Development, Education, and Recreation Opportunities | | | X | X |
| Non-Energy: Public Health, Safety, and Security | Reducing Medical and Insurance Costs | X | X | X | X |
| | Avoiding Loss of Quality of Life | X | X | X | X |

From Kalley et al., 2021: [Application of a Standard Approach to Benefit-Cost Analysis for Electric Grid Resilience Investments - Designing Resilient Communities: A Consequence-Based Approach for Grid Investment Report Series]

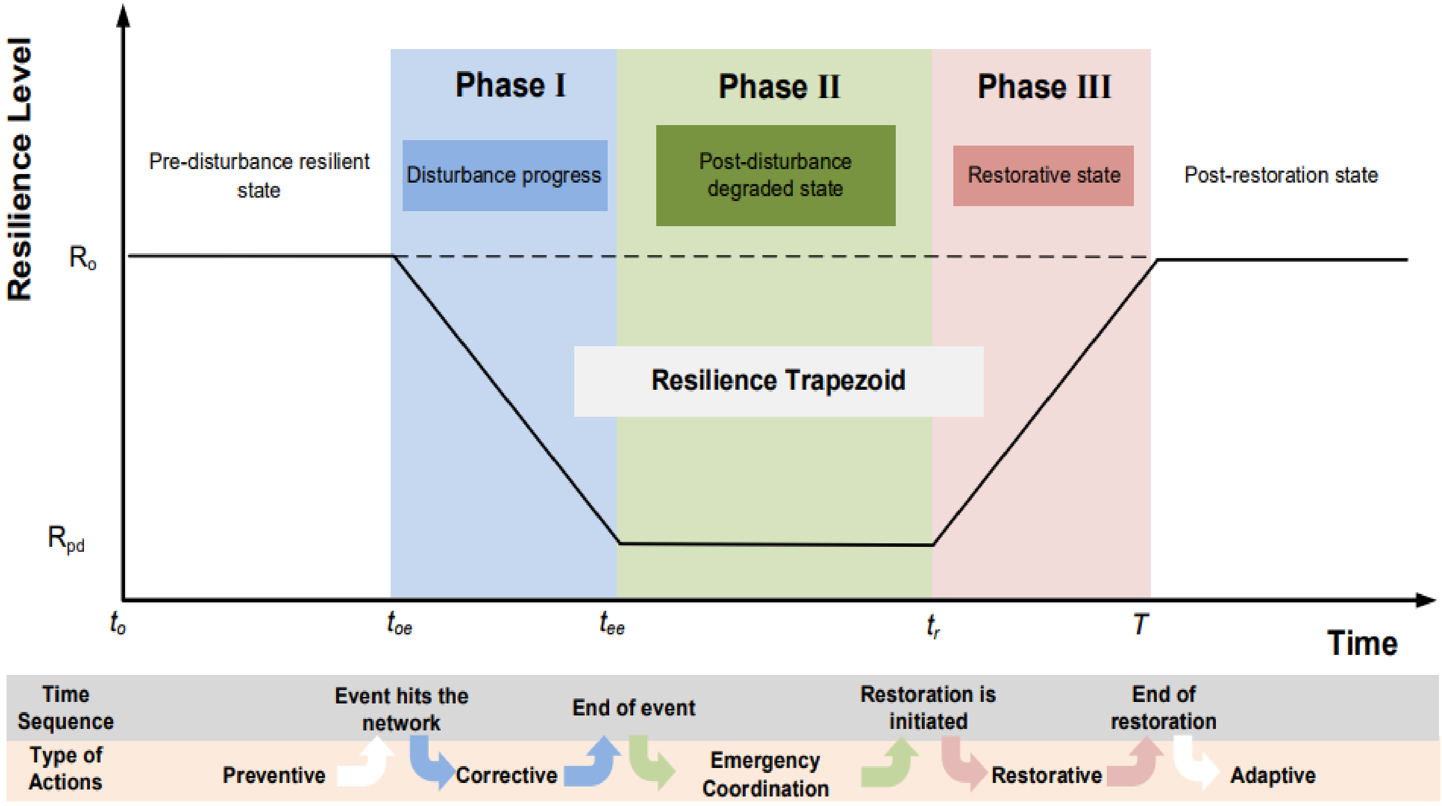
# 10-minute Break

# Resilience Metrics - Kostas Oikonomou

- Resilience Phases/Trapezoid
- Resilience Metrics – DOE
- Risk Spend Efficiency
- Power Grid Investments with Potential Resilience Benefits

# Resilience Trapezoid

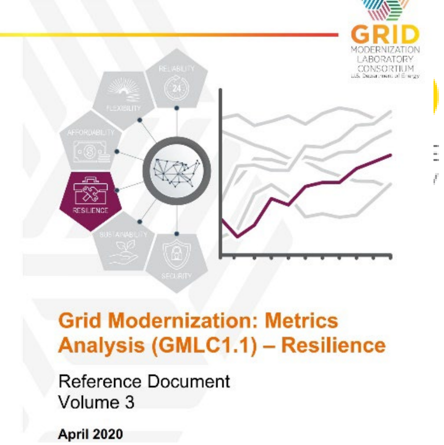
- Resilience is often visualized through the disturbance and impact resilience evaluation curve, which is also referred to as the resilience trapezoid (McJunkin and Rieger 2017)




McJunkin, T.; Rieger, C.G. Electricity distribution system resilient control system metrics. In Proceedings of the 2017 Resilience Week (RWS), Wilmington, DE, USA, 18–22 September 2017; IEEE: Piscataway, NJ, USA, 2017

- **Phase I** : The phase between the time of event occurrence to the end of the disruptive event impact
- **Phase II** : The phase in which the system is degraded following the end of the disruptive event until restoration efforts commence
- **Phase III** : The transition phase that begins from the time of commencement of restoration to full or satisfactory functionality.

# Resilience Metrics (DOE)



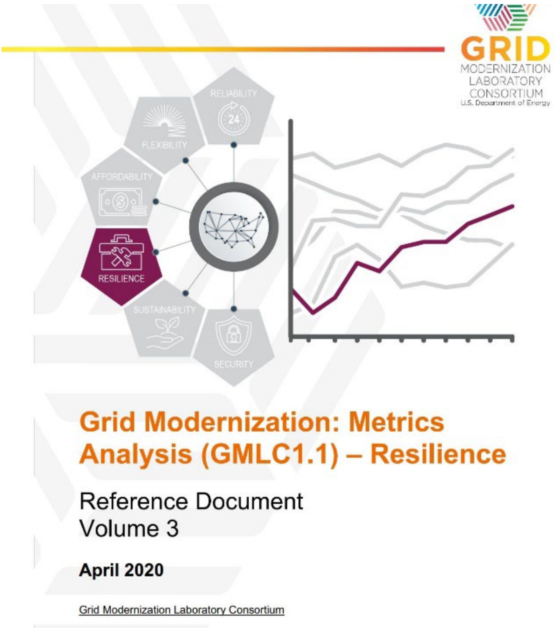

- Resilience metrics can be categorized into two types (Petit et al. 2020):
  - **Multi-criteria decision analysis metrics**
    - What is the current state of the resilience of the electric system, and what are the options to enhance its resilience over time?
    - Provide a baseline to understand the system’s current resilience and facilitate consideration of resilience enhancement options
    - The application of these metrics typically requires that analysts follow a process to review their system and determine the degree to which the properties are present within the system.
    - These determinations are usually made by collecting survey responses, developing a set of weighting values that represent the relative importance of the survey responses, and performing a series of calculations that result in numerical scores for the resilience attributes.
  - **Performance-based metrics**
    - How would an investment impact the resilience of the electric system?
    - Measure the potential benefits and costs associated with proposed resilience enhancements and investments.
    - They are ideal for cost-benefit and planning analyses
    - The required data can be gathered from historical events, subject matter estimates, or computational infrastructure models.

Petit F, Vargas V, Kavicky J. 2020. Grid Modernization: Metrics Analysis (GMLC1.1) – Resilience. PNNL-28567. April 2020. U.S. DOE Grid Modernization Laboratory Consortium.

# Examples of Performance-Based & Multi-Criteria Decision Analysis Metrics

## Multi-criteria decision analysis metrics

| Preparedness | Mitigation | Response | Recovery |
|---|---|---|---|
| Anticipate | Resist, Absorb | Respond, Adapt | Recover |
| Define the hazard environment | Prior to an event, plan how to reduce the severity or consequences of a hazard | Manage the adverse effects of an event | Return conditions to an acceptable level of operations |




## Performance-Based Metrics

| Consequence Category | Resilience Metric |
|---|---|
| *Direct* | |
| Electrical Service | Cumulative customer-hours of outages |
| | Cumulative customer energy demand not served |
| | Average number (or percentage) of customers experiencing an outage during a specified time period |
| Critical Electrical Service | Cumulative critical customer-hours of outages |
| | Critical customer energy demand not served |
| | Average number (or percentage) of critical loads that experience an outage |
| Restoration | Time to recovery |
| | Cost of recovery |
| Monetary | Loss of utility revenue |
| | Cost of grid damages (e.g., repair or replace lines, transformers) |
| | Cost of recovery |
| | Avoided outage cost |
| *Indirect* | |
| Community Function | Critical services without power (e.g., hospitals, fire stations, police stations) |
| | Critical services without power for more than *N* hours (e.g., *N* > hours of backup fuel requirement) |
| Monetary | Loss of assets and perishables |
| | Business interruption costs |
| | Impact on Gross Municipal Product or Gross Regional Product |
| Other Critical Assets | Key production facilities without power |
| | Key military facilities without power |


Petit F, Vargas V, Kavicky J. 2020. Grid Modernization: Metrics Analysis (GMLC1.1) – Resilience. PNNL-28567. April 2020. U.S. DOE Grid Modernization Laboratory Consortium. https://gmlc.doe.gov/sites/default/files/resources/GMLC1.1_Vol3_Resilience.pdf

# Statistical Properties to Represent Uncertainty

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

► To include uncertainties, resilience metrics need to include a measure of consequences and the relevant statistical property from the probability distribution of those consequences.

| Statistical Property | Description |
|---|---|
| Expected Value (Mean) | The probability weighted average. |
| Quantiles (Confidence Intervals) | Quantiles divide the range of a probability distribution into contiguous intervals with equal probabilities, and the confidence interval is the specified probability that any predicted value lies within a given quantile. |
| Value at Risk | A measure of the risk for a chosen probability. For example, a 5% Value at Risk of 1,000 means there is a 5% probability the distribution exceeds 1,000 units. 5% is a commonly selected probability for Value at Risk. |
| Conditional Value at Risk (CVaR) | Another measure of risk. Assuming a loss occurs (conditional), it estimates the expected value for the worst *X* percentage of cases; that is, CVaR considers a distribution's tail shape. For example, a 5% CVaR of 5,000 means the expected value of the largest 5% of the distribution is 5,000. |
| Maximum/Minimum (Worst Case) | The largest/smallest predicted value; depending on the metric, it defines one of these extremes as the worst case. |
| Other | In some cases, functions that combine several statistical properties are employed. For instance, a linear combination of the mean and the CVaR accounts for a risk-averse approach that also takes into account average outcomes. |

Petit F, Vargas V, Kavicky J. 2020. Grid Modernization: Metrics Analysis (GMLC1.1) – Resilience. PNNL-28567. April 2020. U.S. DOE Grid Modernization Laboratory Consortium. https://gmlc.doe.gov/sites/default/files/resources/GMLC1.1_Vol3_Resilience.pdf

# Additional DOE Metrics


SANDIA REPORT
SAND2021-5919
Printed May 2021

Sandia National Laboratories

**Performance Metrics to Evaluate Utility Resilience Investments**

**Designing Resilient Communities: A Consequence-Based Approach for Grid Investment Report Series**

- Performance metrics to evaluate utility resilience investments (Kallay et al. 2021a)

- Excel-based tool to organize the calculation of the following metric types:
  - **Annual Performance Metrics**: Provide a suite of resilience performance metrics for annual review.
  - **Resilience Event Performance Metrics**: Provide a suite of performance metrics for review of each resilience event in the year when it occurs, and in the years directly following each event.

- A categorization was developed between critical customers:
  - **Tier I —** Critical Community Services: Includes assets delivering life-sustaining services to a significant portion of the population, such as hospitals, urgent care facilities, community cooling centers, water and sewer treatment and pumping facilities, vehicle fueling stations, and grocery stores.
  - **Tier II** — Critical Individual Services: May include vulnerable residential customers who require additional individual attention due to higher health risks or lower mobility.
  - **Tier III** — Non-Critical Users: Customers other than those described in Tier I or II.

Kallay J, Letendre S, Woolf T, Havumaki B, Kwok S, Hopkins A, Broderick R, Jeffers R, Jones K, DeMenno M. 2021c. Application of a Standard Approach to Benefit-Cost Analysis for Electric Grid Resilience Investments - Designing Resilient Communities: A Consequence-Based Approach for Grid Investment Report Series. SAND2021-5627. Synapse Energy Economics, Sandia National Laboratories, and Bosque Advisors. May 2021. https://www.synapse-energy.com/sites/default/files/Standard_Approach_to_Benefit-Cost_Analysis_for__Electric_Grid_Resilience_Investments_19-007.pdf

Pacific Northwest NATIONAL LABORATORY

# Resilience Event Metrics


SANDIA REPORT
SAND2021-5919
Printed May 2021

Sandia National Laboratories

Performance Metrics to Evaluate Utility Resilience Investments

Designing Resilient Communities: A Consequence-Based Approach for Grid Investment Report Series

## A.4. Resilience Events Metrics, Event Level Reporting

| Event Level Reporting | | | |
|---|---|---|---|
| **Metrics** | **Calculations** | **Data** | **Sources** |
| **Event Characteristics** | | | |
| Threat Type(s) | | | |
| Location(s) | | | |
| Starting Date | | | |
| Ending Date | | | |
| Duration (days) | | | |
| Probability of Event Occurrence | | | |
| **Utility Staff Impacts** | | | |
| Affected Utility Staff | a | | |
| Total Utility Staff | b | | |
| Affected Utility Staff as a Percent of Total Utility Staff | a / b | | |
| Staff Injuries | c | | |
| Staff Deaths | d | | |
| Staff Injuries as a Percent of Total Staff | c / b | | |
| Staff Deaths as a Percent of Total Staff | d / b | | |
| **Utility Infrastructure Impacts** | | | |
| Infrastructure Damages ($) | | | |
| **Non-Utility Staff and Population Impacts** | | | |
| Affected Municipal Staff | e | | |
| Total Municipal Staff | f | | |
| Affected Municipal Staff as a Percent of Total Municipal Staff | e / f | | |
| Injuries | g | | |
| Deaths | h | | |
| Injuries as a Percent of Total Customers | g / m | | |
| Deaths as a Percent of Total Customers | h / m | | |
| **Non-Utility Goods, Infrastructure and Economic Development Impacts** | | | |
| Critical Goods and Infrastructure Damages ($) | i | | |
| Total Goods and Infrastructure Damages ($) | j | | |
| Critical Goods and Infrastructure Damages as a Percent of Total Damages | i / j | | |
| Critical Goods Not Produced/Sold ($) | l | | |
| Total Goods Not Produced/Sold ($) | m | | |
| Critical Goods Not Produced/Sold as a Percent of Total Goods Not Produced/Sold | l / m | | |
| Forgone Future Economic Development Opportunities ($) | | | |

Pacific Northwest NATIONAL LABORATORY

SANDIA REPORT
SAND2021-5919
Printed May 2021

Sandia National Laboratories

**Performance Metrics to Evaluate Utility Resilience Investments**

**Designing Resilient Communities: A Consequence-Based Approach for Grid Investment Report Series**

# Annual Performance Metrics – Customer Level

## A.2. Annual Performance Metrics, Customer Level Reporting

| Customer Level Reporting | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Metrics | Calculations | TOTAL CUSTOMERS | Tier I: Critical Community Services | | | | Tier II: Critical Individual Services | Tier III: Non-Critical | | | | |
| | | | Customer Sub Category 1 | Customer Sub Category 2 | Customer Sub Category 3 | Customer Sub Category 4 | Customer Sub-Category 5 | Customer Sub-Category 1 | Customer Sub-Category 2 | Customer Sub-Category 3 | Customer Sub-Category 4 | Customer Sub-Category 5 |
| **Customers and Load** | | | | | | | | | | | | |
| Total Customers | c | | | | | | | | | | | |
| Percent of Customers by Customer Subcategory | | | | | | | | | | | | |
| Total Load (kWh) | d | | | | | | | | | | | |
| Percent of Load by Customer Subcategory | | | | | | | | | | | | |
| Average Customer Size | d / c | | | | | | | | | | | |
| Critical Customers | e | | | | | | | | | | | |
| Percent of Critical Customers by Customer Subcategory | | | | | | | | | | | | |
| Critical Customers as a Percent of Total Customers | e / c | | | | | | | | | | | |
| Critical Load (kWh) | f | | | | | | | | | | | |
| Percent of Critical Load by Customer Subcategory | | | | | | | | | | | | |
| Critical Load as a Percent of Total Load | f / d | | | | | | | | | | | |
| **Islandable Resources** | | | | | | | | | | | | |
| Number of customers with any islandable resources: | | | | | | | | | | | | |
| Total | g | | | | | | | | | | | |
| FOM Supply source provided by the utility | h | | | | | | | | | | | |
| BTM solar PV + storage generator | i | | | | | | | | | | | |
| BTM battery storage system (no solar PV) | j | | | | | | | | | | | |
| BTM natural gas generation | k | | | | | | | | | | | |
| BTM diesel generation | l | | | | | | | | | | | |
| BTM propane generation | m | | | | | | | | | | | |
| Percent of customers with any islandable resources: | | | | | | | | | | | | |
| Total | g / c | | | | | | | | | | | |
| FOM Supply source provided by the utility | h / c | | | | | | | | | | | |
| BTM solar PV + storage generator | i / c | | | | | | | | | | | |
| BTM battery storage system (no solar PV) | j / c | | | | | | | | | | | |
| BTM natural gas generation | k / c | | | | | | | | | | | |
| BTM diesel generation | l / c | | | | | | | | | | | |
| BTM propane generation | m / c | | | | | | | | | | | |
| **Customer Resilience** | | | | | | | | | | | | |
| Normal Days - CAIDI (reporting period) | | | | | | | | | | | | |
| Major Event Days - CAIDI (reporting period) | | | | | | | | | | | | |
| Resilience Event Days - CAIDI (reporting period) | | | | | | | | | | | | |
| All Days - CAIDI (reporting period) | | | | | | | | | | | | |
| Normal Days - CAIDI (baseline period) | | | | | | | | | | | | |
| Major Event Days - CAIDI (baseline period) | | | | | | | | | | | | |
| Resilience Event Days - CAIDI (baseline period) | | | | | | | | | | | | |
| All Days - CAIDI (baseline period) | | | | | | | | | | | | |
| Normal Days - CAIFI (reporting period) | | | | | | | | | | | | |
| Major Event Days - CAIFI (reporting period) | | | | | | | | | | | | |
| Resilience Event Days - CAIFI (reporting period) | | | | | | | | | | | | |
| All Days - CAIFI (reporting period) | | | | | | | | | | | | |
| Normal Days - CAIFI (baseline period) | | | | | | | | | | | | |
| Major Event Days - CAIFI (baseline period) | | | | | | | | | | | | |
| Resilience Event Days - CAIFI (baseline period) | | | | | | | | | | | | |
| All Days - CAIFI (baseline period) | | | | | | | | | | | | |

Pacific Northwest NATIONAL LABORATORY

# Annual Performance Metrics – System Level Reporting

SANDIA REPORT
SAND2021-5919
Printed May 2021

Sandia National Laboratories

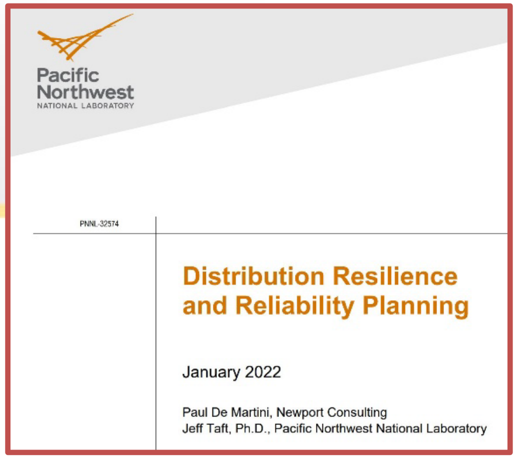
**Performance Metrics to Evaluate Utility Resilience Investments**

**Designing Resilient Communities: A Consequence-Based Approach for Grid Investment Report Series**

## A.3. Annual Performance Metrics, System Level Reporting

| System Level Reporting | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Metrics | Calculations | TOTAL SYSTEM | Tier I: High Consequence Geographies | | Tier II: Medium Consequence Geographies | | Tier III: Low Consequence Geographies | |
| | | | System Sub-Category 1 | System Sub-Category 2 | System Sub-Category 3 | System Sub-Category 4 | System Sub-Category 5 | System Sub-Category 6 |
| **Equipment** | | | | | | | | |
| Total Substations | n | | | | | | | |
| Customers Served by Substations | o | | | | | | | |
| Average Number of Customers Served per Substation | o / n | | | | | | | |
| Critical Substations | p | | | | | | | |
| Customers Served by Critical Substations | q | | | | | | | |
| Percent of Customers Served by Critical Substations | q / c | | | | | | | |
| Average Number of Customers Served per Critical Substation | q / p | | | | | | | |
| Total Feeders | r | | | | | | | |
| Customers Served by Feeders | s | | | | | | | |
| Average Number of Customers Served per Feeder | s / r | | | | | | | |
| Critical Feeders | t | | | | | | | |
| Customers Served by Critical Feeders | u | | | | | | | |
| Percent of Customers Served by Critical Feeders | u / c | | | | | | | |
| Average Number of Customers Served per Critical Feeder | u / t | | | | | | | |
| **System Resilience** | | | | | | | | |
| Normal Days - SAIDI (reporting period) | | | | | | | | |
| Major Event Days - SAIDI (reporting period) | | | | | | | | |
| Resilience Event Days - SAIDI (reporting period) | | | | | | | | |
| All Days - SAIDI (reporting period) | | | | | | | | |
| Normal Days - SAIDI (baseline period) | | | | | | | | |
| Major Event Days - SAIDI (baseline period) | | | | | | | | |
| Resilience Event Days - SAIDI (baseline period) | | | | | | | | |
| All Days - SAIDI (baseline period) | | | | | | | | |
| Normal Days - SAIFI (reporting period) | | | | | | | | |
| Major Event Days - SAIFI (reporting period) | | | | | | | | |
| Resilience Event Days - SAIFI (reporting period) | | | | | | | | |
| All Days - SAIFI (reporting period) | | | | | | | | |
| Normal Days - SAIFI (baseline period) | | | | | | | | |
| Major Event Days - SAIFI (baseline period) | | | | | | | | |
| Resilience Event Days - SAIFI (baseline period) | | | | | | | | |
| All Days - SAIFI (baseline period) | | | | | | | | |

# Overview of Risk Spend Efficiency (RSE)


Pacific Northwest NATIONAL LABORATORY

PNNL-32574

Distribution Resilience and Reliability Planning

January 2022

Paul De Martini, Newport Consulting
Jeff Taft, Ph.D., Pacific Northwest National Laboratory

- RSE is an estimate of the cost effectiveness of initiatives based on the risk reduction benefits and costs for a specific solution (Taft and De Martini 2022).

- An RSE score is determined for specific solutions by dividing the benefit expressed in terms of the magnitude of community/customer outage risk reduction in terms of avoided interruption duration by the solution cost (i.e., capital investment or third-party solution expenditures) by

$$Risk\ Spend\ Efficiency = \frac{Risk\ Reduction * Number\ of\ Years\ of\ Expected\ Risk\ Reduction}{Total\ Mitigation\ Cost\ (in\ thousands)}$$

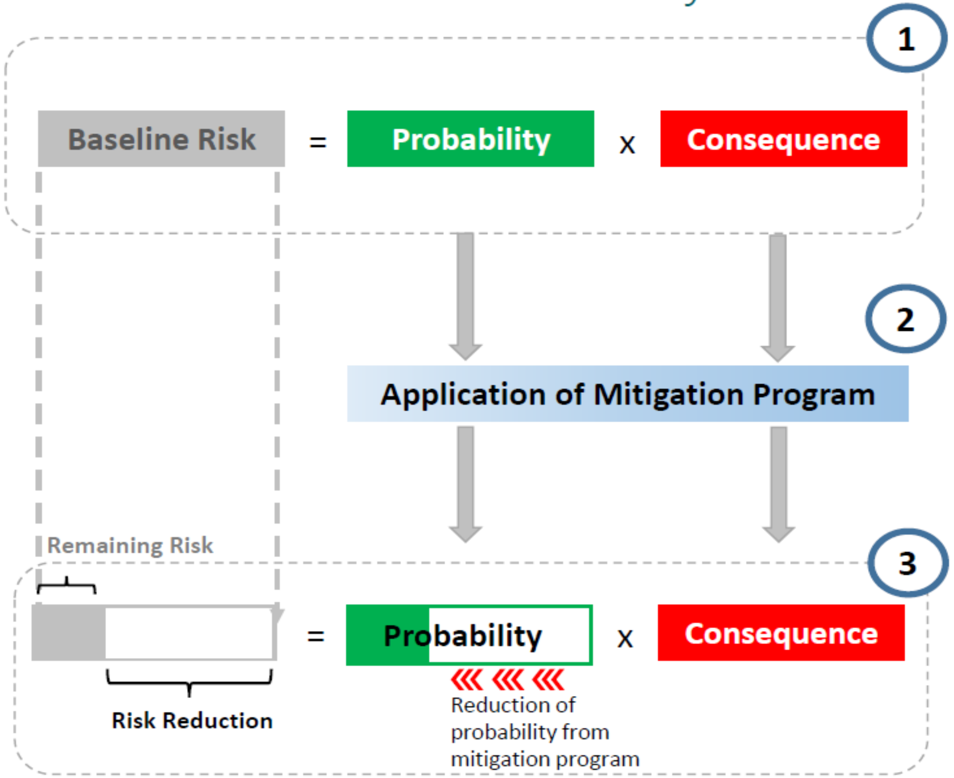
- RSE is currently applied by many power and gas utilities in the west: **PG&E, SCE, SoCalGas**

- For RSE, a solution's benefit is assessed in terms of estimated customer interruption minutes avoided over the planning horizon.

Taft J, De Martini P. 2022. Distribution Resilience and Reliability Planning. PNNL-32574. January 2022. Pacific Northwest National Laboratory. https://gridarchitecture.pnnl.gov/media/advanced/Resillience_Solution_Analysis_paper.pdf

# Southern California Edison Risk Spend Efficiency Calculation Method

## RSE Calculation Summary




4

$$RSE_{mitigation\ program} = NPV\left(\frac{Risk\ reduction \times useful\ life}{Cost}\right)$$

1. Each asset has a distribution of **probabilities** at the risk driver level (e.g. animal contact, transformer failure, etc.) and associated **consequences** (safety, reliability, and financial)
2. Each mitigation program has an associated **mitigation effectiveness**, reducing the probability (at the risk driver level) or consequence of a risk event.
3. Mitigated risk score is calculated based on a reduction in probability or consequence. The difference between baseline and the mitigated risk score is the **risk reduction**.
4. RSE is calculated by taking the benefit stream divided by cost.

Southern California Edison (SCE). 2021. SCE Risk Spend Efficiency Workshop Presentation. December 9, 2021. Prepared for: Office of Energy Infrastructure Safety. https://efiling.energysafety.ca.gov/eFiling/Getfile.aspx?fileid=51907&shareable=true

# RSE Score

- An RSE score is identified for each solution and then used to rank all the solutions to create a prioritized list of solutions within a given budget.

- The budget reflects the practical considerations of customer rate impacts and utility financial constraints

Example of Weighted Risk Spend Efficiency Analysis (Taft and De Martini 2022)

| | Outage Impact Reduction | | | | Risk-Spend Efficiency | |
|---|---|---|---|---|---|---|
| Solution | Weighted Community at Risk | Annual Location Event Probability | Estimated Event Duration (min) | Weighted Avoided Community Interruption (mins) | Solution Cost | RSE Score |
| A | 8000 | 10% | 2160 | 1,728,000 | $2,000,000 | 0.86 |
| B | 5000 | 20% | 2880 | 2,880,000 | $1,000,000 | 2.88 |
| C | 5500 | 5% | 1440 | 396,000 | $500,000 | 0.79 |
| D | 5500 | 8% | 1440 | 633,600 | $250,000 | 2.53 |
| E | 26500 | 3% | 4320 | 3,434,400 | $15,000,000 | 0.23 |

# Grid Investments with Potential Resilience Benefits

| Investments | Description | Utility-Side | Customer-Side |
|---|---|---|---|
| **Transmission and Distribution System** | | | |
| Grid Hardening | Pole, wire, transformer, circuit, feeder, and substation upgrades or replacements | X | |
| Physical Security | Fencing, locks, enclosures, platforms, building extensions, monitoring systems, and alarms, among other investments that protect transmission and distribution system assets | X | |
| Replacement Parts | Local store of replacement parts that are in high demand and/or difficult to procure on short notice | X | |
| Physical Spacing and Barriers | Undergrounding, relocation, elevation, and enclosures to prevent threats from jeopardizing critical equipment | X | |
| Vegetation Management | Tree and brush trimming, removal, and planting of utility-friendly varieties | X | |
| **Generation** | | | |
| Distributed Energy Resources | Energy efficiency, demand response, load curtailment, electric vehicles, distributed generation, and distributed storage that serve the critical load, reducing the utility resources required to restore that load immediately after a resilience event | X | X |
| Supplemental Heating and Hot Water Systems | Electric, fossil, solar, or biomass fueled supplemental water and heating systems that provide a secondary or alternate source of water and/or space heating during a resilience event | | X |
| Backup Generation | Diesel and natural gas generators, fuel cells, or renewable energy paired with storage that provide a secondary or alternate source of power during a resilience event | | X |
| Physical Security | Fencing, locks, platforms, building extensions, monitoring systems, and alarms, among other investments that protect generation assets | | X |
| Replacement Parts | Local store of replacement parts that are in high demand and/or difficult to procure on short notice | X | X |
| Physical Spacing and Barriers | Relocation, elevation, and enclosures to prevent threats from jeopardizing critical equipment | X | X |

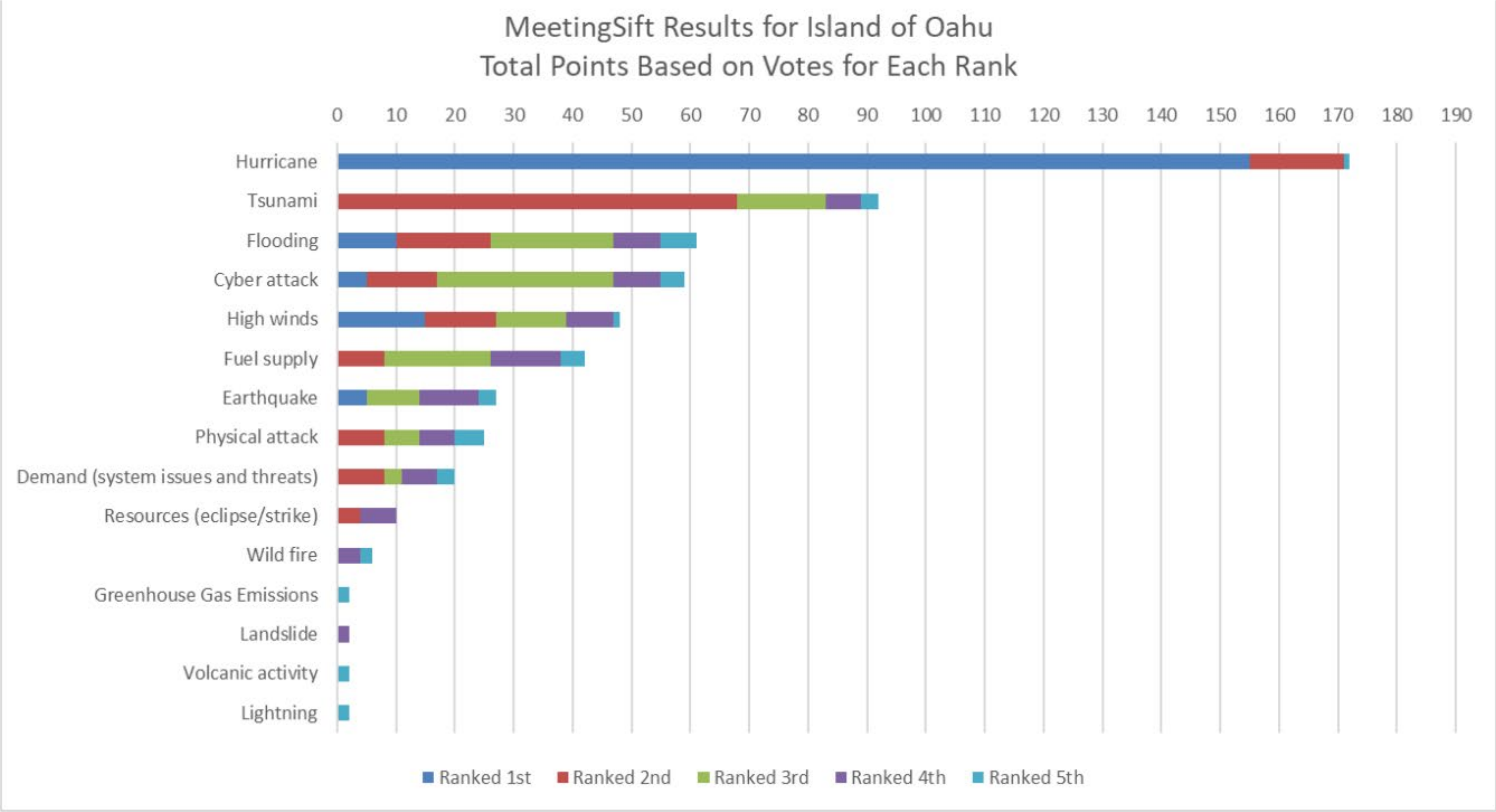
| Investments | Description | Utility-Side | Customer-Side |
|---|---|---|---|
| **Automation & Controls** | | | |
| Transmission and Distribution Grid Automation and Controls | Advanced distribution management systems (ADMS), flexible AC transmission system (FACTS) devices, geographic information systems (GIS), distribution system supervisory control and data acquisition (DSCADA), outage management systems (OMS), distributed energy resource management systems (DERMS), fault location, isolation and service restoration systems (FLISR), volt-var optimization (VVO), voltage stabilization (for example, SVC STATCOM), and network monitoring devices | X | |
| Meters | Customer electric meters that provide outage and restoration notification and/or on-demand data (e.g., advanced meter infrastructure (AMI)) | X | |
| Metering Controls | Communication networks and data management systems | X | X |
| Cyber Protection System Controls | Communications between control centers, cyber system categorization, system security management and controls, electronic security perimeters, configuration change management, and information protection | X | X |
| **Cross Cutting** | | | |
| Microgrids | A group of interconnected electricity generators and users operating as part of the larger grid normally, but able to operate in islanded mode during resilience events | X | X |
| Threat and Vulnerability Assessments | Studies of risks and consequences to inform planning | X | X |
| Mapping of Hosting Capacity | Electric grid impact evaluation of changes to load | X | X |
| Critical load identification and prioritization | Definition, list, and restoration sequence for priority customers, load, and the substations and feeders that serve priority customers | X | X |
| Planning | Facility management planning, community emergency preparedness, cyber and physical system response, restoration, and recovery planning | X | X |
| Training | Classroom instruction for key staff and practice drills on threat response | X | X |
| Performance Measurement and Evaluation | Defining and reporting resilience performance metrics | X | X |

From Kalley et al., 2021: Application of a Standard Approach to Benefit-Cost Analysis for Electric Grid Resilience Investments - Designing Resilient Communities: A Consequence-Based Approach for Grid Investment Report Series

# State and Utility Examples – Juliet Homer

- Hawaii
- Connecticut
- Washington
- Xcel Energy – Colorado
- Southern California Edison
- Southern California Gas
- California – Smart Grid Investment Plan (SGIP)

# Hawaii - Stakeholder informed threat-risk prioritization




Source: Hawaiin Electric Resilience Working Group Report, 2019
https://www.hawaiianelectric.com/documents/clean_energy_hawaii/integrated_grid_planning/stakeholder_engagement/working_groups/resilience/20200429_rwg_report.pdf

# Hawaii

- Hawaii's performance-based ratemaking proceeding includes resilience reporting metrics
- Parties to the docket suggested resilience metrics associated with the following.
  - Percentage of circuits with automation/remote control equipment, and/or remote monitoring functionality
  - Total amount of time that critical loads are without power in a year
  - Cumulative customer-hours without power
  - Economic impact of outages
  - Avoided outage cost
  - Speed and extent to which outages are recovered from
  - Ability for system to respond to rapid shocks as measured by response to disturbances and stabilization of voltage and frequency

Hawaii Public Utilities Commission (HPUC). 2020. Order 37787 In the Matter of Public Utilities Commission Instituting a Proceeding to Investigate Performance-Based Regulation. Docket 2018-0088. December 23, 2020. https://dms.puc.hawaii.gov/dms/DocumentViewer?pid=A1001001A21E17B53226E00118

# Hawaii – Commission approved resilience PBR metrics

| Resilience Reported Metrics | |
|---|---|
| | Metric |
| Critical Load | Total amount of time that critical loads[244] are without power in a year |
| NIMS Certification | Total number of employees completing National Incident Management System Incident Command System 100, 200, and 300 certifications |
| Emergency Response Training | Total number of employees that have attended emergency response training, annually |
| Commission Inclination: reported on an annual basis | |

Hawaii Public Utilities Commission (HPUC). 2020. Order 37787 In the Matter of Public Utilities Commission Instituting a Proceeding to Investigate Performance-Based Regulation. Docket 2018-0088. December 23, 2020. https://dms.puc.hawaii.gov/dms/DocumentViewer?pid=A1001001A21E17B53226E00118

# Connecticut

- As part of the distribution system planning docket, the Connecticut Public Utilities Regulatory Authority comprehensively evaluated the cost-effectiveness of Connecticut's two investor-owned electric distribution companies' (EDC) reliability and resilience programs.
- The three steps or paths in this activity include the following:
  - Path A: Investigation into which current reliability and resilience programs and measures provide the greatest marginal returns to ratepayers.
  - Path B: Investigation into new reliability and system resilience programs as well as measures the EDCs may wish to deploy, and the marginal returns to ratepayers of those programs/measures.
  - Path C: Investigation into reliability and system resilience metrics and targets, and associated incentives for EDCs to meet/exceed them.
- In March 2022, the EDCs presented resilience metrics and targets.
  - Eversource created a prediction system for resilience evaluation that uses machine learning to create physics-based fragility curves to estimate infrastructure vulnerabilities. The machine-learning algorithm was trained on impacts of 173 storms from 2005–2020 and aggregates data from 928 circuits.
- Eversource split metrics into three categories based on their role in program development: investment progress measures, community vulnerability measures, and performance measures.

# Connecticut - Eversource Slide on the Role of Metrics in Developing Resilience Program

## Role of Metrics in Program Development

**Investment Progress Measures**

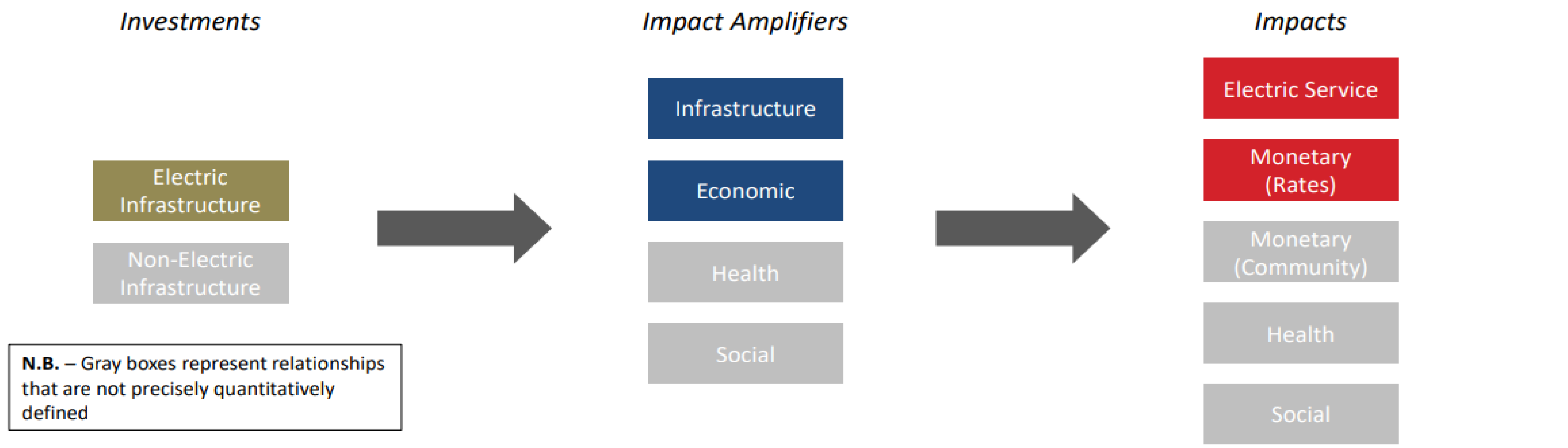
- Where have investments already been made?
- Where does the system still need to be hardened?
- Where can we decrease the most vulnerability (system)?

**Community Vulnerability Measures**

- Where will these investments have the most societal impact?
- Where can we decrease the most vulnerability (social)?
- Where/how are social justice objectives being addressed?

**Performance Measures**

- What adverse impacts have been averted (retrospective)?
- What adverse impacts will likely be averted (prospective)?




Eversource. 2022. Resilience Program Measurement and Metrics Slides. Docket No. 17-12-03RE08. Technical Meeting 4. Quanta Technology.
http://www.dpuc.state.ct.us/2nddockcurr.nsf/8e6fc37a54110e3e852576190052b64d/6c9c050f67b750dd8525881000540764/$FILE/Quanta%20Technology%20-%20Resilience%20Program%20Measurement%20and%20Metrics.pdf

# Connecticut - Eversource Slide on Investment Progress Measures

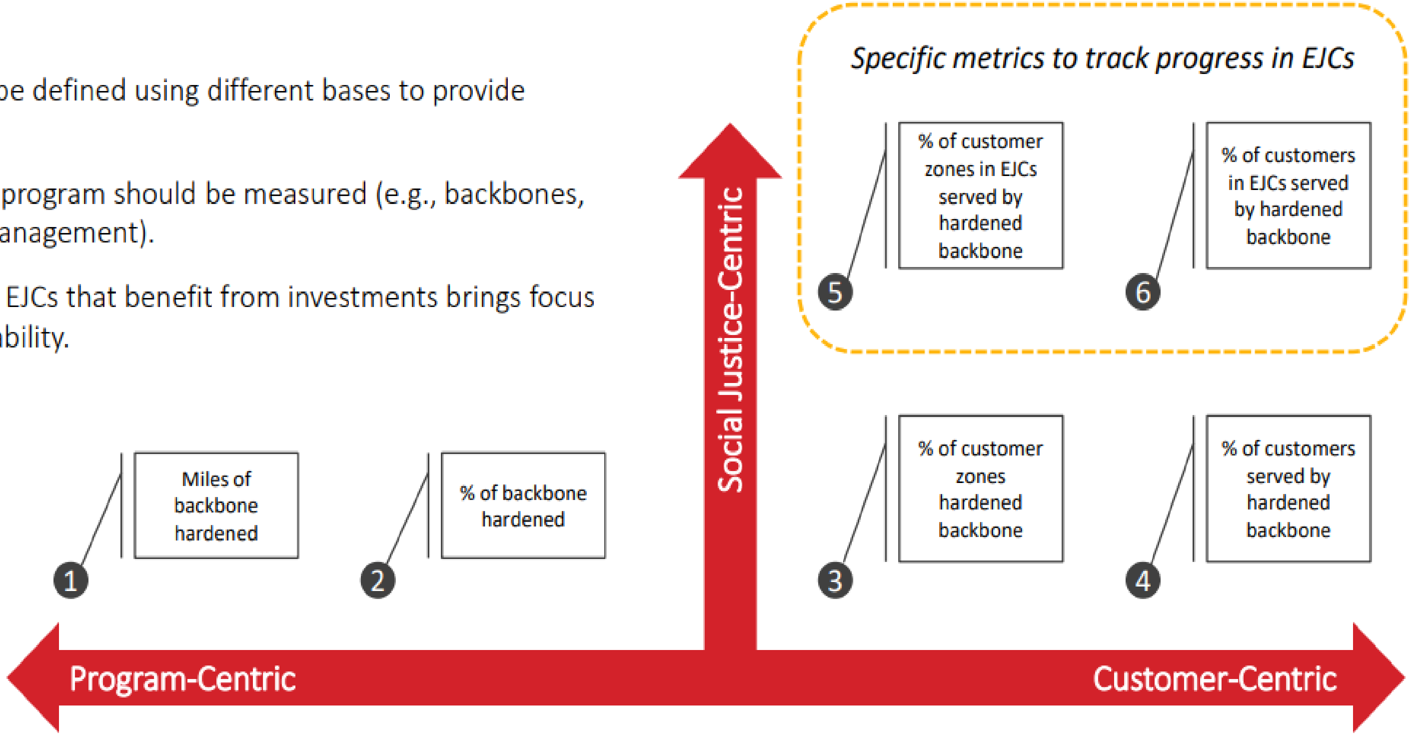
## Investment Progress Measures

**Objective**

To communicate implementation progress of planned investments.

**Considerations**

- Progress metrics can be defined using different bases to provide additional insight.
- Each component of a program should be measured (e.g., backbones, laterals, vegetation management).
- Tracking customers in EJCs that benefit from investments brings focus to community vulnerability.

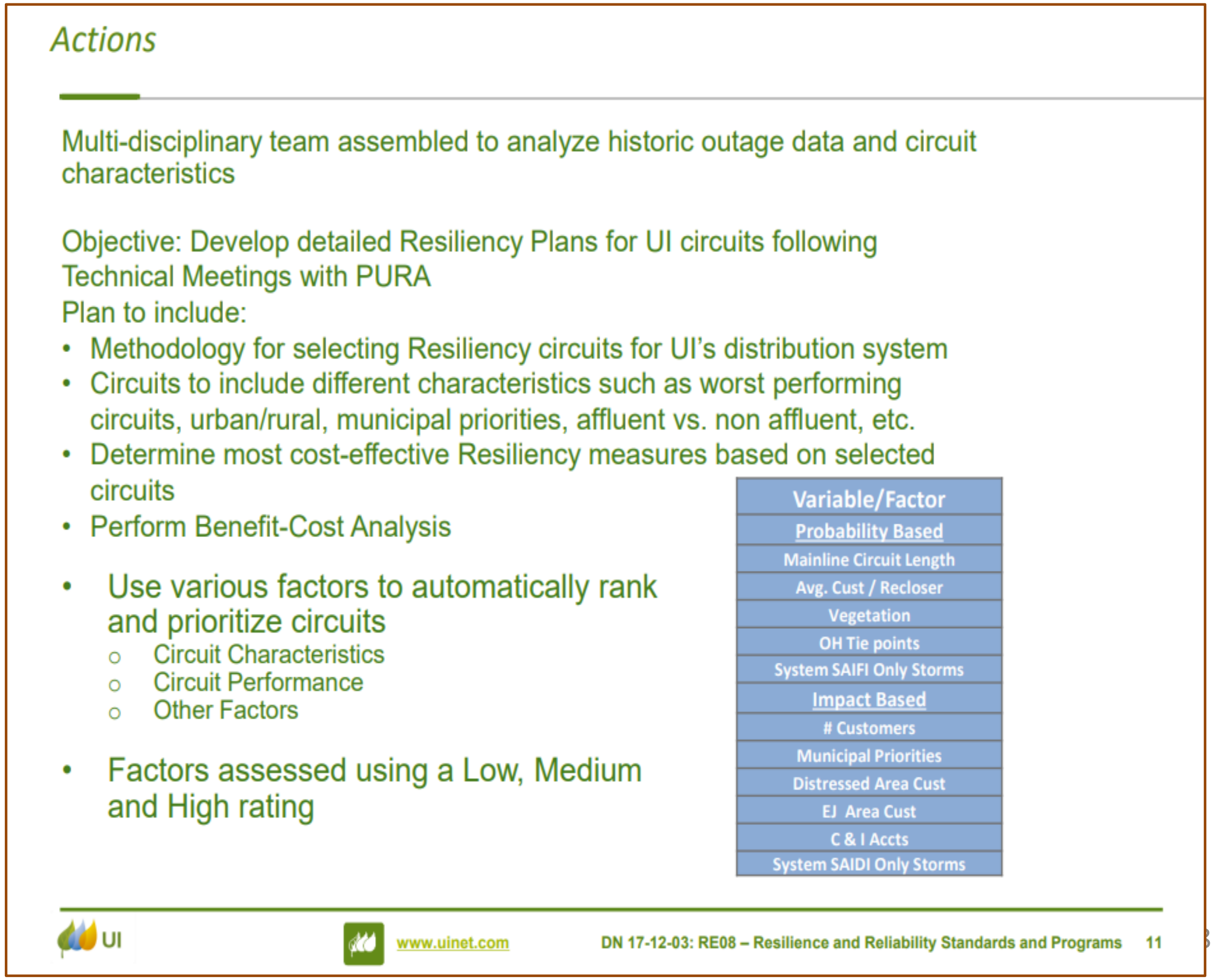



Eversource. 2022. Resilience Program Measurement and Metrics Slides. Docket No. 17-12-03RE08. Technical Meeting 4. Quanta Technology.
http://www.dpuc.state.ct.us/2nddockcurr.nsf/8e6fc37a54110e3e852576190052b64d/6c9c050f67b750dd8525881000540764/$FILE/Quanta%20Technology%20-%20Resilience%20Program%20Measurement%20and%20Metrics.pdf

# Connecticut – United Illuminating Company resilience strategies

GRID MODERNIZATION INITIATIVE
U.S. Department of Energy

- United Illuminating Company (UI) listed a number of potential resilience programs for implementation, but no precise resilience metrics
- The resilience improvements that are being considered by UI include:
  - Adding additional sources to circuit sections with no backup (aerial cable ties, overhead ties, battery storage, undergrounding),
  - Enhanced tree trimming,
  - Selective undergrounding, and
  - Adding automation (reclosers)




United Illuminating (UI). 2022. Resilience Strategies Slides. 17-12-03 RE08 – Resiliency and Reliability Standards and Programs. March 28-29, 2022. http://www.dpuc.state.ct.us/2nddockcurr.nsf/8e6fc37a54110e3e852576190052b64d/703a75f0e7b30f3c85258810006fd46f/$FILE/55020444.pdf/2022-03-25%20UI%20Presentation%20for%202022-03-28%20&%202022-03-29%20Technical%20Mtgs%20%2317-12-03RE08.pdf

# Washington Clean Energy Implementation Plans

- In Washington utilities' Clean Energy Implementation Plans, utilities were required to develop **customer benefit indicators (CBIs)** describing how each utility will achieve an equitable distribution of benefits to customers while achieving a transition to clean energy
- **Resilience** is one of the required indicator categories
- Utilities must also **identify highly impacted communities and vulnerable populations**, also defined by the Clean Energy Transformation Act, within their service territories
- The resilience indicators proposed by all three Washington utilities that submit Clean Energy Implantation Plans were consistent and related to decreasing the <u>frequency</u> and <u>duration</u> of outages

# Washington – Clean Energy Implementation Plan Customer Benefit Indicators (CBIs)

- Puget Sound Energy (PSE):
  - For energy security and resilience, the CBI is decreased frequency and duration of outages.
    - The metrics are the **number of outages, total hours of outages, and total backup load served during outage**
  - For risk reduction, energy security, and resiliency, the CBI is increased resiliency
    - The metric is the **number of customers who have access to emergency power in their home or at a community center** (PSE 2021).
- Avista:
  - Resilience CBI is **outage duration**
    - Avista will calculate the **average duration of outages for both named communities** and for other customers to identify if there are differences between quality of service (Avista 2021)
- PacifiCorp:
  - Resilience CBI is the frequency and duration of energy outages;
    - the benefits categories are energy resiliency, risk reduction, and energy benefit; and the **metrics are SAIDI, SAIFI, and CAIDI at the area level, including and excluding major events** (PacifiCorp 2021).

# Xcel Energy - Colorado

- Proposed Resiliency Service Program
  - On March 24, 2022, Xcel Energy asked the Colorado Public Utilities Commission for approval of a **Resiliency Service Program** that would include analysis, design, construction, and maintenance of on-site electric generation, storage and control equipment.
  - Xcel Energy would provide a turnkey **resiliency as a service solution**, with customers paying for the assets through a service charge on their bill over a term of 10 to 20 years.
  - Equipment would be **owned and maintained by Xcel Energy** over the payment period, then transferred to the customer.
  - The proposed opt-in tariff would be available as an optional service to any Xcel Energy customer in Colorado taking electric service under a commercial rate, including Small Commercial or Commercial & Industrial Secondary, Primary or Transmission customers.
  - Non-participating customers' electric bills (including all residential customers) would not be impacted
  - Costs to participating customers would be set on a case-by-case basis, based on each customer's specific needs.
  - Xcel is proposing a similar product in Texas

https://www.xcelenergy.com/company/rates_and_regulations/filings/resiliency_service_program

# Southern California Edison's Risk-Informed Decision-Making Process

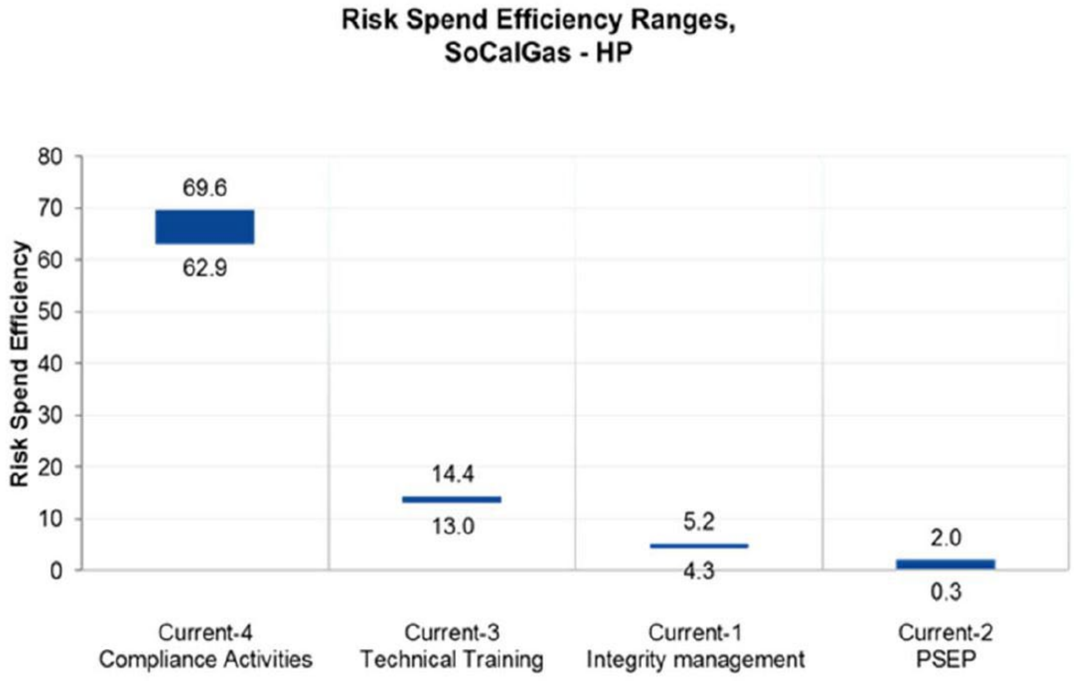
- In September 2018, SCE filed an application with the CPUC for the **Grid Safety and Resiliency Program** that considered multiple investment alternatives and was predicated on a "risk-informed" decision-making process (SCE 2018).
- The risk-informed decision-making process examines the likelihood and impact associated with potential risk events, such as wildfires, and includes the following six step process:
  1. Risk Identification
  2. Risk Evaluation
  3. Risk Mitigation Identification
  4. Risk Mitigation Evaluation
  5. Decision-Making and Planning
  6. Monitoring and Reporting.
- SCE evaluated the past wildfire data and trends, identified potential mitigation alternatives, and evaluated the potential benefits of each mitigation.
- In April 2020, the CPUC approved SCE's program and authorized $400 million of capital investments and more than $70 million for vegetation management to bolster fire prevention and improve system resilience

# Southern California Gas – Risk Spend Efficiency - 1

- Southern California Gas (SoCalGas) Company is required by the California PUC (CPUC) from Order D.16-08-018 to “explicitly include a calculation of risk reduction and a ranking of mitigations based on risk reduction per dollar spent” (CPUC 2016)
- SoCalGas applied a Risk Spend Efficiency (RSE) calculation to a set of mitigations or mitigation groupings, then ranked the proposed mitigations in accordance with the RSE result (SCG 2016).
- General steps include:
  - Group potential mitigations for analysis
  - Identify mitigation groupings as either current controls or incremental mitigations
  - Identify a method to quantity the impact of each mitigation grouping
  - Calculate the risk reduction (change in risk score)

# Southern California Gas – Risk Spend Efficiency - 2

| ID | Mitigation | Potential Risk Drivers Addressed | 2017-2019 Capital[25] | 2019 O&M | Mitigation Total[26] | GRC Total[27] |
|---|---|---|---|---|---|---|
| 1 | CFR 192 Subpart M – Maintenance* | • Outside Forces<br>• Equipment<br>• Corrosion | $38,930 - 43,020 | $7,690 - 8,500 | $46,620 - 51,520 | $46,620 - 51,520 |
| 2 | CFR 192 Subpart N – Qualifications of Pipeline Personnel* | • Incorrect Operations | n/a | 400 - 440 | 400 - 440 | 400 - 440 |
| 3 | CFR 192 Subpart I – Requirements for Corrosion Control * | • Corrosion | 2,920 - 3,780 | 520 - 1,140 | 3,440 - 4,920 | 3,440 - 4,920 |
| 4 | CFR 192 Subpart L – Operations* | • Corrosion<br>• Manufacturing<br>• Construction<br>• Equipment<br>• Incorrect Operations | 14,280 - 15,780 | 18,120 - 20,030 | 32,400 - 35,810 | 32,400 - 35,810 |
| 5 | CFR Part 192 Subpart O – Gas Transmission Pipeline Integrity Management* | • Corrosion<br>• Manufacturing<br>• Construction<br>• Equipment<br>• Incorrect Operations | 124,920 - 187,120 | 44,930 - 49,650 | 169,850 - 236,770 | 169,850 - 236,770 |
| 6 | PUC 957 & 958 – PSEP: | • Manufacturing<br>• Construction | 365,250 - 608,750 | 13,500 - 110,000 | 378,750 - 718,750 | 133,750 - 321,750 |



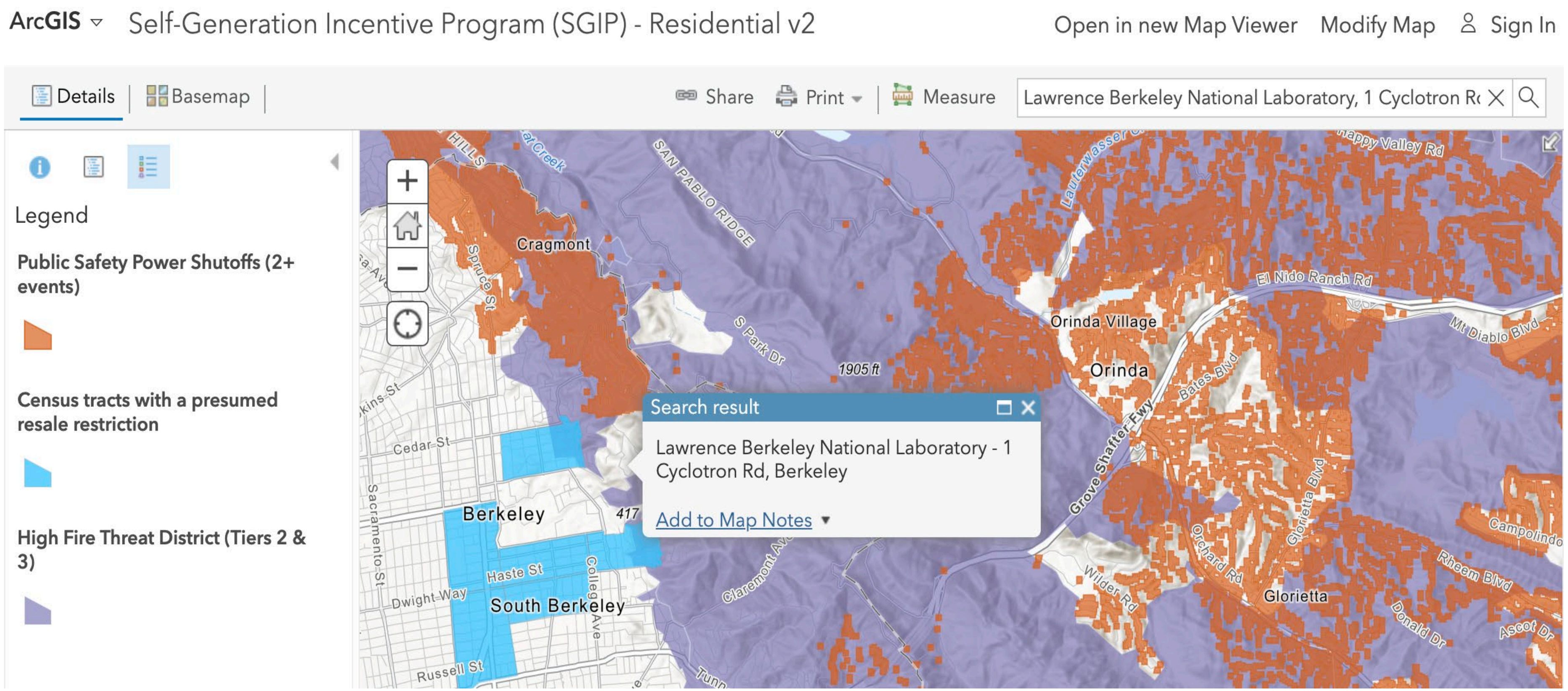
# California Self-Generation Incentive Program (SGIP) Equity Resiliency Budget Map

- Under SB700 in 2018, CPUC was directed to expand the Self Generation Incentive Program (SGIP) by creating a "Residential Equity Resiliency" budget.
- $612 million in ratepayer funds will be collected through 2024 to provide no-cost battery storage systems to vulnerable, low-income households located in high fire-threat districts and public power safety shutoff zones.
- Metrics were used to create eligibility requirements for the program and public maps were created so that households could be pre-qualified with addresses
- As defined by the CPUC (2022), eligible "Equity Resiliency" budget customers:
  - Have experienced two or more utility public safety power shutoffs OR live in a Tier 2 or 3 high fire threat district AND have one of the following additional criteria:
    - Live in multifamily deed-restricted housing or a single-family home subject to resale restrictions as defined by U.S. Department of Housing and Urban Development (HUD), AND/OR
    - Currently enrolled in a utility Medical Baseline Program as defined by the CPUC, AND/OR
    - Have notified their utility of serious illness and/or life-threatening condition, AND/OR
    - Have already qualified for low-income solar-related incentives, AND/OR
    - Home relies on electric pump wells for water AND have an annual household income no greater than 80 percent of area median income, attest that the installation site is their primary residence occupied by either a homeowner or tenants, and attest that the residence is not provided water by a municipal or private utility.

California Public Utilities Commission (CPUC). 2022. *Participating in Self-Generation Incentive Program (SGIP)* website and map. https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/self-generation-incentive-program/participating-in-self-generation-incentive-program-sgip.

# California Self-Generation Incentive Program Equity Resilience Map – cont.

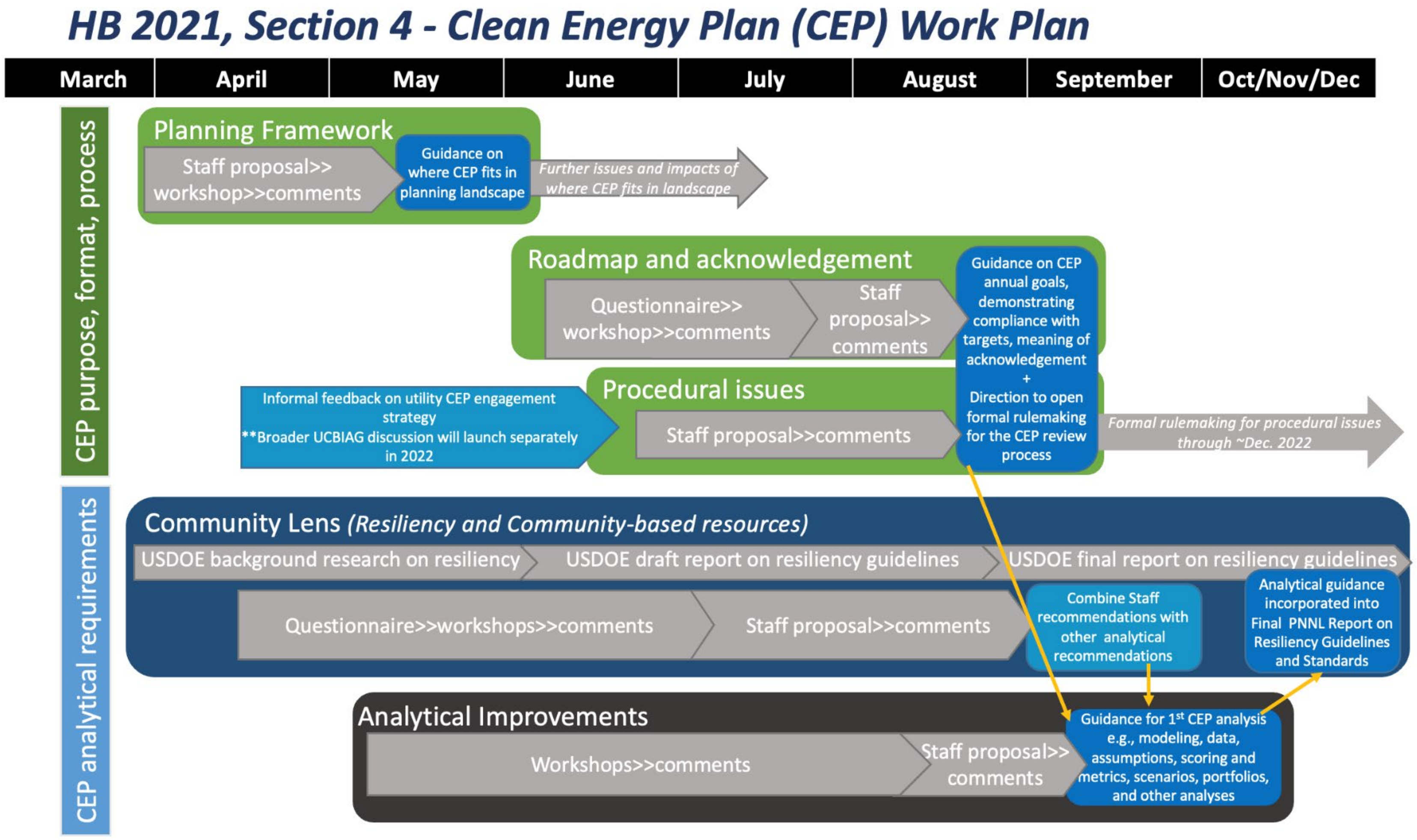
- CPUC created geographic information system (GIS) maps to streamline incentive deployment and simplify pre-qualification. The HUD, public safety power shutoffs, and high fire threat districts were overlayed within a searchable map that could be used to find an eligible property by address




California Public Utilities Commission (CPUC). 2022. *Participating in Self-Generation Incentive Program (SGIP)* website and map. https://www.cpuc.ca.gov/industries-and-topics/electrical-energy/demand-side-management/self-generation-incentive-program/participating-in-self-generation-incentive-program-sgip.

# Next steps

- ► Conduct additional research and develop a draft summary report based on feedback received today
- ► Develop draft final report
  - ■ August 2022
- ► Develop final report
  - ■ October 2022
- ► Present to stakeholders
  - ■ November 2022



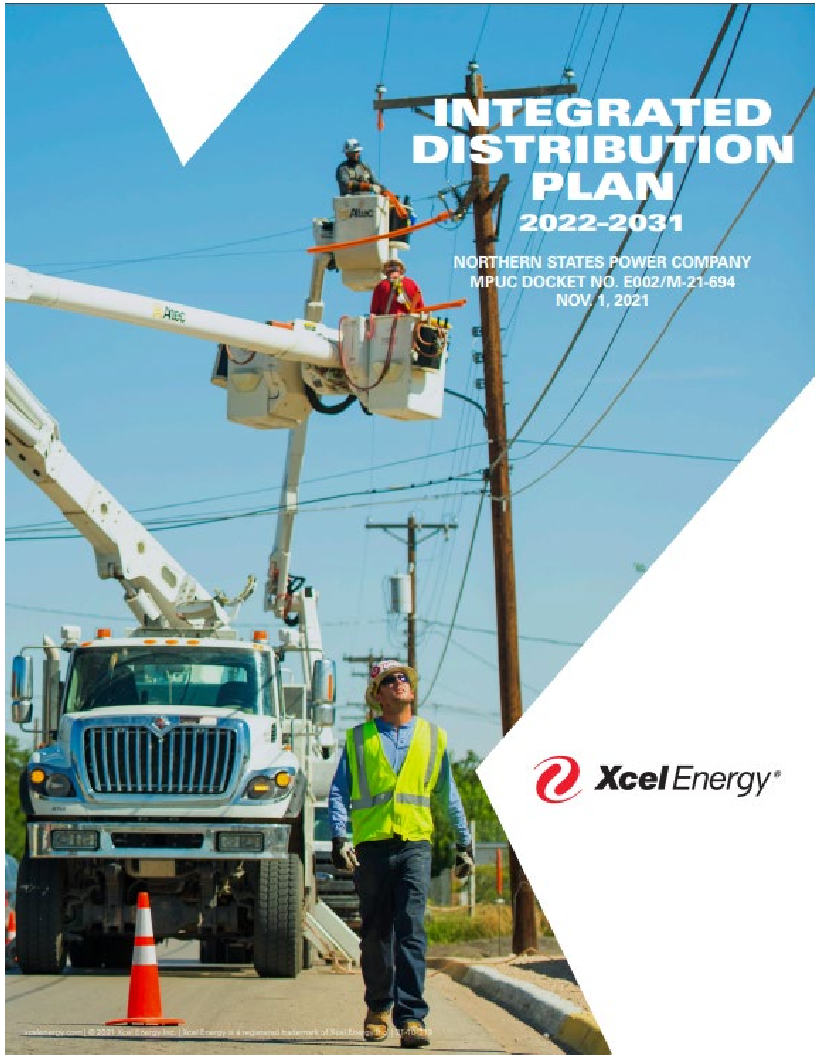
# Thank you!

- Juliet Homer – Pacific Northwest National Laboratory
- Karyn Boenker - Pacific Northwest National Laboratory
- Kostas Oikonomou - Pacific Northwest National Laboratory
- Rebecca Tapio - Pacific Northwest National Laboratory
- Alice Lippert – Argonne National Laboratory
- Hope Corsair – Oak Ridge National Laboratory

# Extra Slides

# Xcel Energy - Minnesota

- Xcel Energy Integrated Distribution Plan 2022 - 2031
- In describing a proposed Resilient Minneapolis initiative focused on improving communities' resilience to crises while advancing the Commission's objectives for Integrated Distribution Plans (IDPs), Xcel Energy states (emphasis added):
  - *"The term "resiliency" is used in different ways in different contexts. Sometimes, it is used to refer to the ability of the electric grid or other infrastructure to recover quickly from an outage or other disruption, and/or "hardening" of electricity assets to withstand increasing extreme weather. <u>At other times</u>, the term is used to refer to that communities' own ability to withstand and recover from a variety of disruptions… by ensuring continued access to electricity and other critical services. This proposal addresses primarily the latter sense of resiliency."*




From Xcel Energy 2021: Integrated Distribution Plan 2022-2031

# Pacific Power Community Resilience Pilot Site Selection

Quantified benefits of battery storage to "customer, utility, and society" using "resilience factors." Included site selection criteria, use cases, cost/benefit models all within the context of three resilience scenarios; standard, enhanced, and comprehensive. Showed system and local benefits in the form of fuel savings, GHG reductions, and security. Despite promising results, low market demand creates deployment issues.

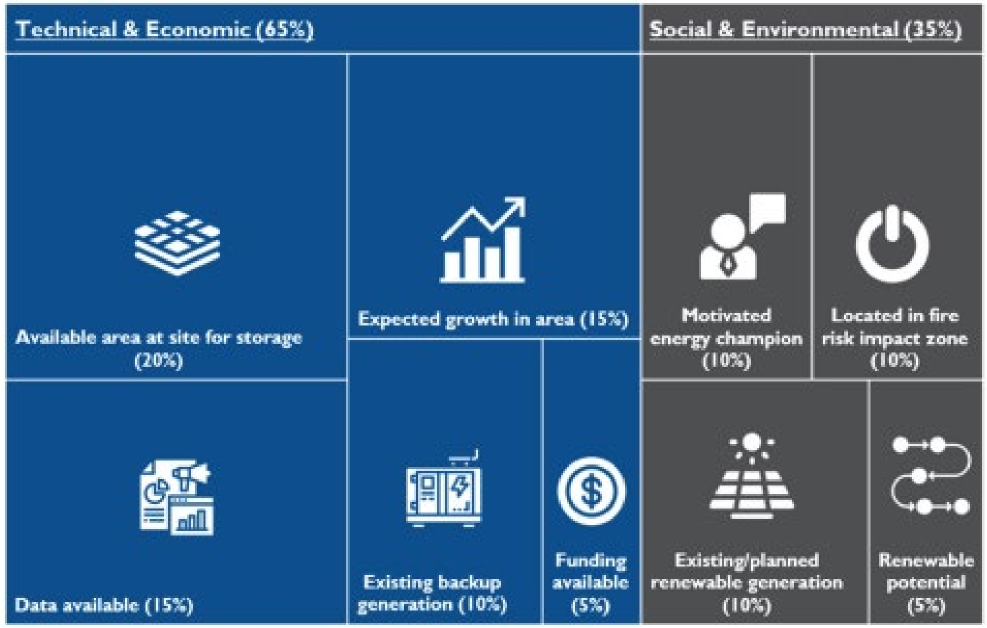



Figure 4: Site Criteria Summary

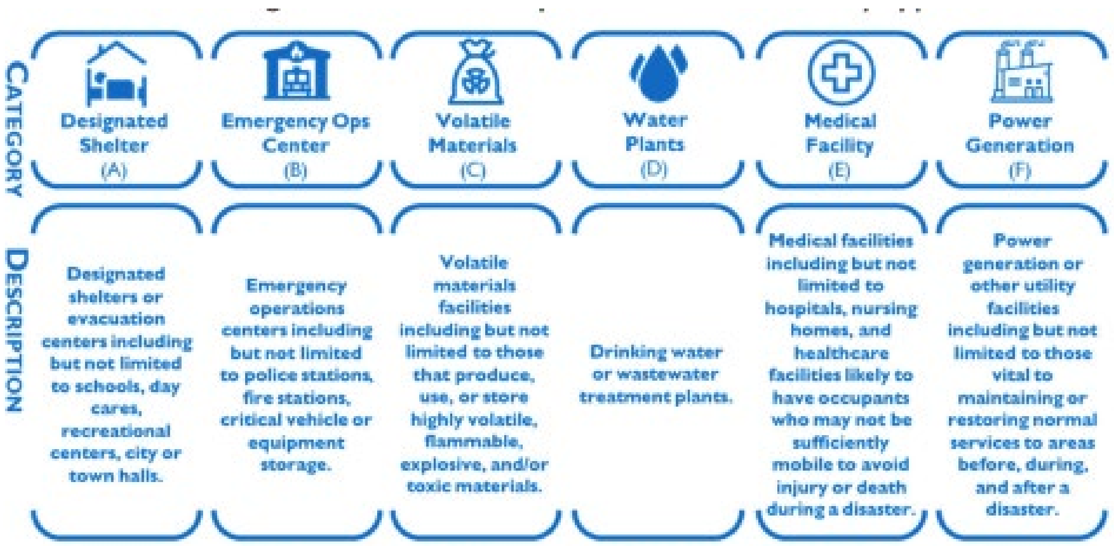



Figure 6: Categorization of Typical Critical Facilities Identified by FEMA

*"Each configuration was evaluated for the potential to reduce GHG emissions, provide electricity bill savings, lower the risk associated with generator fuel deliveries, and provide community resiliency benefits."*

# Resilience Capacities & Attributes

- Resilience phases are further taxonomized into resilience capacities (Watson et al., 2015)
- Each resilience capacity consists of a number of resilience attributes that impact system performance

| Capacities | Prepare | Withstand | Adapt | Recover |
|---|---|---|---|---|
| Example Infrastructure Attributes | Advance warning | Robustness | Rerouting | Mutual Aid Agreements |
| | Prepositioning | Redundancy | Substitution | Situational Awareness |
| | Stockpiling | Storage | Rationing | Resource Availability |
| | | Separation | Reorganization | |

Watson JP, Guttromson R, Silva-Monroy C, Jeffers R, Jones K, Ellison J, Rath C, Gearhart J, Jones D, Corbet T, Hanley C, Walter LT. 2015. Conceptual Framework for Developing Resilience Metrics for the Electricity, Oil, and Gas Sectors in the United States. Sandia National Laboratory. SAND2014-18019. September 2015