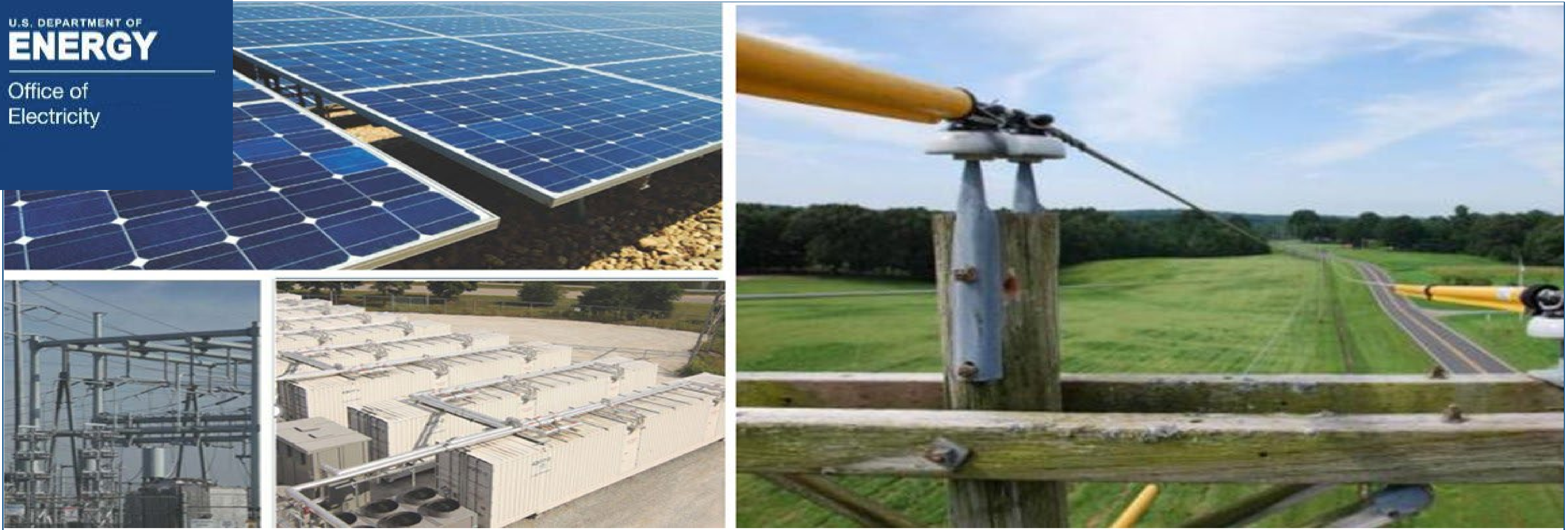
U.S. DEPARTMENT OF ENERGY
Office of Electricity



A Snapshot of Select U.S. DOE Resilience Activities

Gil Bindewald, Office of Electricity (OE)

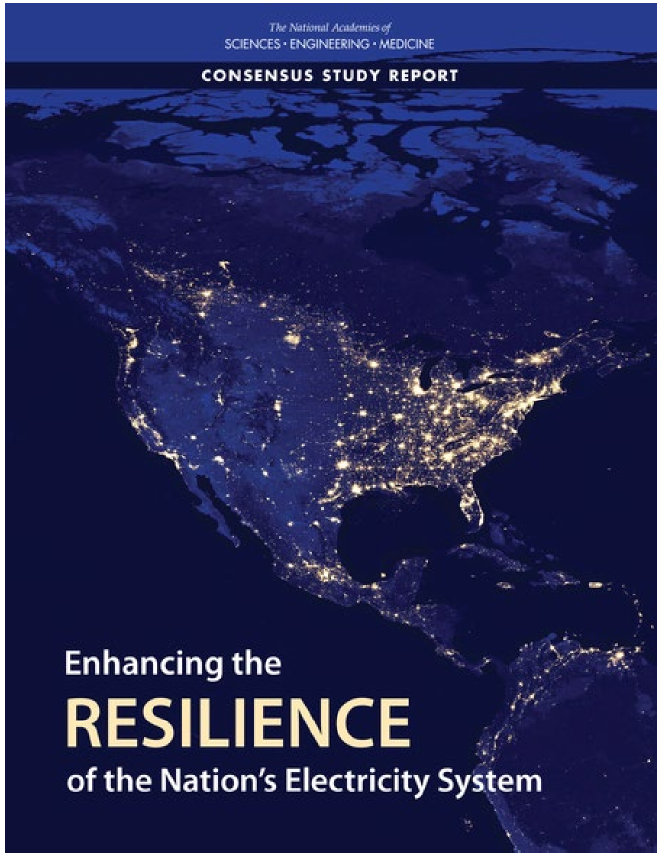
Acknowledgments: Joe Paladino, OE; Paul Spitsen, EERE; Kevin Lynn, EERE; Bobby Jeffers, NREL; Charlie Hanley, SNL; et al

June 25, 2022

Resilience Defined

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

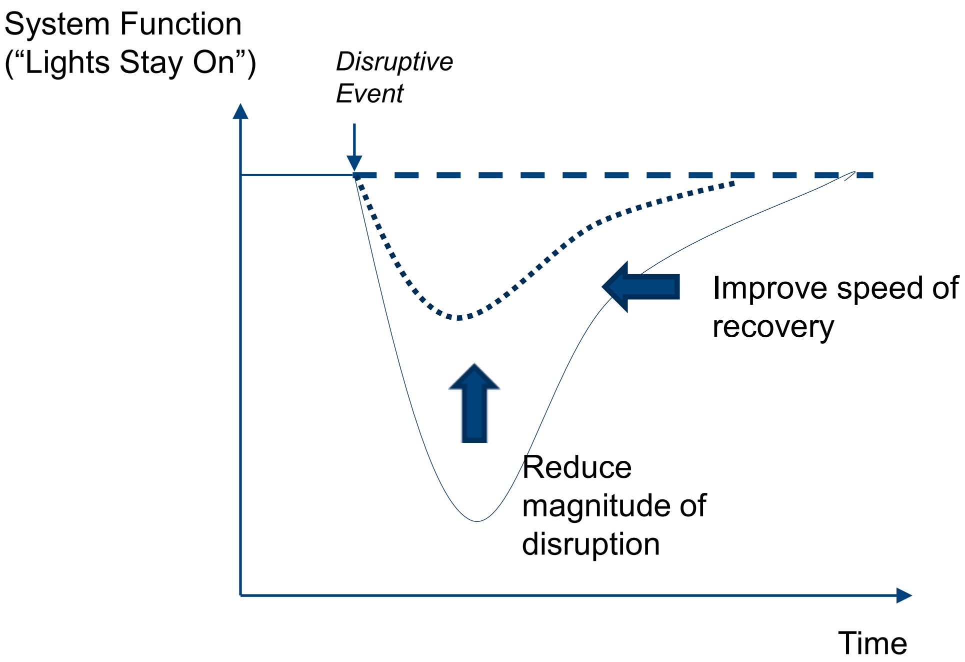
– Presidential Policy Directive 21 (Feb. 2013)



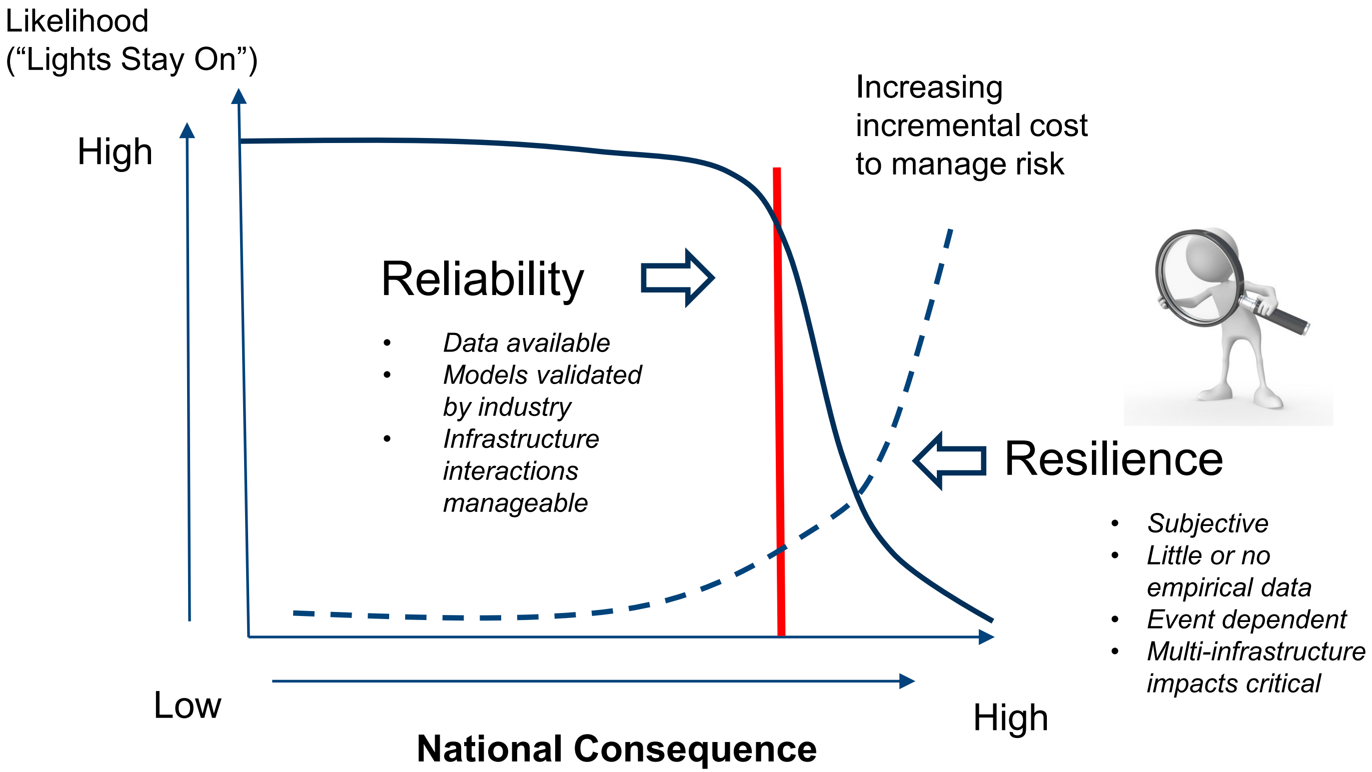
National Academies (2017)

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

Reliability vs. Resilience



Resilience Goal



NOTE: Curves are illustrative

Elements of Federal Definition of Resilience

Language from PPD21

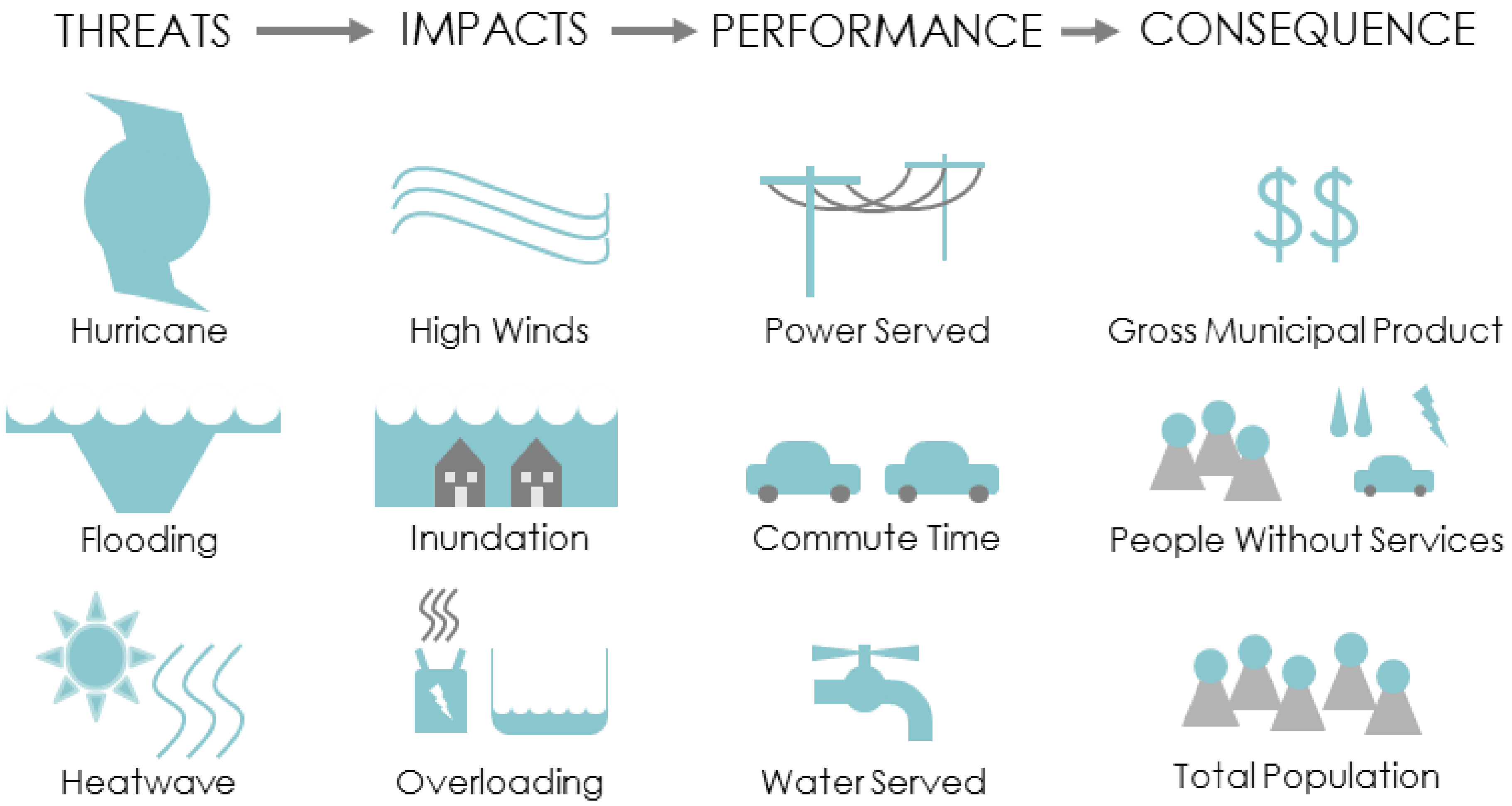
- Planning capability – “ability to prepare for”
- Strong / hardened – “withstand”
- Efficient redundancies – “recover rapidly”
- Multiple equilibria – “adapt to changing conditions”
- Multi-hazard / threat neutral – “deliberate attacks, accidents or naturally occurring”

Resilience is not solely about adapting in the moment, but depends on robust planning, preparation, and prudent investment.

Resilience across R&D, demonstration, and deployment

Early-Stage R&D	Late-Stage R&D	Demonstration and Deployment
Predicting with acceptable confidence the performance of the grid and society during significant disruptions.	Developing and populating metrics that allow valuation of social, economic, and national security resilience benefits.	Engaging with communities to provide technical assistance in support of novel place-based resilience solutions.
Developing new technology that allows the grid to self-heal, flexibly prioritizing the most critical societal needs during any disruption.	Integrating resilience approaches into electric utility planning practices.	Supporting and implementing direct federal investment in grid resilience.
…	…	…

Underlying threat-to-consequence approach

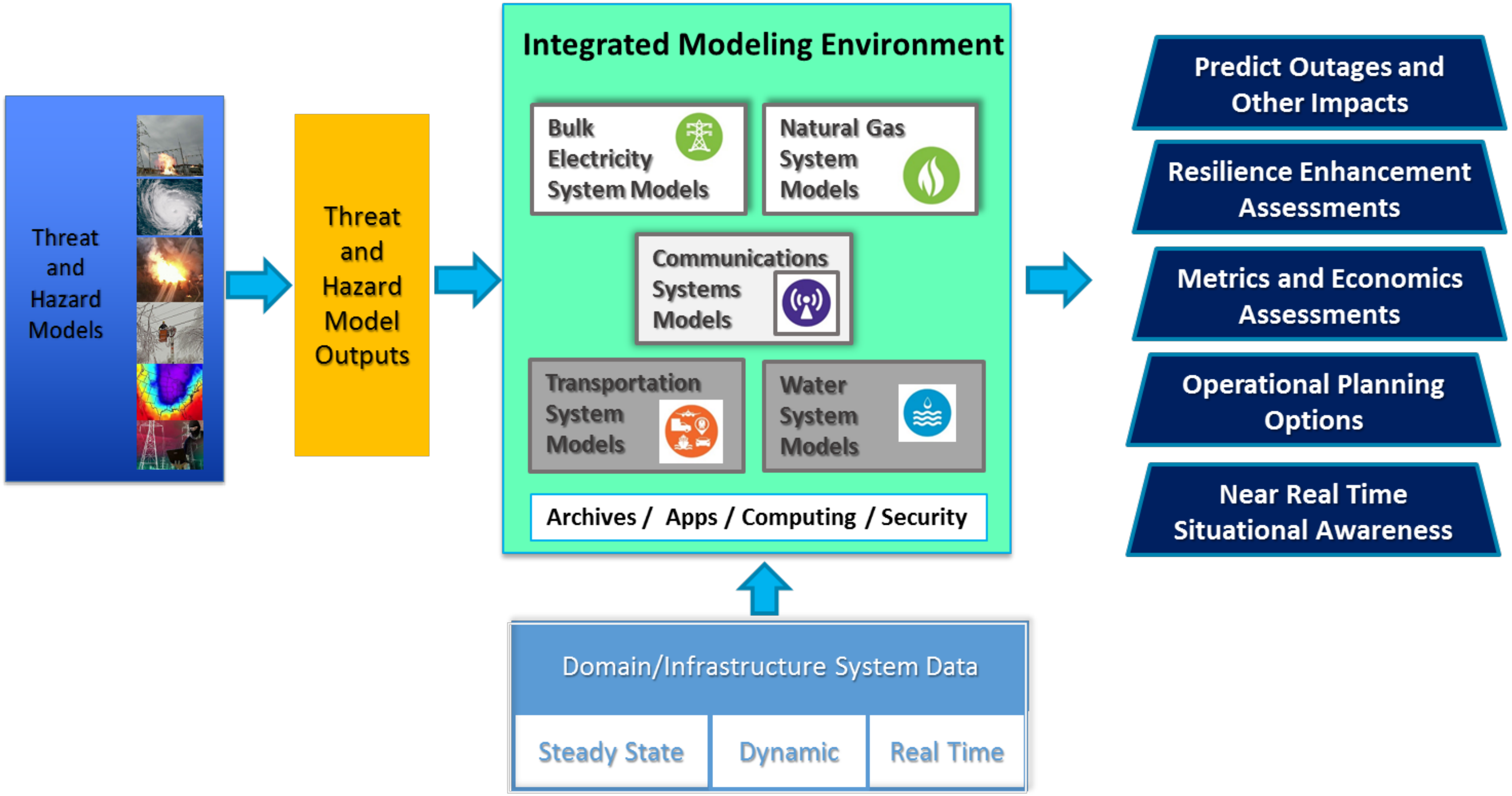


R. Jeffers/NREL

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

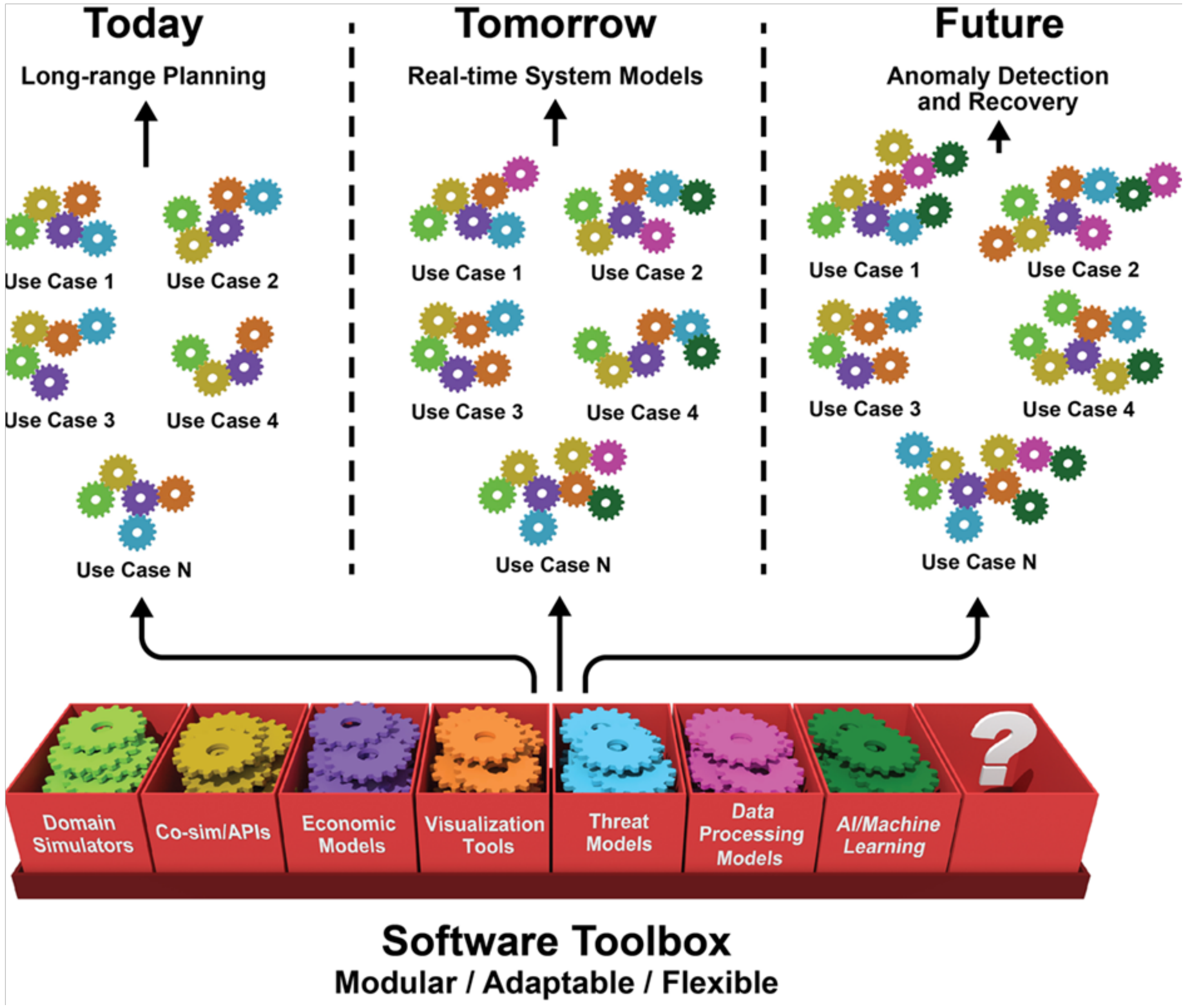
North American Energy Resilience Model (NAERM)

Vision - Rapidly predict energy system interdependencies, consequences and responses to extreme events at a national scale

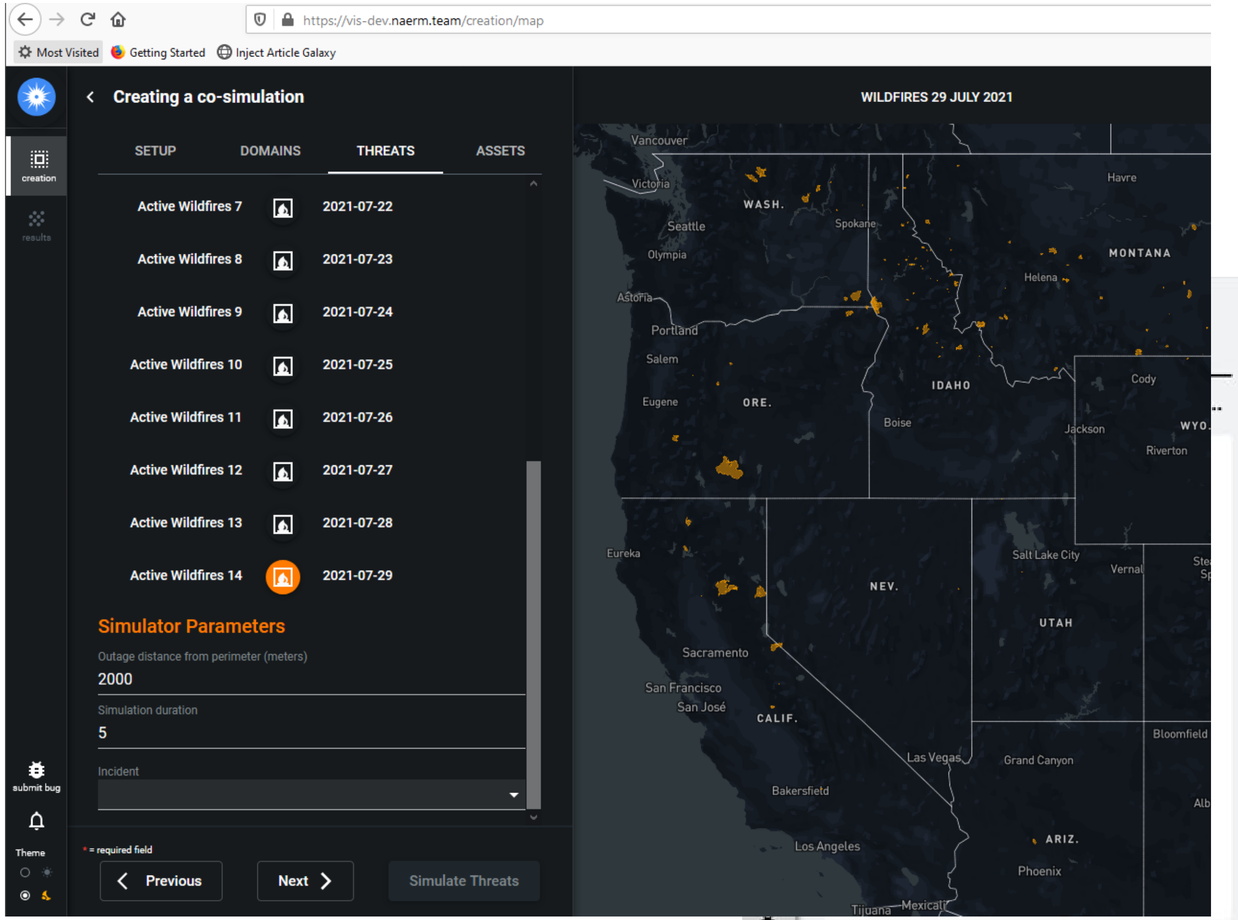


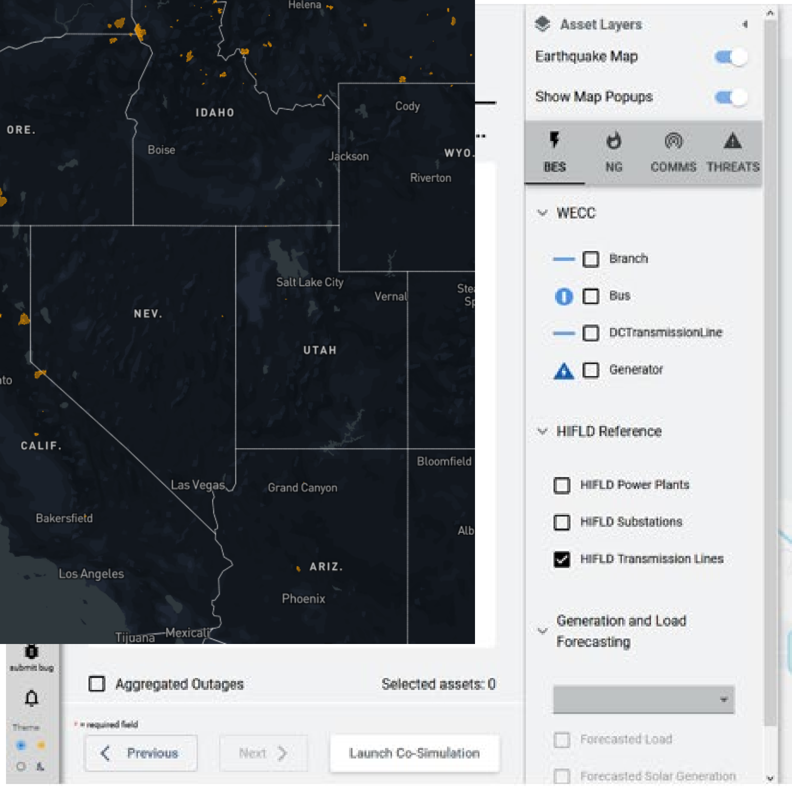
NAERM is a “toolbox” of interactive, modular software elements

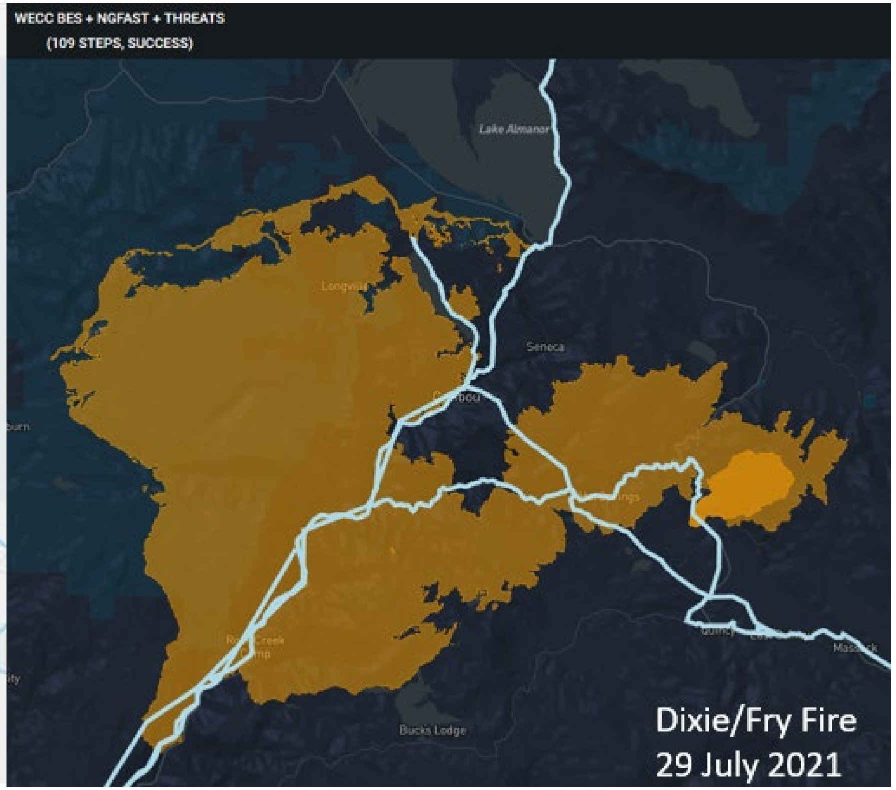
The different elements are assembled in relation to the threat and hazard scenarios being addressed



DOE-OE used NAERM to monitor and model the impact of wildfire in the Western U.S.

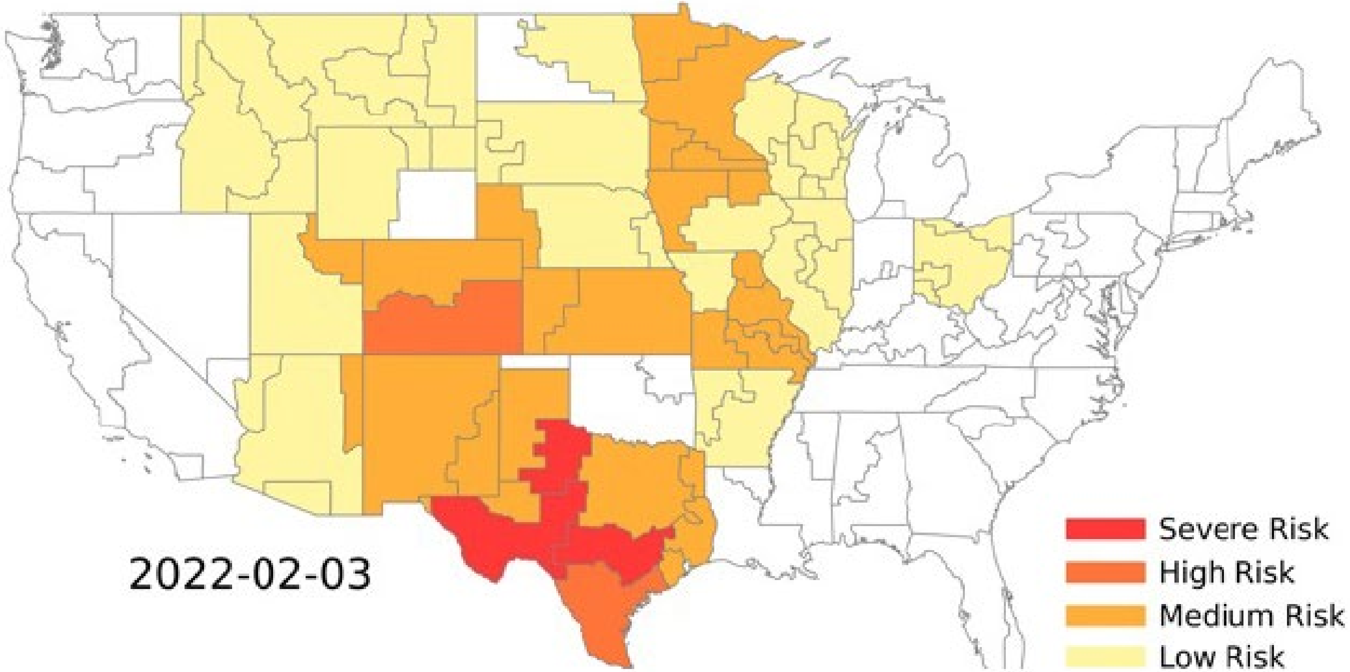




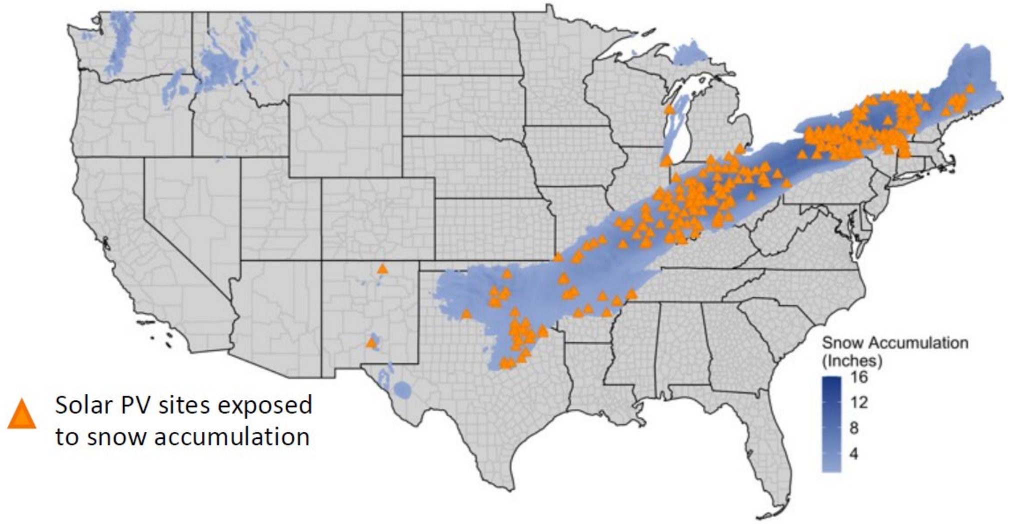


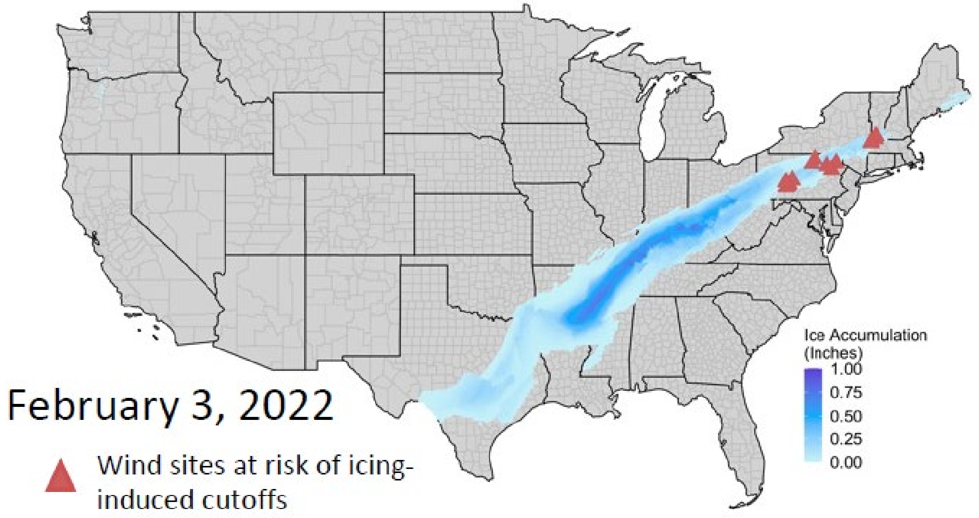
U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

Reports on cold wave events during the 2021-22 winter season



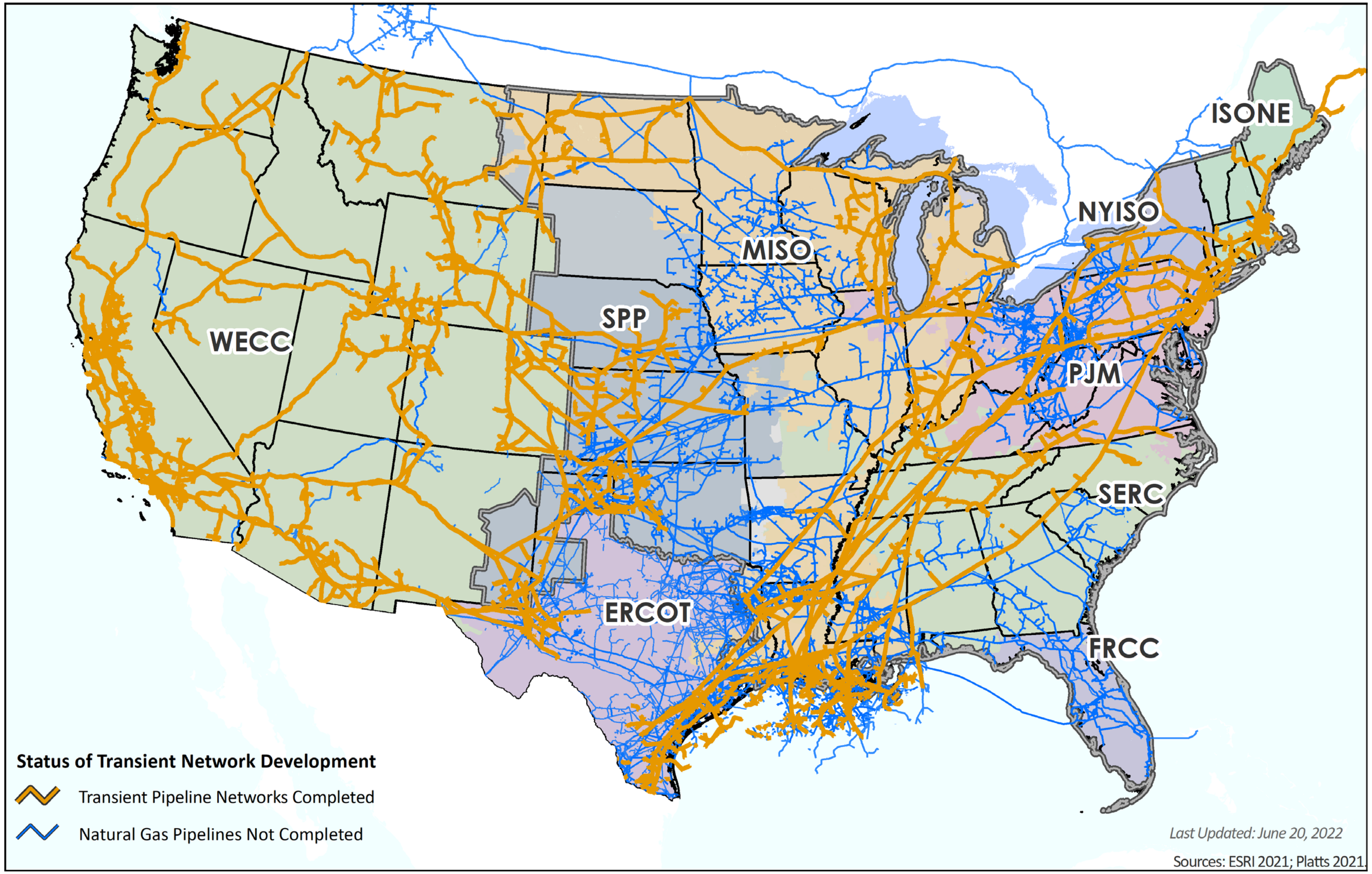
Risk of load-not-served due to weather-driven generation impacts and increased demand based on what-if scenario





U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

Transient Gas Pipeline Modeling

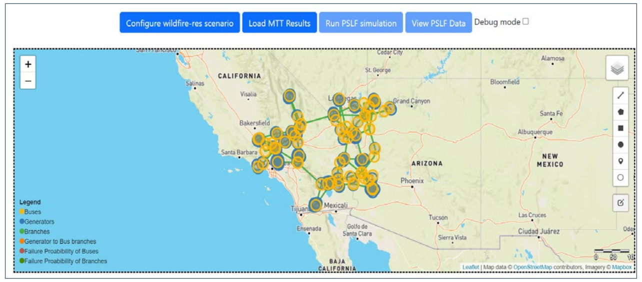


DYNAMIC MONITORING TO ANALYZE GRID VULNERABILITY TO FIRE

Funded by LDRD

PI: Holly Eagleston, haeagle@sandia.gov

Forecasting fire spread and simulating grid component damage with near-real-time fuel condition data and wildfire risk map products



Webmap for fire spread and grid modeling

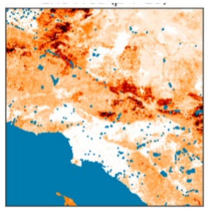
R&D Challenge

Determine wildfire risk to critical infrastructure in near-real-time and understand resulting impacts to the loadshed that could lead to cascading failure

Wildfires pose a ***physical threat to critical infrastructure*** leaving thousands of people without power for extended periods of time. Current fuels maps are based on yearly updates to the data, not capturing seasonal changes to vegetation or the flux of fuel moisture, a known limitation for fire spread simulations.

Approach

Apply machine learning to weather station data weather station data to determine near-real-time fuel moisture, leverage wildfire spread software and SNL grid modeling to identify component damage



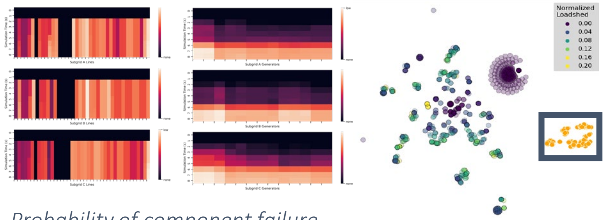
Energy release component, southern California

- Create interactive webmap that incorporates wildfire spread software and grid modeling software, running off of our ML generated data layers.
- Look at a single fire to determine impacts to components and loadshed
- Run Monte Carlo simulations to determine burn probabilities and identify components with high probability of impact that should be hardened or have vegetation treatment applied to be more resilient to wildfire

Impact & Benefit

Provide decision makers with an interactive map which shows our near-real-time fuels condition layer, allows the user to run wildfire simulations and analyze component damage

- Our analyses also show which components have the highest probability of wildfire risk and could help decision makers prioritize resiliency strategies.
- Weigh the costs and benefits of different mitigation strategies from hardening components to vegetation treatments



Probability of component failure

Pacific Northwest NATIONAL LABORATORY

Framework for Risk-Based Dynamic Contingency Analysis

Dynamic Contingency Analysis Tool (DCAT)

- Dynamic analysis to calculate load served during disruptions causing multiple asset failures (n-k sequences)
- Handles “cascading” failures on the grid

HEADOUT data (ANL)

List of assets with probability of failure

Map HEADOUT assets to GIS-PSSE elements

GIS Mapping

EGRASS→DCAT Temporal Sequence Model

Model temporal sequence for asset failure

Probabilistic method

Create contingencies with sequential Monte Carlo sampling of HEADOUT probabilities

- For each hurricane, many contingency scenarios can be generated
- Contingencies include groups of outages for each timestep

DCAT Simulation, DCAT Analytics, and Data management

Asset Impact

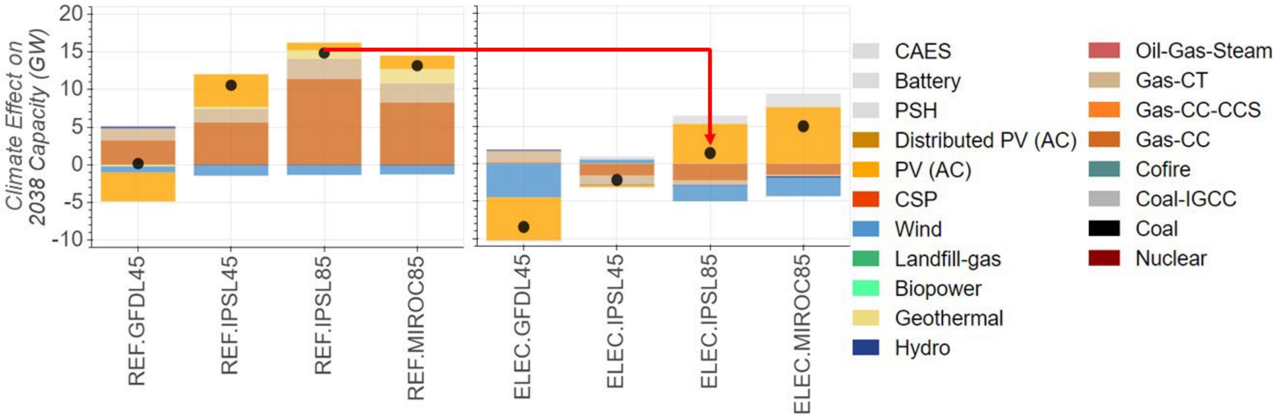
Update with risk mitigation measures

- Vegetation management
- Preventive unloading
- Infrastructure upgrades (not tested yet)

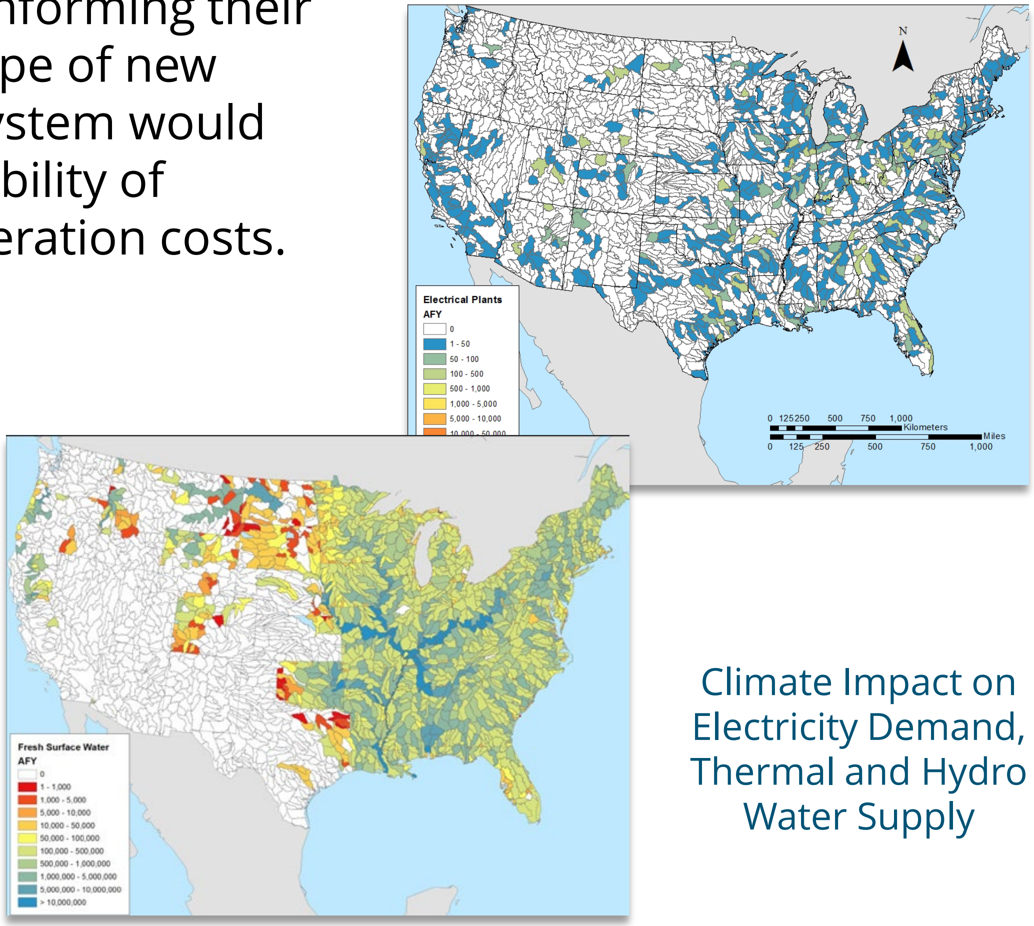
Integrating Water and Climate into Electric Power Planning

This project:

Assisted WECC in their long-range transmission planning, informing their process on how climate could influence the amount and type of new generation additions and retirements, how the resultant system would perform under future drought extremes, impacts on availability of hydropower resources, and implications on capital and operation costs.



Climate and Water Impacts on Capacity Expansion



Climate Impact on Electricity Demand, Thermal and Hydro Water Supply

Measuring resilience – performance vs. attribute

Attribute-based:

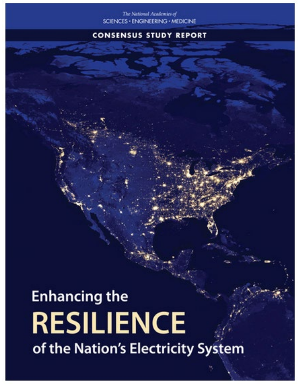
- What makes the system more/less resilient?
- Things you can count now (on a blue-sky day)
- Often grouped into categories that describe some aspect of resilience
  - Robustness, adaptivity, recoverability, etc.
- Often populated via surveys or checklists
  - Relatively simple to populate

Performance-based:

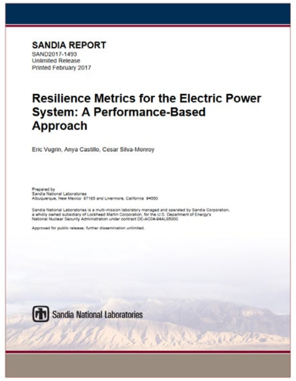
- How resilient is/was the system?
- Things you can measure only during disruption
- Often uses data from an event or a model of an event
  - Can be difficult to populate for planning
- Useful to weigh resilience against other goals
  - (e.g. within benefit cost analysis)

Either approach can be:

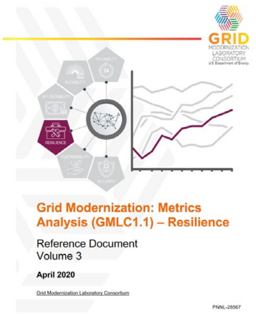
- Retrospective or forward-looking
- Power-focused or consequence-focused
- Threat-informed or threat-agnostic



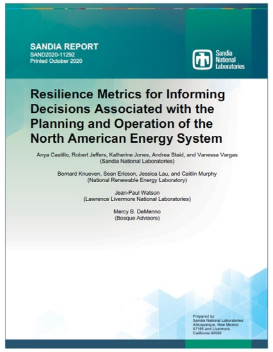
National Academies (2017), Recommendation #1 to DOE: "Improve understanding of customer and societal value associated with increased resilience and review and operationalize metrics for resilience…"



Vugrin et al. (2017) under GMLC 1.1 Foundational Metrics: First power-focused discussion of attribute-based and performance-based resilience metrics.

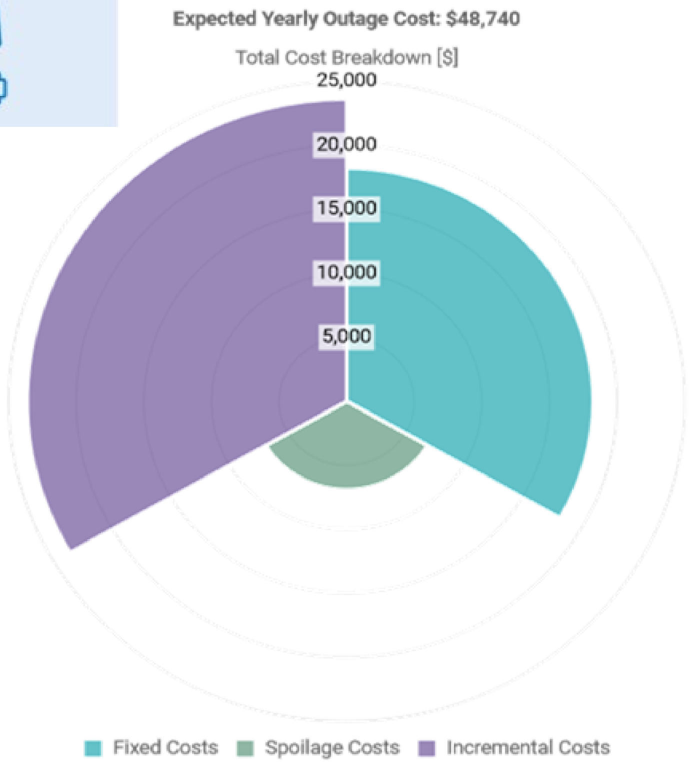


GMLC 1.1 Final Report (2020): Begins to clarify how attribute and performance-based approaches can complement.

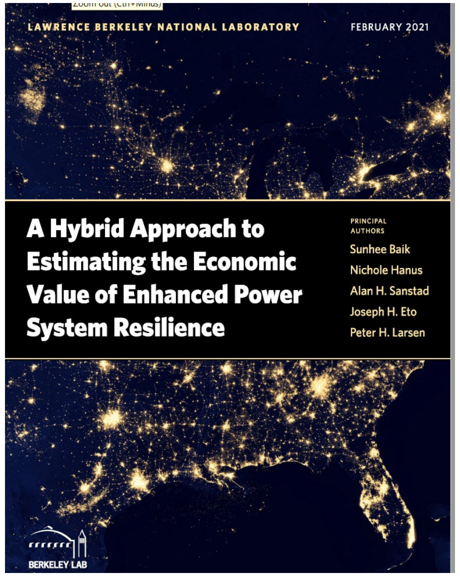


NAERM Metrics Report (2020): Describes consequence dimensions and metric formulation

Metrics for resilience planning - economic



The DOE-funded **ICE Calculator** allows users to estimate the direct costs to customers from power interruptions lasting 24 hours or less—or the value of investments in power system *reliability*


LAWRENCE BERKELEY NATIONAL LABORATORY
FEBRUARY 2021
A Hybrid Approach to Estimating the Economic Value of Enhanced Power System Resilience
PRINCIPAL AUTHORS
Sunhee Baik
Nichole Hanus
Alan H. Sanstad
Joseph H. Eto
Peter H. Larsen
BERKELEY LAB

POET will allow users to estimate the direct and indirect economic impact of widespread, long duration power interruptions—or the value of investments that enhance power system resilience

The **Customer Damage Function calculator** allows a more granular estimate of economic losses for individual facilities or customers.

BERKELEY LAB

NREL
NATIONAL RENEWABLE ENERGY LABORATORY

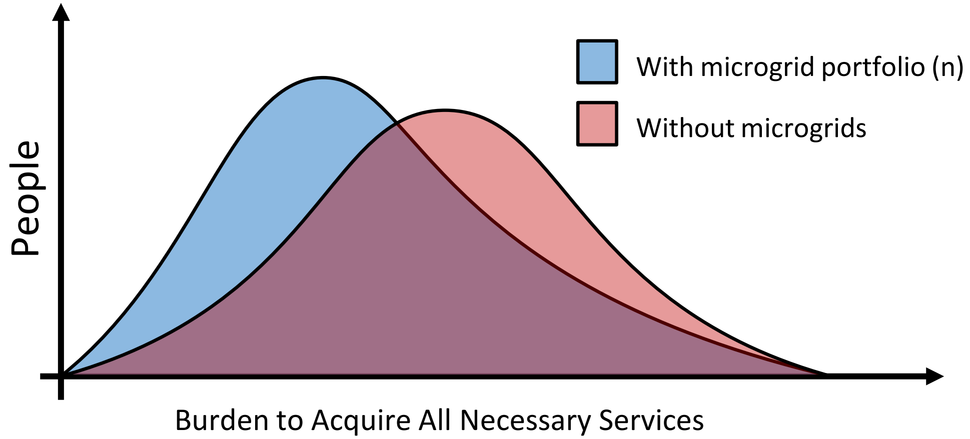
U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

Metrics for resilience planning - social

DOE has invested in quantifying the performance of society, developing a novel "social burden" metric and quantification approach:

- How hard must people work to **maintain wellbeing** during disruptions?

Aligns DHS FEMA "Community Lifelines" and the Social Justice "Capabilities" theory relating infrastructure availability to human wellbeing



While we have resilience metrics, we have **not validated** these metrics at the appropriate scale - **Limited by data**

Sandia National Laboratories

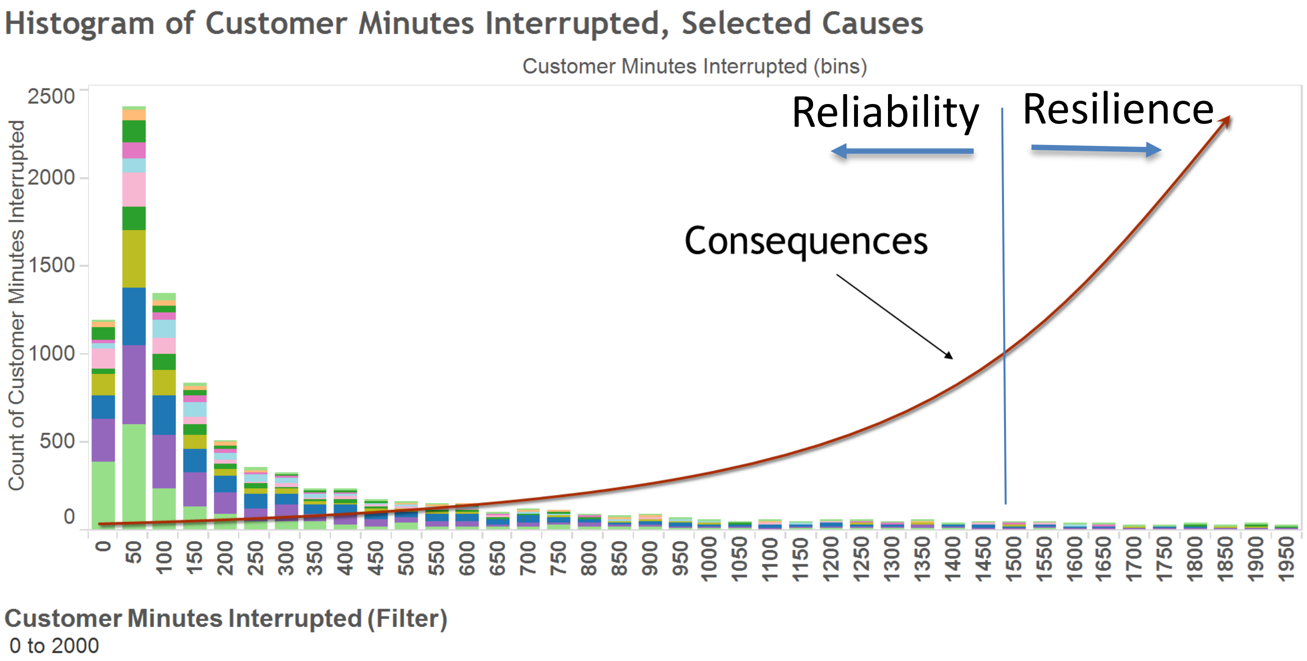
NREL NATIONAL RENEWABLE ENERGY LABORATORY

Based on the capabilities framework, Sen and Nussbaum, later applied to energy by Day et al. (2016):
Nussbaum, Capabilities as fundamental entitlements: Sen and social justice. 2003; Sen, Human Rights and Capabilities. 2005;
Day, R., Walker, G., Simocck, N. Conceptualising energy use and energy poverty using a capabilities framework. Energy Policy. 2016.

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

Resilience and Utility Planning Processes

- Utility reliability metrics such as SAIDI, SAIFI, CAIDI, etc., don't adequately address Major Event Days – low probability, high consequence events – to avoid 'gold plating' infrastructure.
- Therefore, in standard reliability-focused planning, long-duration and historically "rare" outages are not explicitly considered.
- Some utilities are encouraged to emphasize resilience AFTER disasters – through one-off resilience investment proceedings (e.g. NJ Energy Strong, Puerto Rico)

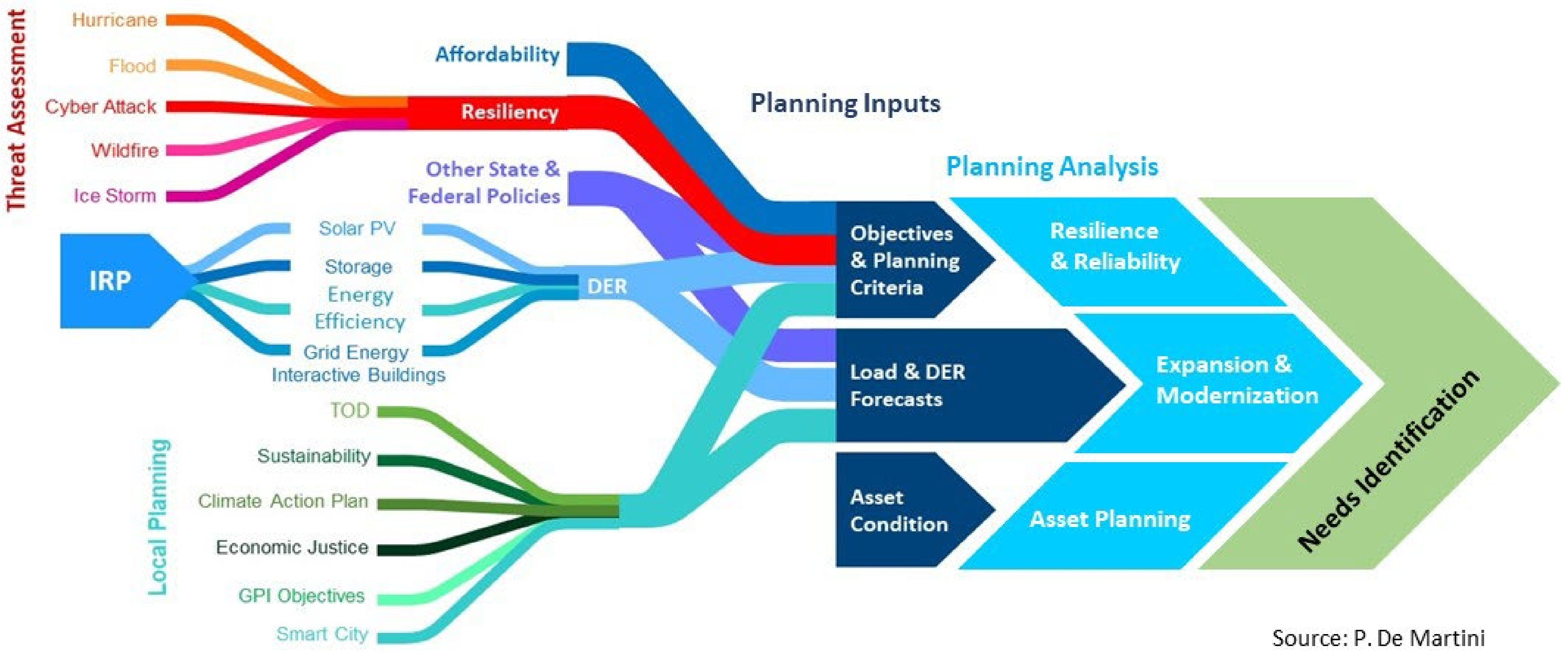


Utilities have a long history of assessing the damage (costs) to their systems in the immediate aftermath of a natural disaster...but utilities and other stakeholders struggle to justify preventative investments, because they do not know the risk to or value of those investments (e.g., avoided economic impact or social burden).

Resilience improvements will occur through a) transforming risk assessment into planning objectives and b) continuous improvements, e.g. in asset management processes and hardening.

Distribution System Planning Inputs

Distribution planning increasingly dependent upon IRP/bulk power planning, local sustainability & resilience plans, and use of DER



Source: P. De Martini

U.S. DEPARTMENT OF ENERGY | OFFICE OF ELECTRICITY

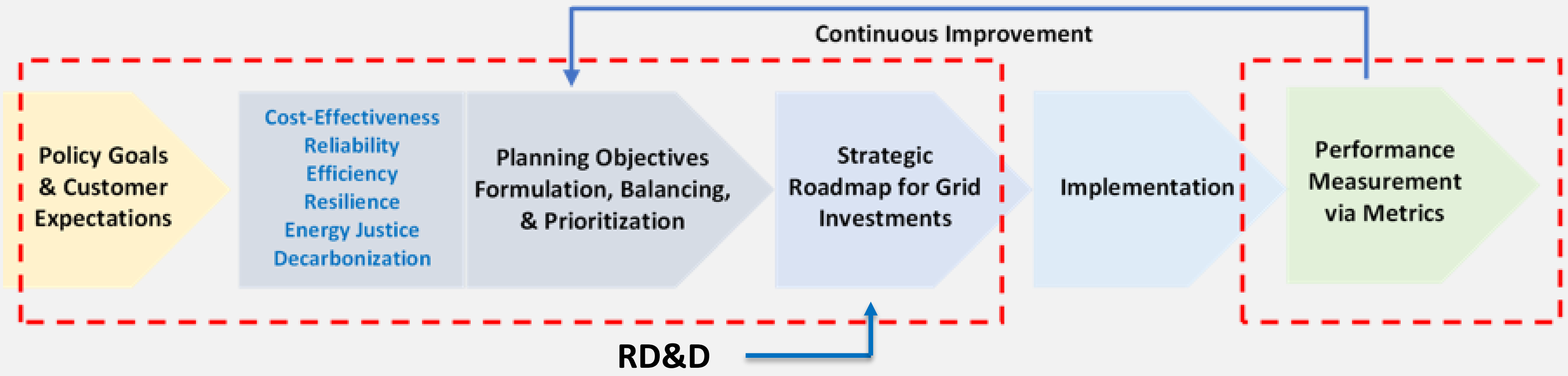
Decision Process Framework

Three interrelated components that form a framework to organize and inform decision-making

Roles and Responsibilities of Participants

Roles and responsibilities of decisionmakers and stakeholders within the decision process

Decision Process

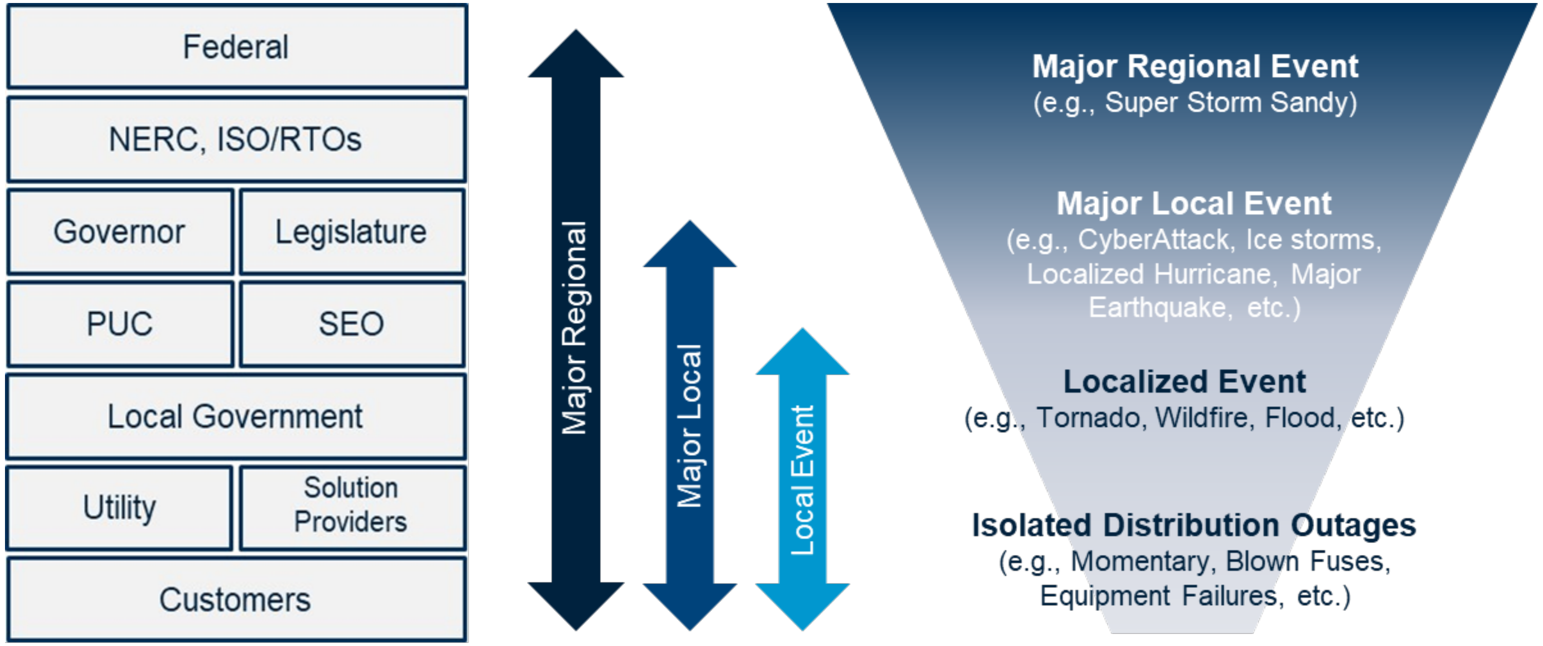


Supporting Analytical Methods and Tools

To inform decision-making within the decision process

Roles and Responsibilities

Scale of potential impact shapes who will be involved in process

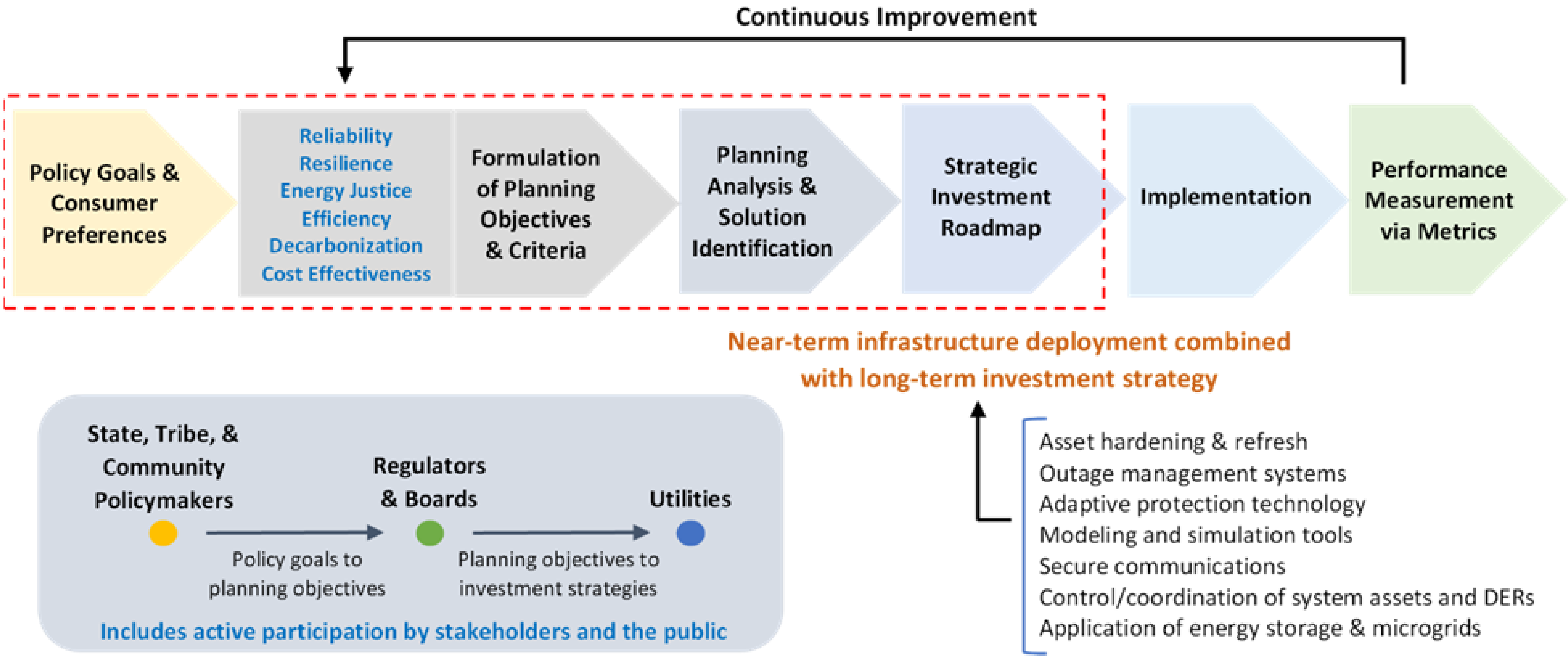


Note: Diagram is simplified - cities, communities, emergency services, and other key stakeholders are all part of the process

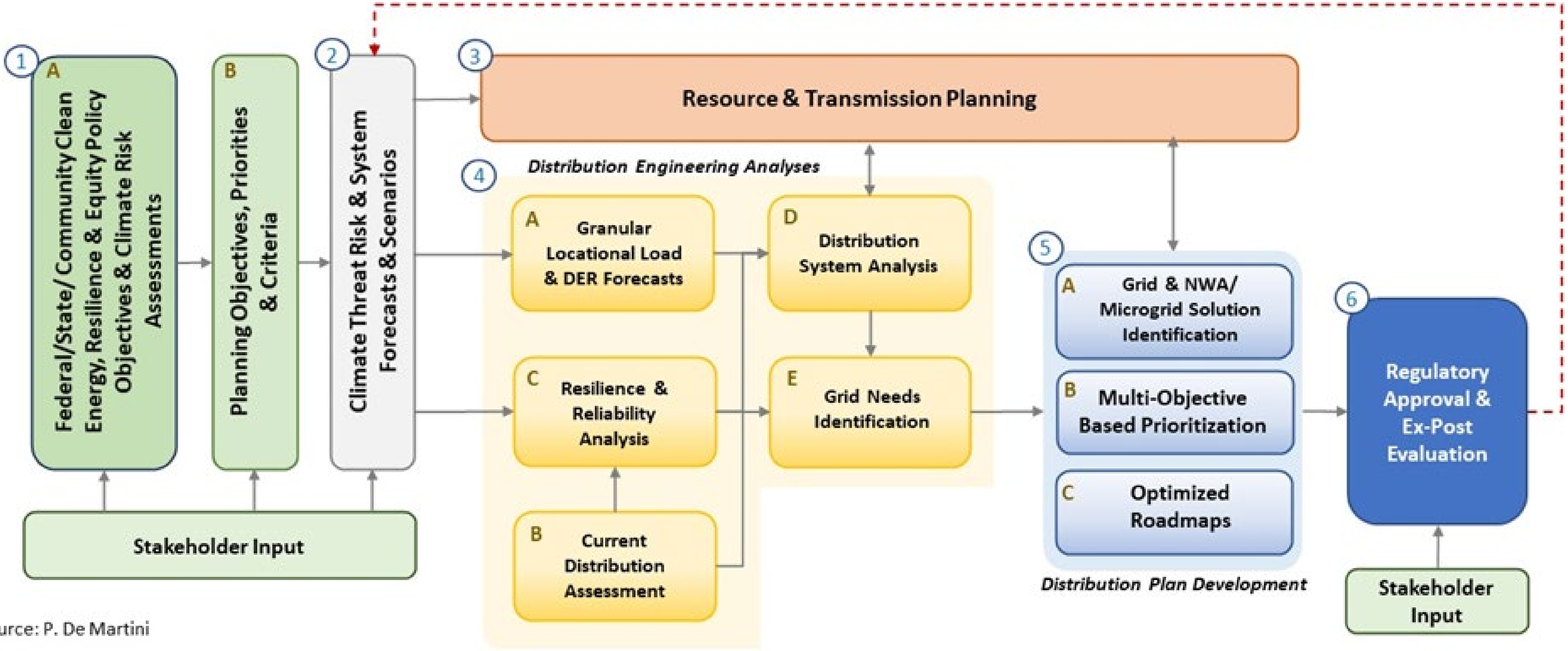
Developed by Paul De Martini

Emerging Focus of Integrated Distribution Planning

Creating a shared understanding among stakeholders of strategies for grid transformation needed to meet myriad objectives, including those addressing resilience, decarbonization, and equity



Integrated Grid Resilience Planning



Source: P. De Martini

Threat-Based Risk Assessment

Policy Development	Regulation
E.G., policies on: • Tax-based funding for resilience measures • Treatment of vulnerable or disadvantaged populations • Establishment of special committees, studies, and working groups	• Provision of planning objectives and criteria to utilities, plus metrics • Integrated planning guidelines • Evaluation and approval of utility plans • Establishment of working groups

Planning guidance to utilities

Utility Planning and Analysis

Utility annual and long-term plans to address resilience and grid modernization

Tiering of key infrastructure and populations

Formulation of resilience-based objectives and metrics

Emergency Preparedness

Reference HECO IGP Resilience Working Group Report, June 1, 2020: https://www.hawaiianelectric.com/clean-energy-hawaii/integrated-grid-planning/stakeholder-and-community-engagement/working-groups/resilience-documents.

Threat-Based Risk Assessment	
Where: risk = f(threat, vulnerability, consequence)	
Threat assessment: identification and prioritization	Threat scenarios: assessment of impact of threat on infrastructure and populations

Forecasting of threat severity (low, medium, and high)

Transformational Decision-making Process to Inform Resilience Planning

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Key gaps to address:

- Insufficient information about how outage risks are evolving due to climate change
- Insufficient projections of how different technologies result in decreased outage risk for different customers
- Insufficient ability to quantify and equitably distribute the benefits – economic and social – of a reduced outage risk

Characterize Threats, Analyze Grid Vulnerability, and Develop Interruption Scenarios

Baseline Social and Economic Consequences Subject to Interruption Scenarios

Specification of Resilience Investment Alternatives and Impact on Outage Risk

Value of Resilience Investment Alternatives: Avoided Social and Economic Consequences

Outreach to Determine Information Needs Supporting Resilience Planning Transformation AND
Technical Assistance to Key Stakeholders to Incorporate Critical Information into Investment Decision-making

Workflow Example #1: Extreme Drought / Wildfire in the West

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Characterize Threats, Analyze Grid Vulnerability, and Develop Interruption Scenarios

Baseline Social and Economic Consequences Subject to Interruption Scenarios

Specification of Resilience Investment Alternatives and Impact on Outage Risk

Value of Resilience Investment Alternatives: Avoided Social and Economic Consequences

Identify and characterize the threat(s) and desired system scope

Identification of extreme weather metrics and thresholds conducive to wildfire impacts on power systems

Identify interruption scenarios and vulnerabilities

Power system vulnerabilities

Frequency and duration of power disruptions caused by wildfires

Examples include:

- SNL Wildfire
- NAERM

Obtain data and baseline consequences subject to interruption scenarios

Baseline economic and social consequences of power disruptions

Examples include:

- ReNCAT
- ICE Calculator
- POET
- Justice 40

Specification of resilience investment alternatives and impact on outage risk

Examples include:

- MDT
- DER-CAM
- REPAIR
- REopt
- ReNCAT

Example mitigations:
Veg. management
Burn bans
New fire stations
Undergrounding
Microgrids

Value of resilience investment alternatives: Avoided social and economic consequences

Examples include:

- ReNCAT
- ICE Calculator
- POET

Cost-benefit (effectiveness) analysis and visualization of resilience portfolios

Examples include:

- FRONTIER
- GMLC LVAT
- SLOPE
- NAERM

Workflow Example #2: Catastrophic Hurricanes in Southeast

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Characterize Threats, Analyze Grid Vulnerability, and Develop Interruption Scenarios

Baseline Social and Economic Consequences Subject to Interruption Scenarios

Specification of Resilience Investment Alternatives and Impact on Outage Risk

Value of Resilience Investment Alternatives: Avoided Social and Economic Consequences

Identify and characterize the threat(s) and desired system scope

Summer risk as well as additional year-round extreme wind and rain
Downscaled and extreme weather metrics identified

Identify interruption scenarios and vulnerabilities

Power system vulnerabilities

Frequency and duration of power disruptions caused by wildfires

Examples include:
- NAERM
- HEADOUT
- EPfast

Obtain data and baseline consequences subject to interruption scenarios

Baseline economic and social consequences of power disruptions

Examples include:
- ReNCAT
- POET
- ICE Calculator
- Justice 40

Specification of resilience investment alternatives and impact on outage risk

Examples include:
- MDT
- REPAIR
- DER-CAM
- REopt
- ReNCAT

Example mitigations:
Microgrids
Buried lines
Substation flood hardening

Value of resilience investment alternatives: Avoided social and economic consequences

Examples Include:
- WNTR
- ReNCAT
- MDT
- REopt
- POET
- ICE Calculator

Cost-benefit (effectiveness) analysis and visualization of resilience portfolios

Examples include:
- FRONTIER
- GMLC-LVAT

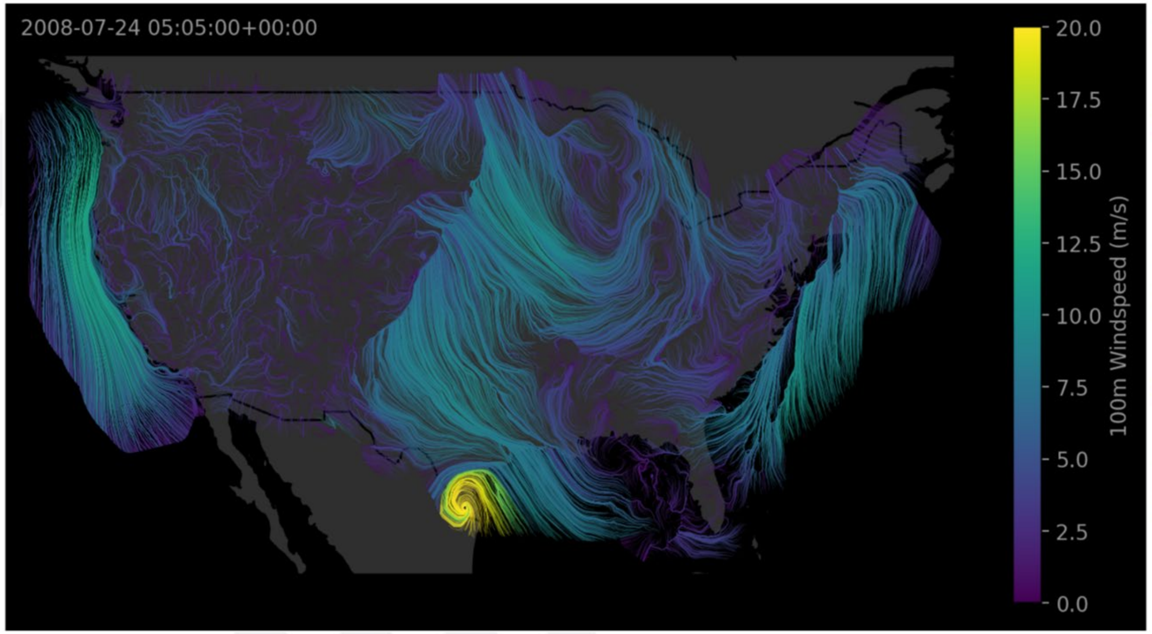
Achieving Resilience

- **Understand context**
  - e.g. threat/event characterization; demand/behavior profiles (needs)
- **Analyze existing flexibility**
  - e.g. sensors; resilience metrics; maturity models
- **Identify gaps and potential solutions**
  - e.g. modeling/analytical tools; energy storage; microgrids
- **Coordinate objectives and facilitate staged decision-making**
  - e.g. technical assistance; architecture; integrated planning

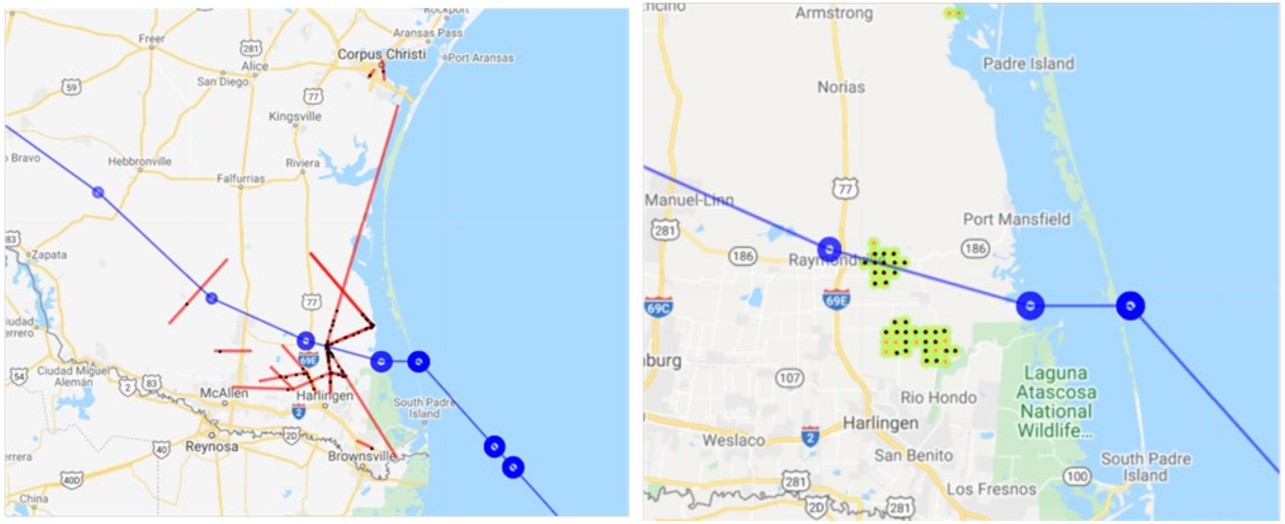
Background: Detailed Tool Descriptions

WIND Toolkit Projections of Extreme Wind

- NREL's WIND Toolkit (WTK) combines wind models with the most robust wind resource dataset for the U.S.
- At least 18 tropical storm events have been evaluated using high-fidelity models
- WTK has been used to estimate damage to wind turbines, substations, transmission lines, and resulting power system impacts



Hurricane Dolly visualization



Transmission (left) and Wind Farm (right) impacts

https://www.nrel.gov/docs/fy22osti/80639.pdf

WELDER: Weather Effects on the Lifecycle of DoD Equipment Replacement (LBNL/U.S. Army Corps of Engineers)

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

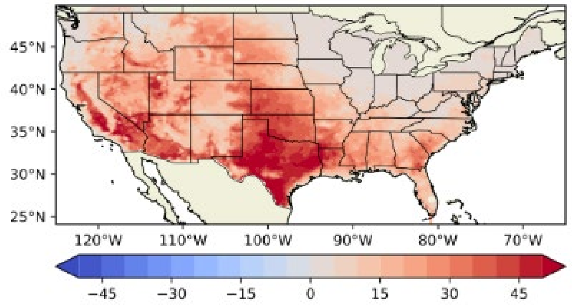
- WELDER is a decision support tool developed with funding from U.S. Department of Defense

- WELDER
  - projects long-term extreme events risk
  - informs planners on how these events may alter the depreciation schedules and the performance profile of individual facilities and their constituent systems and components
  - does so relative to a wide range of extreme event scenarios and the likelihood of potential impacts

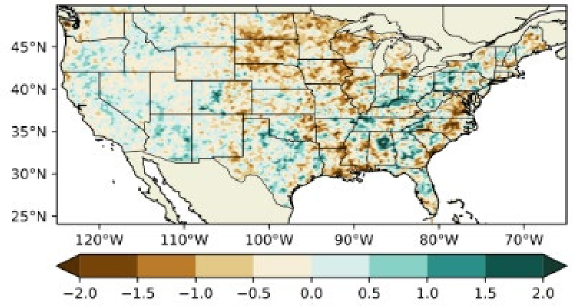
- Downscaled climate model output from the WELDER could be re-purposed to evaluate risk to utility infrastructure
  - 9 different extreme weather metrics projected to 2060
  - 10-25km spatial resolution across the contiguous U.S.

WELDER

CAM5 2060 minus 2005 difference in the number of days per year where the maximum temperature exceeds 100F.



WRF TCM 2060 minus 2005 difference in the number of days per year where the hourly precipitation rate exceeds 0.5 inches.

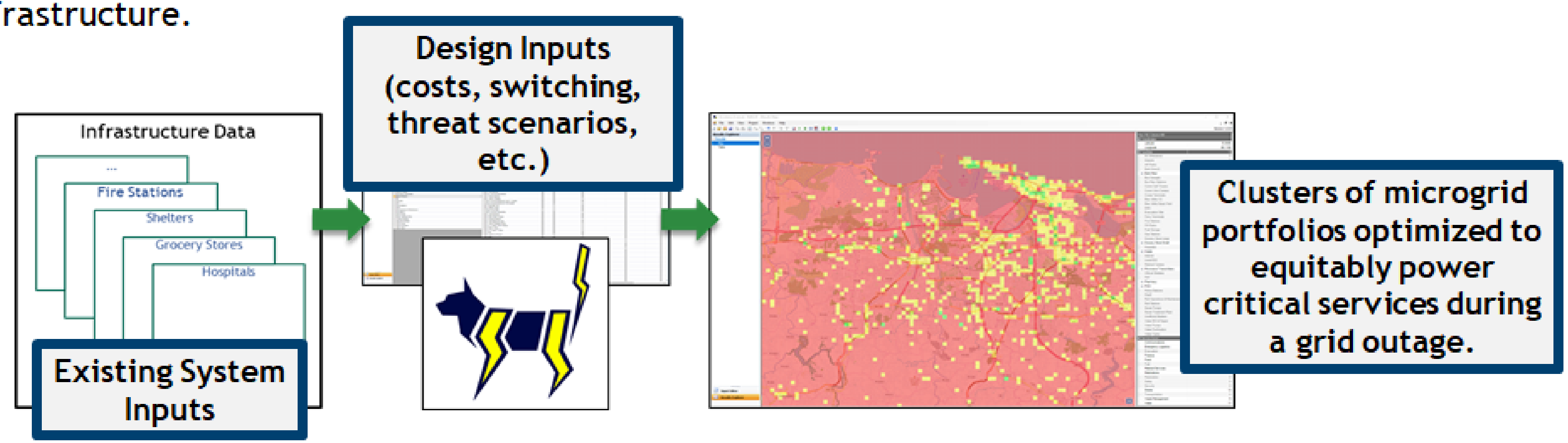


Resilience Node Cluster Analysis Tool (ReNCAT)

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Overview

ReNCAT uses a genetic algorithm to analyze the distribution system and determine optimal placement of microgrids to ensure critical services remain equitably available to the community during grid outages. A key feature of ReNCAT is understanding how critical services map to critical infrastructure.



Applications

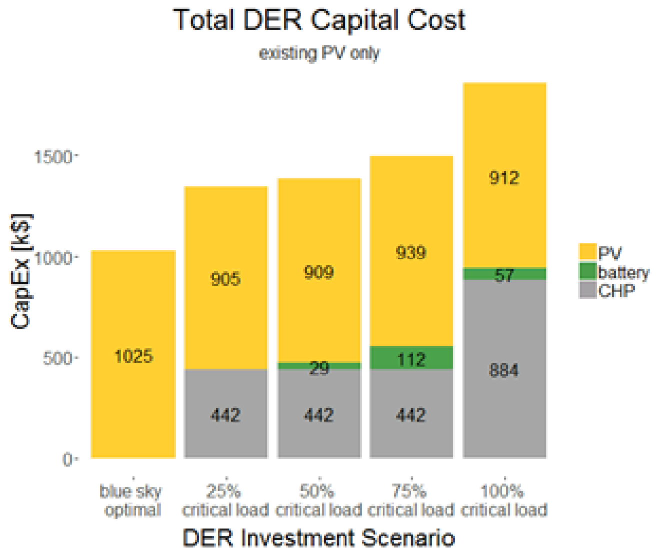
ReNCAT Analysis has most notably been used for analyses in partnership with:

- Puerto Rico
- New Orleans, LA
- San Antonio, TX

Lead Researchers:
Amanda Wachtel, awachte@sandia.gov
Darryl Melander, djmelan@sandia.gov

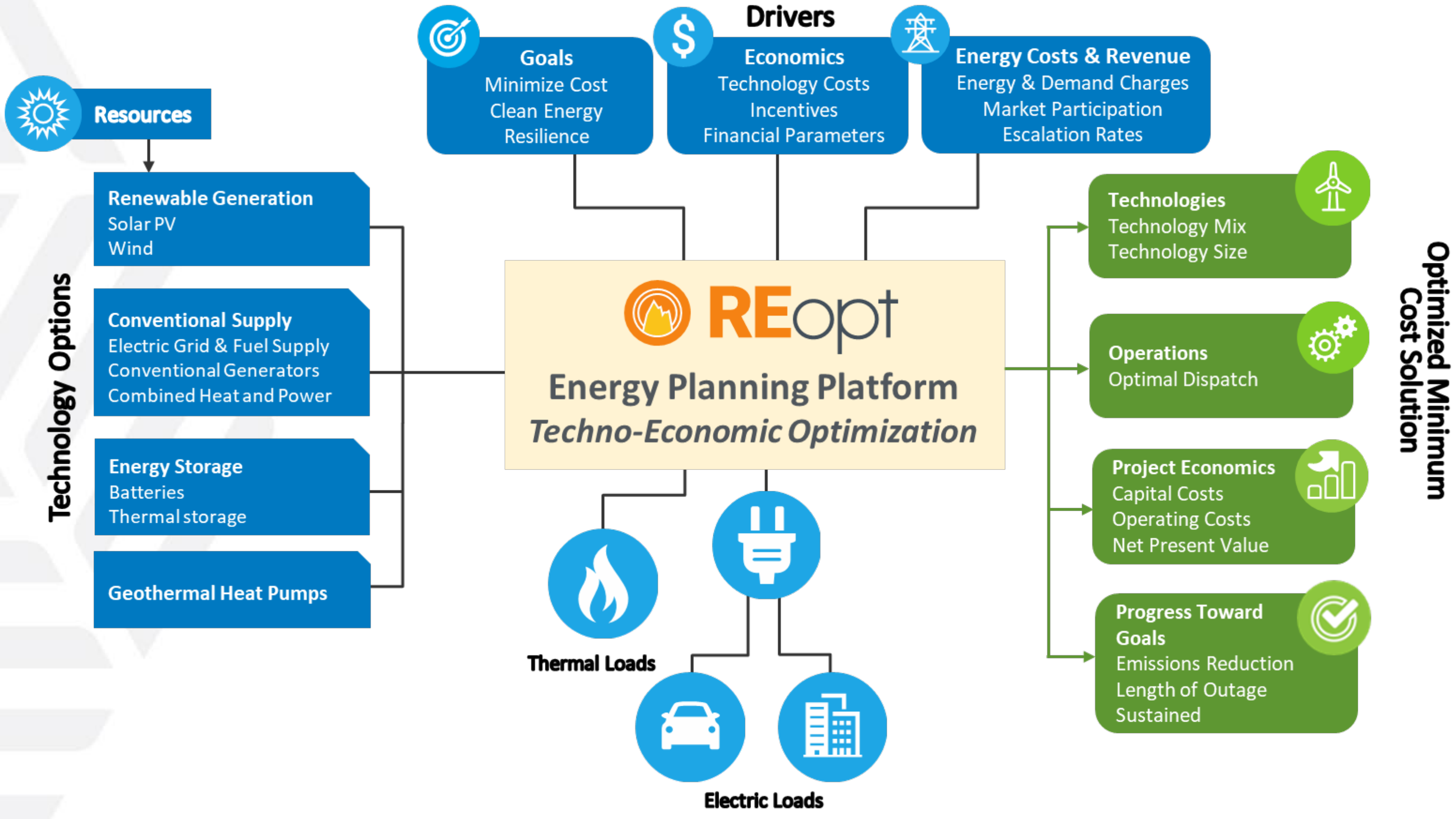
DER-CAM: Optimized Microgrid/DER Decision Support (LBNL)

- DER-CAM is an optimization model for planning, sizing, dispatching, and analyzing microgrids or DER deployments
- Supports quick feasibility studies and exploratory design for resilience & energy cost reduction
- Users provide inputs describing application and objective, DER-CAM provided optimized DER investment recommendations & estimated economic & energy performance metrics
- Relevant to research and direct application (e.g. state and local government stakeholders)



REopt

- NREL's REopt® platform optimizes planning of generation, storage, and controllable loads to maximize the value of integrated systems.
- REopt considers electrical, heating, and cooling loads and technologies simultaneously to identify the optimal technology or mix of technologies.
- REopt analysis guides investment in economic, resilient, sustainable energy technologies.
- **How will this benefit S&T's?**
  - For S&T's that need fast, accessible technoeconomic analysis of conceptual designs for *local* energy systems that co-optimize across resilience, affordability, and sustainability

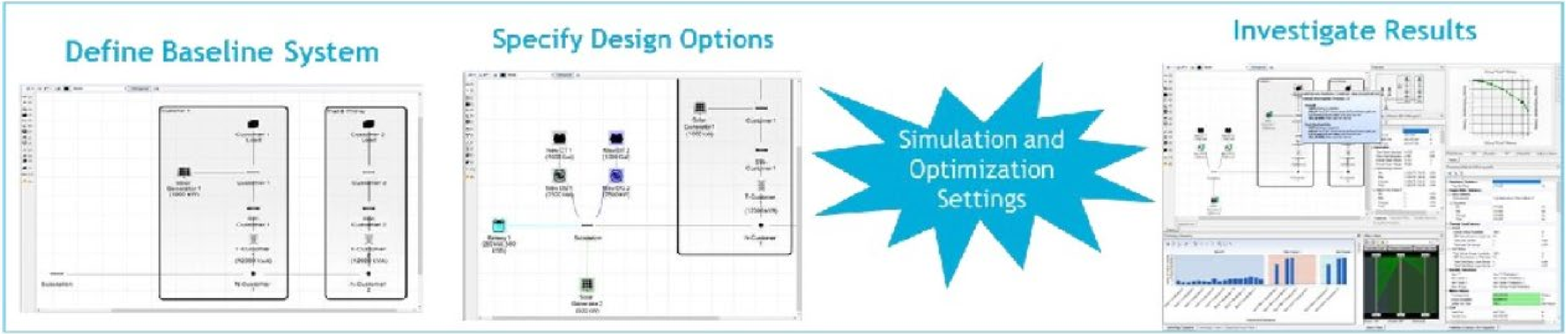


GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Microgrid Design Toolkit (MDT)

Overview

MDT is a visual design and trade-space optimization capability for microgrids. A multi-objective optimization algorithm executes a discrete event Monte-Carlo simulation to characterize performance and reliability of candidate microgrid designs. Results include a Pareto frontier representative of microgrid design variations and visualizations, allowing designers to analyze design tradeoffs easily and effectively.



Applications

The MDT and its underlying technologies have been used by a number of projects and agencies, including the Smart Power Infrastructure Demonstration and Energy Reliability and Security (SPIDERS) project, the City of Hoboken, the NJ backup power system, and the US Marine Corps Expeditionary Energy Office.

Contacts

- Technical Support – Jimmy E. Quiroz, Sandia National Laboratories, jequiro@sandia.gov
- Principal Developer – John Eddy, Sandia National Laboratories, jpeddy@sandia.gov

ICE Calculator: Interruption Cost Estimate Calculator (LBNL)

- Customer costs of power interruptions are of increasing importance for identifying and prioritizing cost-effective utility investments to improve reliability/resilience

- Berkeley Lab’s Interruption Cost Estimate (ICE) Calculator is the leading and only publicly-available tool for estimating the customer cost impacts of power interruptions

- The ICE Calculator is being used to:
  - Support internal utility reliability planning activities
  - Provide a basis for discussing utility reliability investments with regulators
  - Assess the economic impact of past power outages

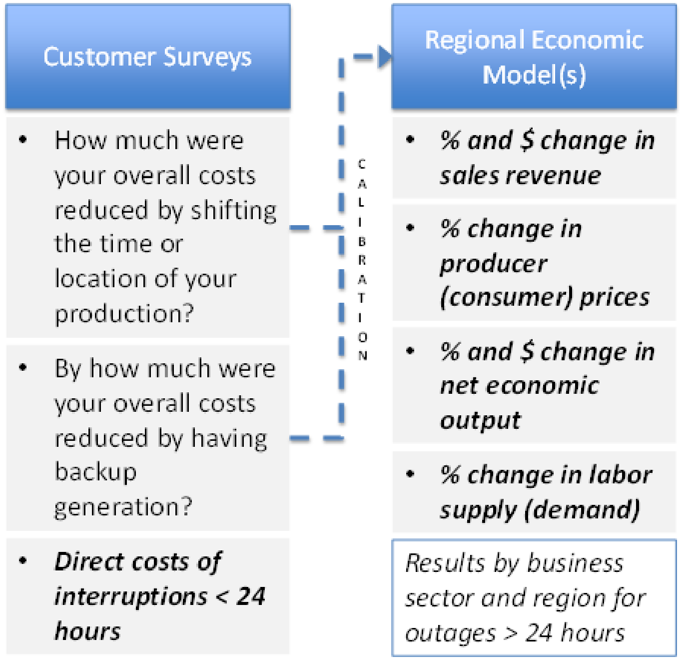
- ICE Calculator is being updated and upgraded with direct support from utilities (2024 release date)

POET: Power Outage Economics Tool (LBNL)

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

- The Power Outage Economics Tool—being piloted in ComEd's service territory—will allow users to estimate the direct and indirect economic impact of widespread, long duration power interruptions—or the economic value of investments that enhance power system resilience
- Hybrid resilience valuation approach that integrates:
  - Survey-based techniques to identify mitigating/adaptive behaviors that residential, commercial, industrial, and public sector customers may take to reduce risk before, during, or after a power interruption occurs
  - Regional economic models that have been calibrated—using survey responses—to assess the full range of economic impacts from power interruptions

ComEd®
An Exelon Company

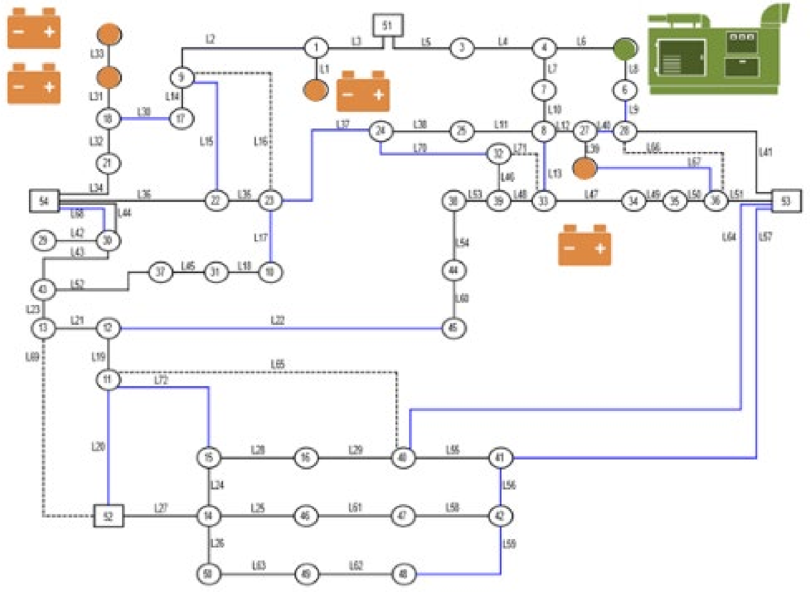


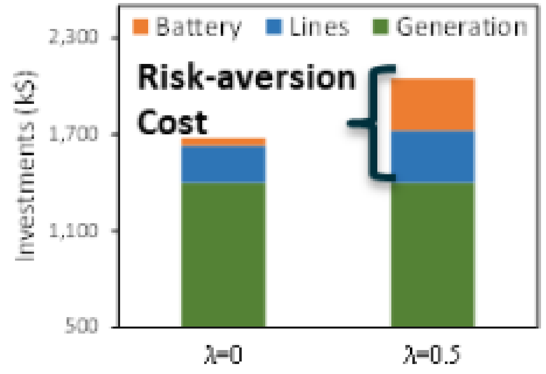
REPAIR: Risk-controlled Expansion Planning with DERs (LBNL)

- A grid planning tool that optimizes utility investments, considering the risk associated with routine failures and extreme events.

- Supports "cost vs risk" decisions, from utilities and regulators, around reliability and resilience investments.

- R&D needs:
  - Including non-dispatchable decarbonization resources, such renewable-based generation, into the model;
  - Model decision-dependent uncertainties, specific to extreme events, such as wildfires.





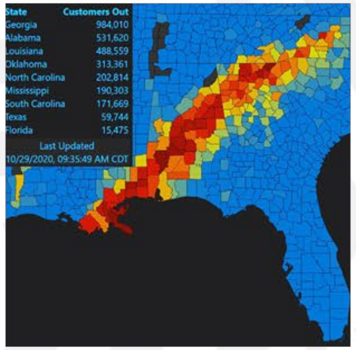
ResStock/ComStock for Resilience

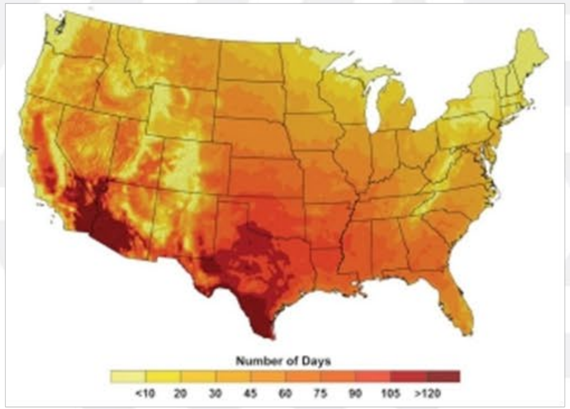
ResStock
ComStock

GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Hazard Region Risk Assessment

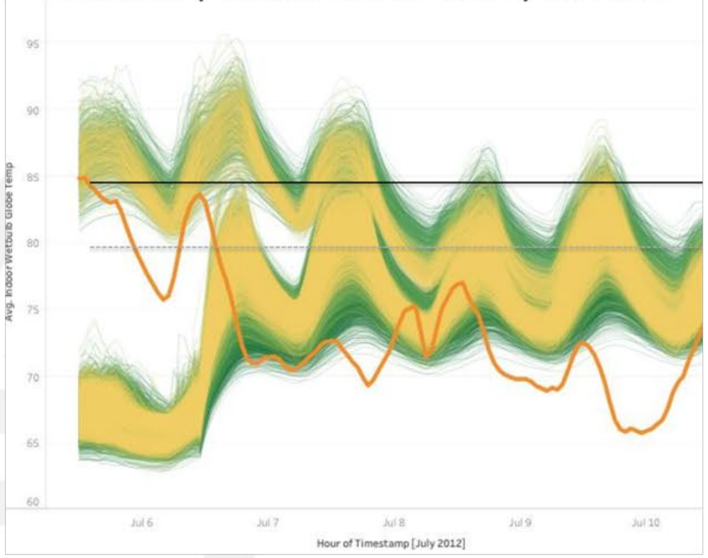
Risk assessment of power disruptions and extreme temperature events





Building Simulation of Mitigation Measures

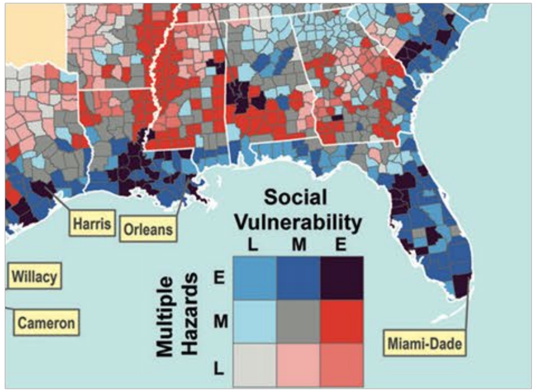
Evaluate passive survivability metrics



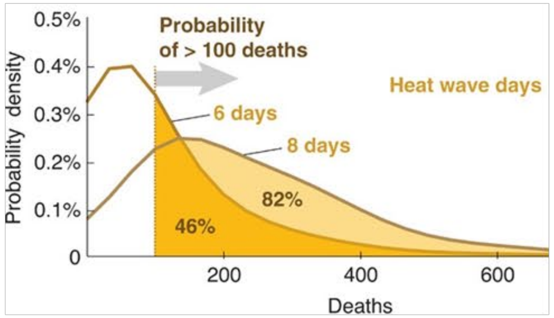
Characterization of efficiency measures and building designs that compliment, conflict, or have no impact on resilience

Vulnerability, Damage, and Loss Analysis

Determine vulnerability of occupants and property



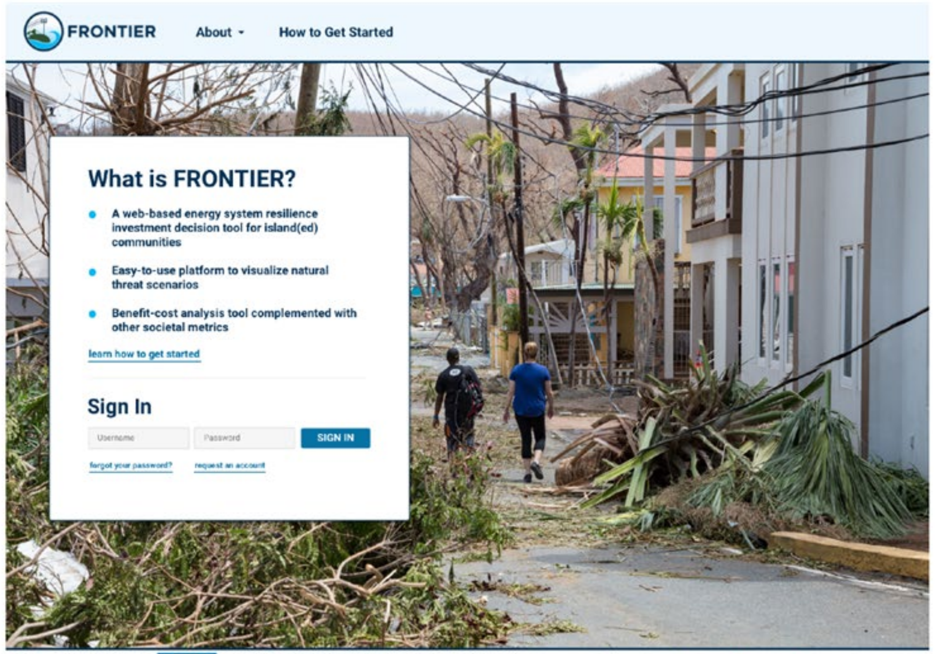
Predict excess mortality rates

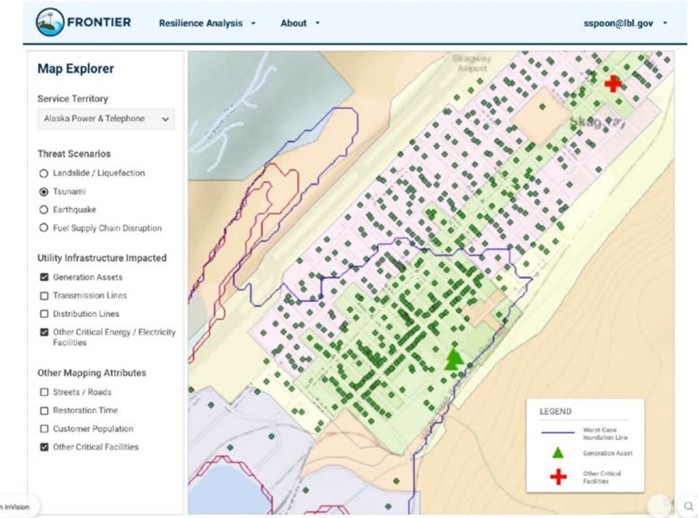


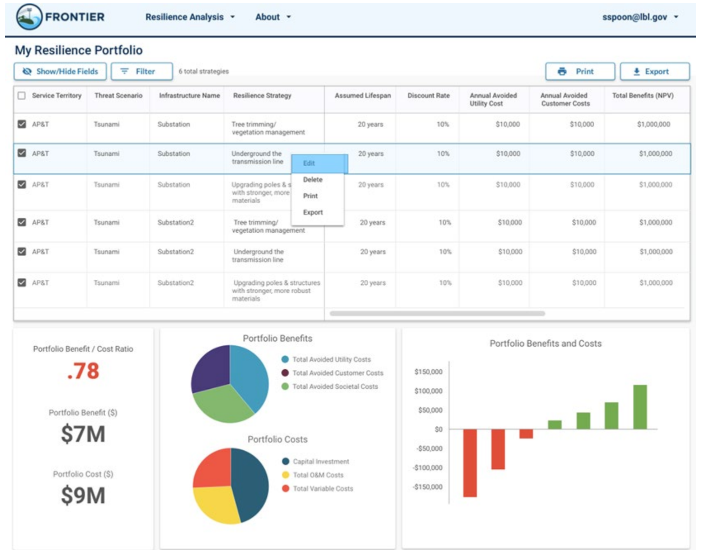
FRONTIER: Cost-Benefit Tool for Overcoming Natural Threats to Islanded Energy Resilience Tool (ANL/LBNL)

- Decision support tool to evaluate the costs and benefits of resilience alternatives

- Could be re-purposed to evaluate risk beyond "islanded communities"



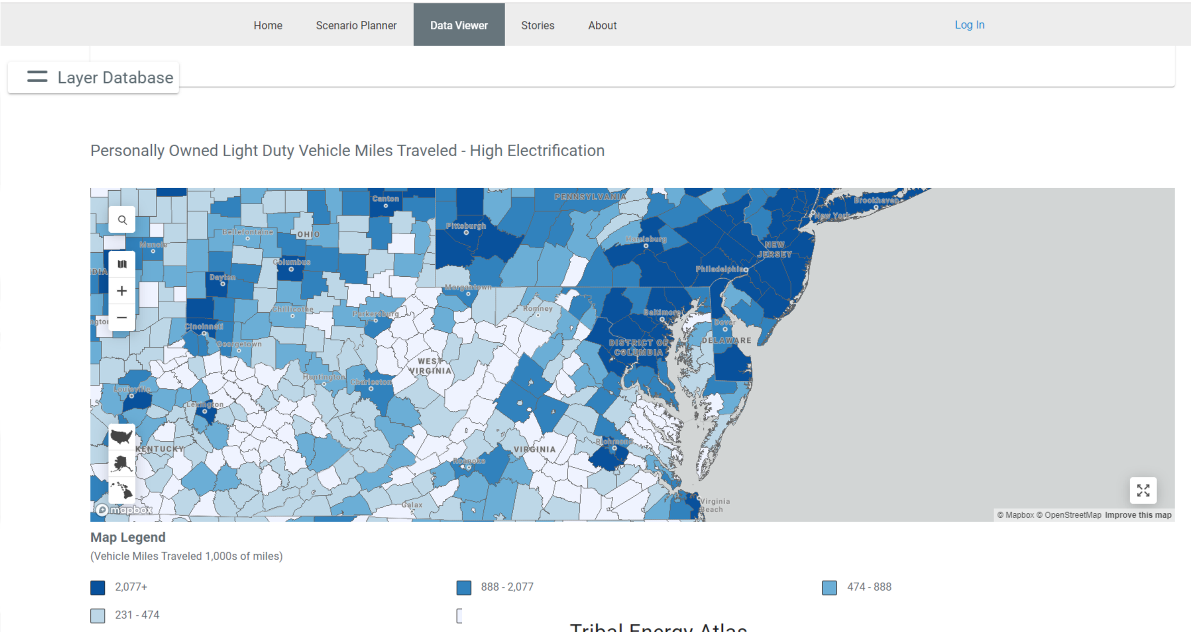


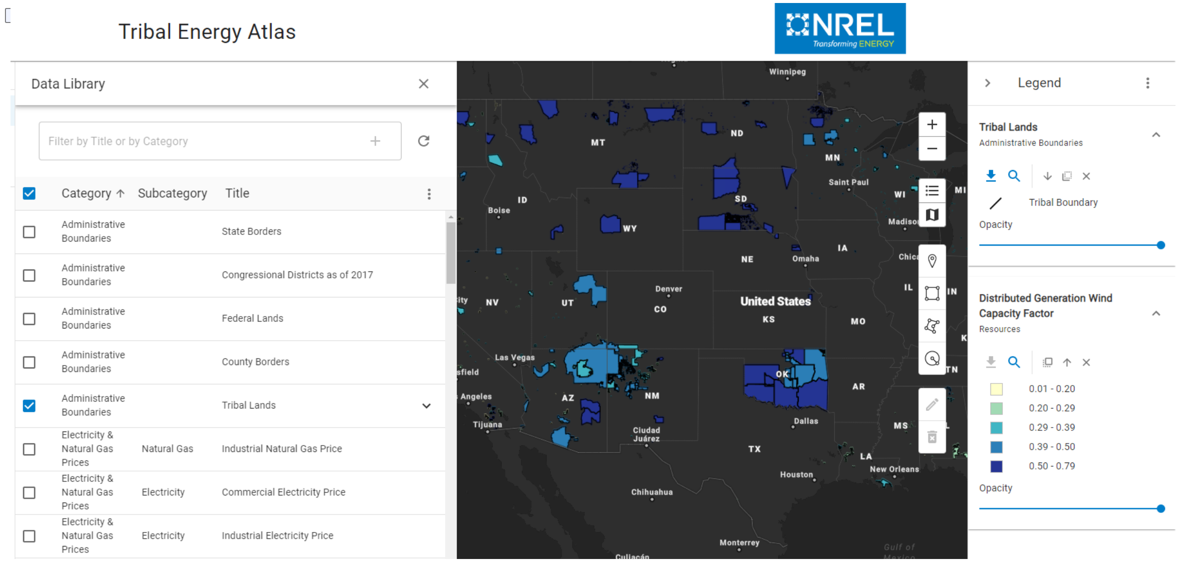


ENERGY TRANSITIONS INITIATIVE | BERKELEY LAB | Argonne | NAU NORTHERN ARIZONA UNIVERSITY | Carnegie Mellon University

SLOPE and Tribal Energy Atlas for Resilience

- The SLOPE Data Viewer is designed to deliver modeled energy data resolved at state and local jurisdictional levels. Users can explore energy data potential and projections to better understand opportunities and options in energy planning.
- The Tribal Energy Atlas allows tribal governments to explore and utilize the data generated from the NREL Study ["Techno-Economic Renewable Energy Potential on Tribal Lands"](#).
- How it will be used for S&T resilience planning:
  - Because these tools are already well-established and go-to resources for S&T energy planners, adding *resilience planning-relevant information* and workflows will augment existing planning approaches





GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy