Welcome to the

GMLC Designing Resilient Communities

WEBINAR

GRID
MODERNIZATION INITIATIVE
U.S. Department of Energy

Sandia National Labs, Converge Strategies, Synapse, University at Buffalo and Partners

April 27, 2021

GMLC 1.5.06 - Designing Resilient Communities: A consequence-based approach for grid investment

BOBBY JEFFERS, ROBERT BRODERICK
SANDIA NATIONAL LABS

04/27/2021

Sandia-hosted Webinar

Designing Resilient Communities

Goals and Objectives Recap

Overarching Goal:

- Demonstrate an actionable path toward more resilient communities through consequence-based approaches to grid planning and investment

Objectives:

- Solidify – through demonstration, outreach, verification, and gap analysis – a framework for community resilience planning focused on grid modernization and investment involving the key stakeholders in the community including electric utilities
- Set a clear, actionable path toward widespread adoption of community-focused resilience planning within the grid community

Why the SAG?

- Inform the technical and regulatory solution space for the project, and advise an actionable path forward to implement community-focused resilience planning for utilities nationwide
- Project partners will educate stakeholders emerging technologies that can provide grid resilience, and address how these technologies can provide community resilience
- Stakeholders will provide feedback on unique aspects of their regions that enable or discourage alignment of community-focused resilience planning with electric utility investment

Designing Resilient Communities

Project Team

Project and Demonstration Partners

Sandia National Laboratories

PIONEERED BY THE ROCKEFELLER FOUNDATION
100 RESILIENT CITIES

cps ENERGY

UTSA

CITY OF SAN ANTONIO

nationalgrid

caño 3.7
g-8 • enlace • fideicomiso

Synapse
Energy Economics, Inc.

University at Buffalo
The State University of New York

NM STATE

CLEMSON UNIVERSITY

CONVERGE STRATEGIES

BOSQUE ADVISORS

City + Utility Stakeholder Advisory Group

THE CITY OF NORFOLK

Dominion Energy

Hawaiian Electric

LA DWP

EVERSOURCE

conEdison

Additional Engaged Stakeholders

CITY OF NEW ORLEANS

SIEMENS

US Army Corps of Engineers

WORLD RESOURCES INSTITUTE

LVAT

BERKELEY LAB

Pacific Northwest
NATIONAL LABORATORY

Designing Resilient Communities

Approach

1. **Development of national "Resilient Community Design" framework**
    - Deep interaction with Stakeholder Advisory Group (SAG)
2. **Demonstration, verification, and validation of the framework as applied to various community/utility constructs**
    - San Antonio and CPS Energy
    - El Caño Martín Peña communities in Puerto Rico
    - Improvement in the Social Burden metric and associated approaches
3. **Investigation of alternative regulatory frameworks and utility business models**
    - Where is the line between resilience and "gold plating"?
    - How can utilities monetize consequence-focused resilience?
4. **Hardware demonstration of "resilience node" concept**
    - Focus on enabling inverter-dominated microgrids
    - Sandia providing adaptive protection and grid-forming inverter R&D

Designing Resilient Communities

Accomplishments – Task 1

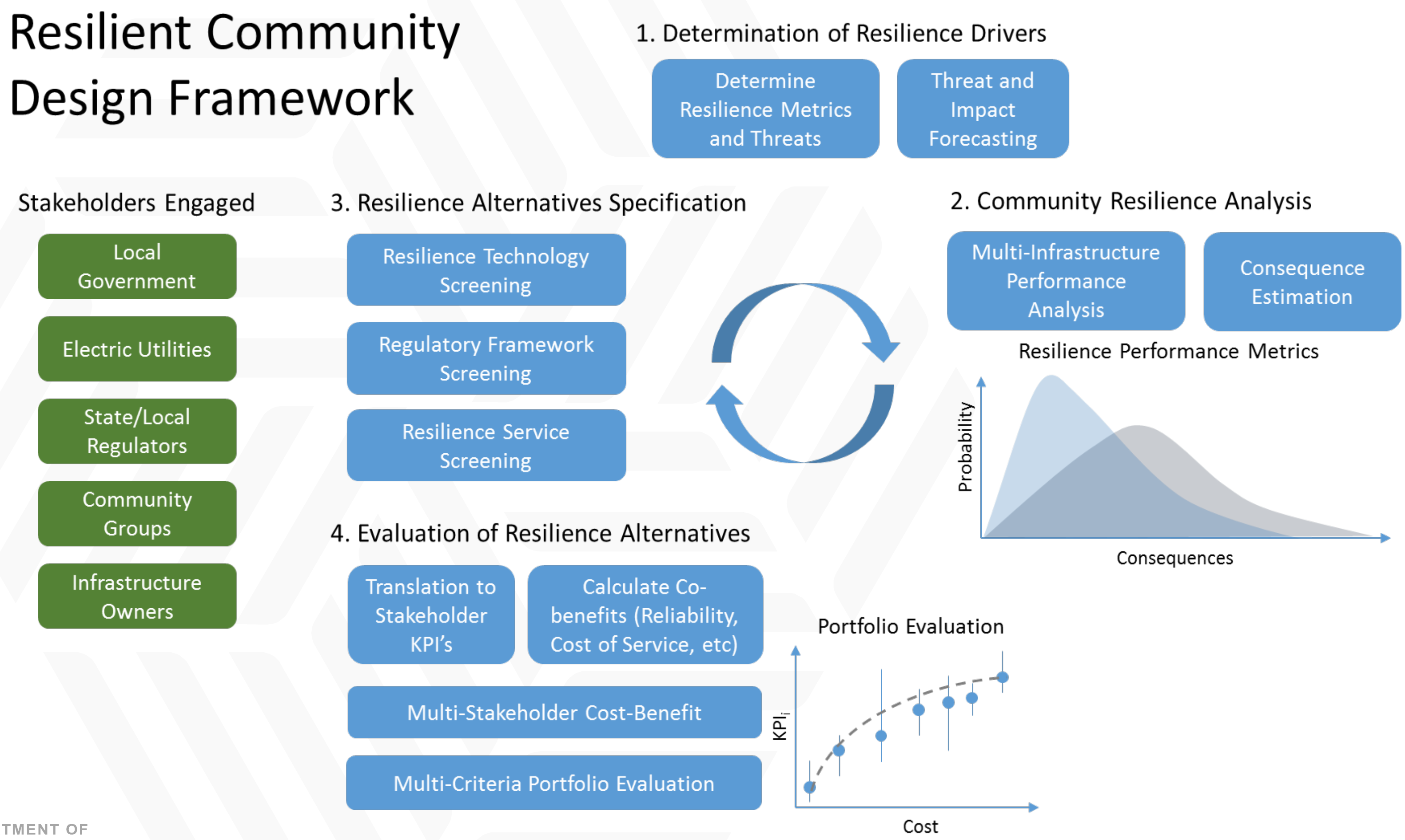
Task 1 Accomplishments:

- Two iterations of a “Resilient Community Design” Framework
  - Connects city, utility, and regulator activities focused on resilience
- Held 4 SAG meetings to date (and associated “lessons learned” reports):
  - July 2018, Washington, D.C.
  - Jan 2019, Los Angeles, CA
  - July 2019, New York, NY
  - Jan 2020, Washington, D.C.
  - Final SAG meeting scheduled – May 2021!
- Built and maintained discussion/sharing with the SAG
- Final report on the framework expected Summer 2021

Designing Resilient Communities

Accomplishments – Task 1

Jan 2018 Iteration of Resilient Community Design Framework:



Resilient Community Design Framework

1. Determination of Resilience Drivers
- Determine Resilience Metrics and Threats
- Threat and Impact Forecasting

2. Community Resilience Analysis
- Multi-Infrastructure Performance Analysis
- Consequence Estimation

Resilience Performance Metrics

Stakeholders Engaged
- Local Government
- Electric Utilities
- State/Local Regulators
- Community Groups
- Infrastructure Owners

3. Resilience Alternatives Specification
- Resilience Technology Screening
- Regulatory Framework Screening
- Resilience Service Screening

4. Evaluation of Resilience Alternatives
- Translation to Stakeholder KPI’s
- Calculate Co-benefits (Reliability, Cost of Service, etc)
- Multi-Stakeholder Cost-Benefit
- Multi-Criteria Portfolio Evaluation

Portfolio Evaluation

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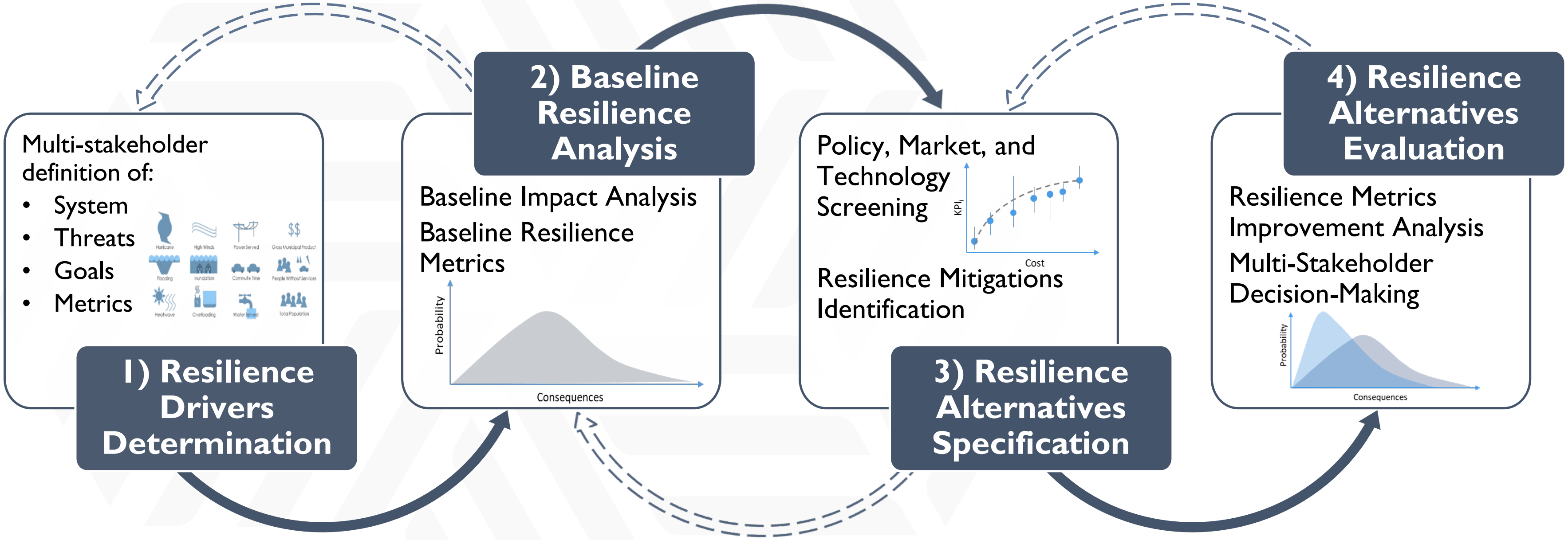
Accomplishments – Task 1

July 2019 Iteration of Resilient Community Design Framework:



1) Resilience Drivers Determination

Multi-stakeholder definition of:

- System
- Threats
- Goals
- Metrics

2) Baseline Resilience Analysis

Baseline Impact Analysis

Baseline Resilience Metrics

3) Resilience Alternatives Specification

Policy, Market, and Technology Screening

Resilience Mitigations Identification

4) Resilience Alternatives Evaluation

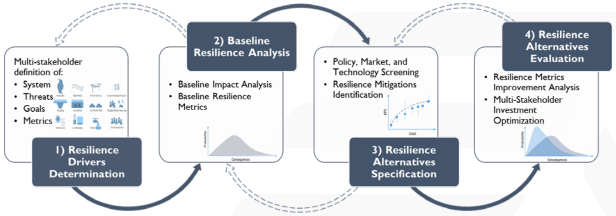
Resilience Metrics Improvement Analysis

Multi-Stakeholder Decision-Making

Designing Resilient Communities

Accomplishments – Task 1

Resilient Community Design Framework Iterative Application



Multi-stakeholder definition of:
- System
- Threats
- Goals
- Metrics

1) Resilience Drivers Determination

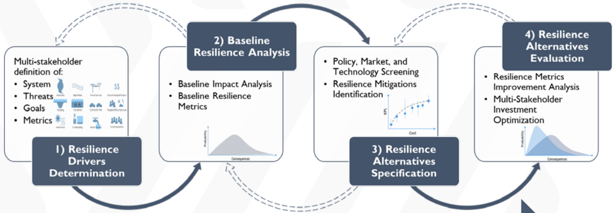
2) Baseline Resilience Analysis
- Baseline Impact Analysis
- Baseline Resilience Metrics

- Policy, Market, and Technology Screening
- Resilience Mitigations Identification

3) Resilience Alternatives Specification

4) Resilience Alternatives Evaluation
- Resilience Metrics Improvement Analysis
- Multi-Stakeholder Investment Optimization

Phase 1: Technology Investments



Multi-stakeholder definition of:
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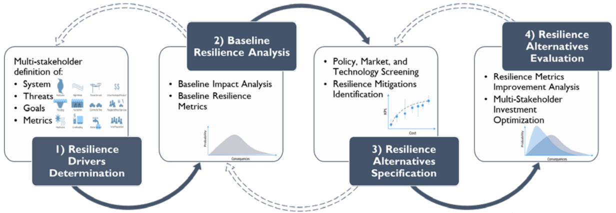
Phase 2: Regulatory Frameworks



Multi-stakeholder definition of:
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4) Resilience Alternatives Evaluation
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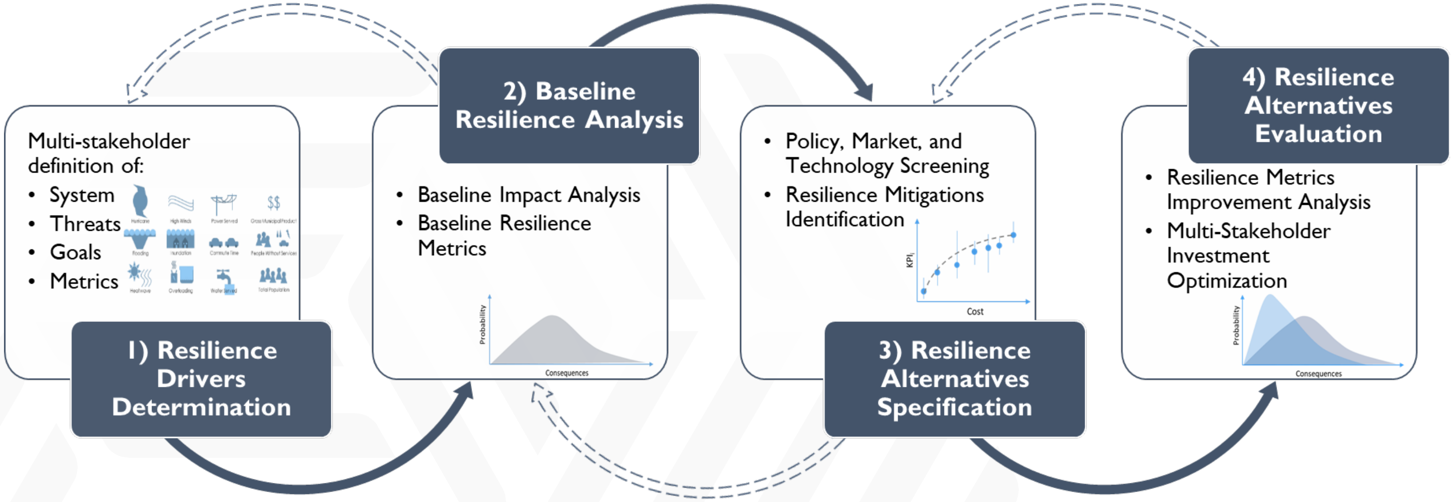
- Multi-Stakeholder Investment Optimization

Phase 3: Utility Business Models

Designing Resilient Communities

Accomplishments – Task 1



1) Resilience Drivers Determination

Multi-stakeholder definition of:
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2) Baseline Resilience Analysis

- Baseline Impact Analysis
- Baseline Resilience Metrics

3) Resilience Alternatives Specification

- Policy, Market, and Technology Screening
- Resilience Mitigations Identification

4) Resilience Alternatives Evaluation

- Resilience Metrics Improvement Analysis
- Multi-Stakeholder Investment Optimization

Cities	• Define Consequence • Define Threats	• Map system performance to consequence	• Connect initiatives • Open new opportunities	• Re-evaluate consequence given alternatives
Utilities	• Define interdependent infrastructures	• Threat to system performance	• Design for triple-bottom-line	• Evaluate system performance under alternatives
Regulators	• Set goals • Determine Metrics	• Balance technical rigor with analysis burden	• Ensure designs address goals	• Ensure final portfolios meet goals, are feasible, and equitable

Designing Resilient Communities

Accomplishments – Task 2

Task 2 Accomplishments:

- Metric Development
  - Established tighter connection between theory, data collection, and modeling for social burden
- San Antonio
  - Analysis of microgrid siting and sizing to provide community resilience in a future with high EV penetration
- Puerto Rico
  - Deep analysis of social burden and connection to local infrastructures
  - Conceptual design of “resilience nodes” for co-optimal blue/black-sky performance

Designing Resilient Communities

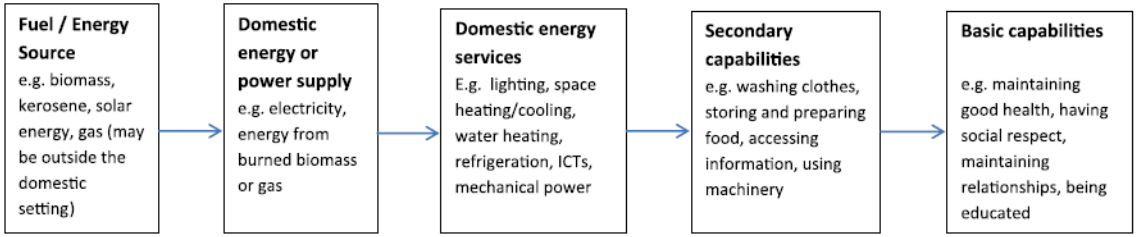
Accomplishments – Task 2

Metric Development

Designing Resilient Communities

Accomplishments – Task 2

Extending social science frameworks:



Fuel / Energy Source e.g. biomass, kerosene, solar energy, gas (may be outside the domestic setting) → **Domestic energy or power supply** e.g. electricity, energy from burned biomass or gas → **Domestic energy services** E.g. lighting, space heating/cooling, water heating, refrigeration, ICTs, mechanical power → **Secondary capabilities** e.g. washing clothes, storing and preparing food, accessing information, using machinery → **Basic capabilities** e.g. maintaining good health, having social respect, maintaining relationships, being educated

Fig. 1. Conceptualising the relationship between energy, services and outcomes.

We are utilizing this theory, but advancing/extending in two ways:

- **Chronic vs. Acute**: we are applying the capabilities framework to acute, post disaster scenarios, whereas previous literature focuses on chronic "blue sky" capabilities
- **Rigorous Quantification**: we are the first to apply a mathematical formulation to the theory

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.

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Accomplishments – Task 2

Social Burden: a *social* resilience metric

Effort

Time + money spent to achieve basic level of human needs

Ability

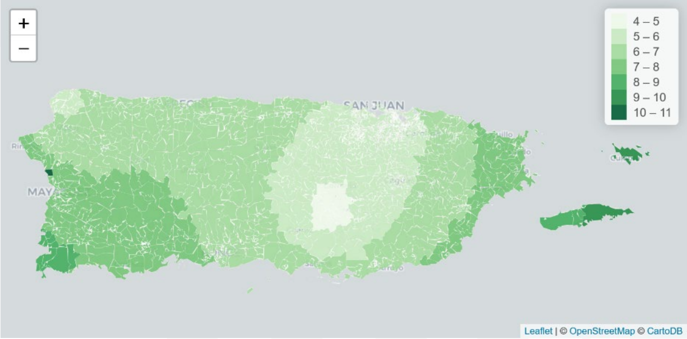
Median household income,
additional predictors

Social Burden

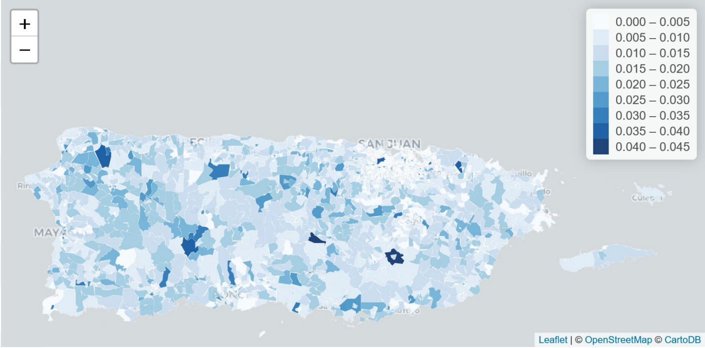
$$B_C = \sum_{inf}\sum_{pop} \frac{E_{inf,pop}}{A_{pop}}$$

Image credit: Wikimedia Commons user “Mdf”

Effort during outage: 80 (out of 159 sited) microgrids



Burden during outage: 80 (out of 159 sited) microgrids



Jeffers et al. (2018) Analysis of Microgrid Locations Benefitting Community Resilience for Puerto Rico. SAND2018-11145

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Accomplishments – Task 2

$$Social\ Burden_{S,f} = \int_{t0}^{tf} \frac{{}^{1}\!\Big/\!\sum_{inf} {}^{Svc_{inf}}\!\big/_{E_{inf}}}{Ability}$$

Units:
Hours of effort per dollar of ability

Designing Resilient Communities

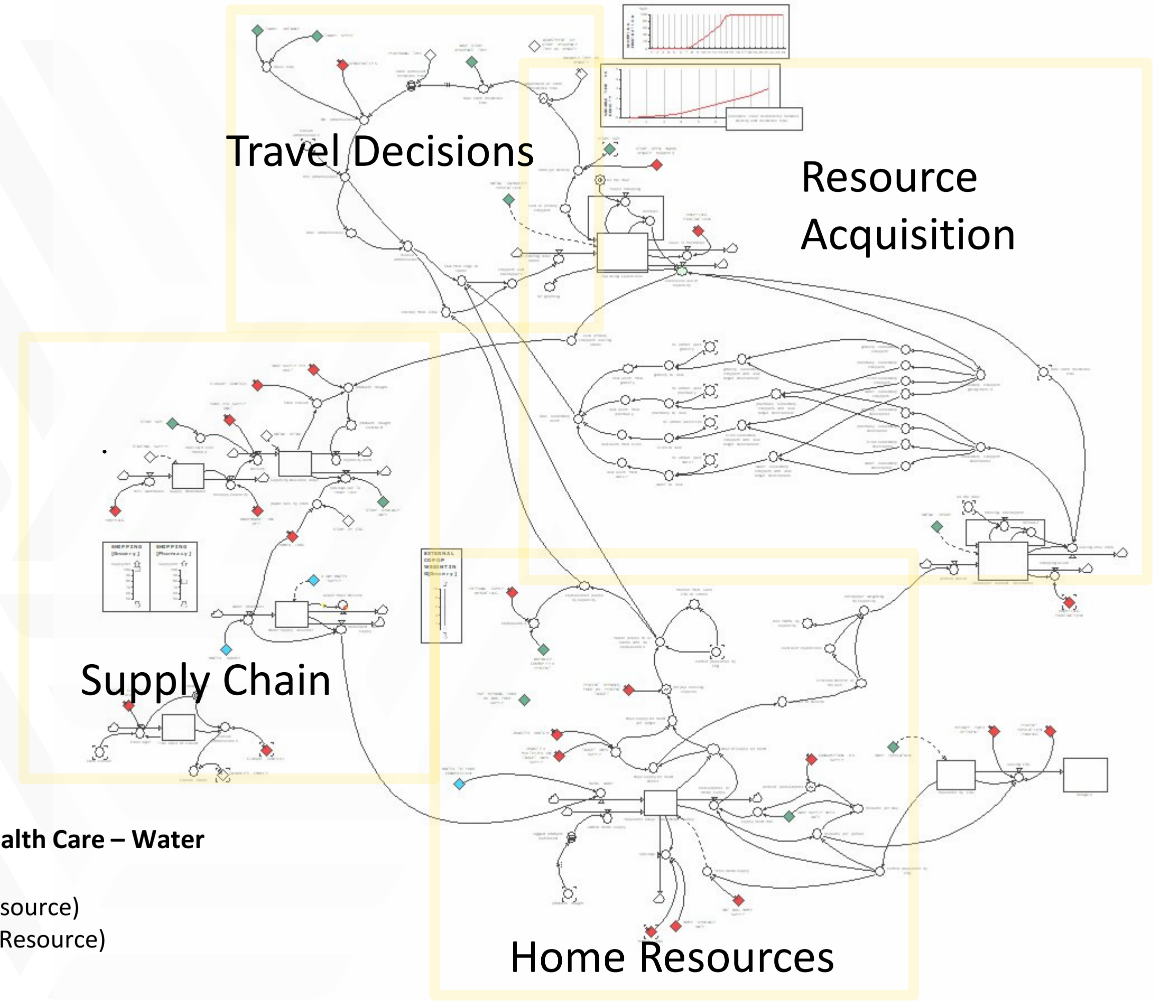
Accomplishments – Task 2

Logit Decision Model

$$\frac{e^{1-\beta_1 r_{ij}-\beta_2 t_{ij}^2}}{\sum e_{ij}}$$

Where:

r = perceived residence time
t = travel time to retail outlet
β = User controlled sensitivity
i = retail outlet
j = CBG



Travel Decisions

Resource Acquisition

Supply Chain

Home Resources

RESOURCE BURDEN

Calculated for Food – Medicine – Health Care – Water

(Residence Time x Population Using Resource)
+ (Travel Time x Population Accessing Resource)

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Accomplishments – Task 3

Task 3 – Regulatory and Business Model Design

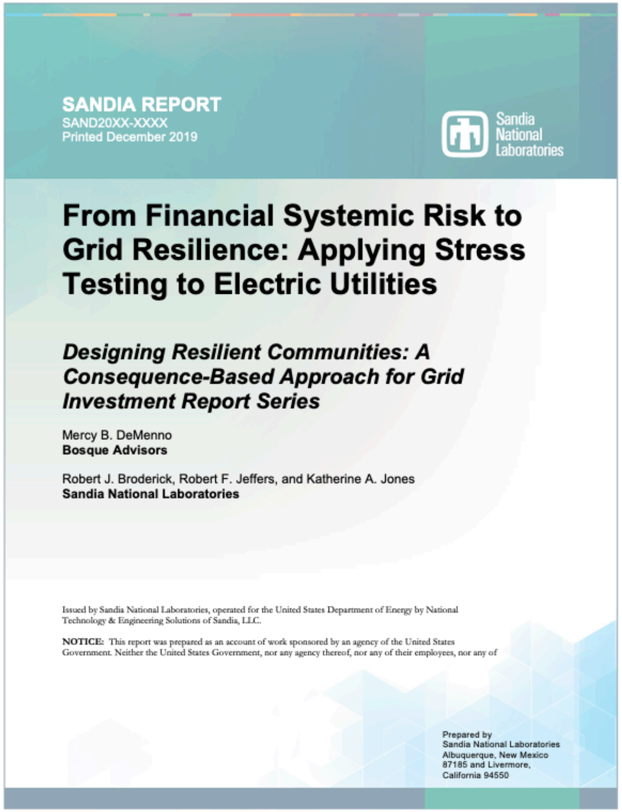
Designing Resilient Communities
Accomplishments – Task 3

	Description	Work Products
Task 1	Outreach, verification and gap analysis	Report on landscape of community and utility experiences
Task 2	Resilient communities design framework demonstration	Resilience performance metrics matrix and report
Task 3	Alternative regulatory frameworks and utility service design	Benefit cost analysis (BCA) report
		Report on microgrids
		Report on alternative regulatory frameworks

Designing Resilient Communities

Accomplishments – Task 3

Report and article on using “stress testing” to enhance grid resilience



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From Financial Systemic Risk to Grid Resilience: Applying Stress Testing to Electric Utilities

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

Mercy B. DeMenno
Bosque Advisors

Robert J. Broderick, Robert F. Jeffers, and Katherine A. Jones
Sandia National Laboratories

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- Presented at the Society for Risk Analysis annual meeting in December 2019
- Journal article under review with *Sustainable and Resilient Infrastructure*: “From Financial Systemic Risk to Grid Resilience: Embedding Stress Testing in Electric Utility Investment Strategies and Regulatory Processes” (Mercy B. DeMenno, Robert J. Broderick, and Robert F. Jeffers, 2021)

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Accomplishments – Task 4

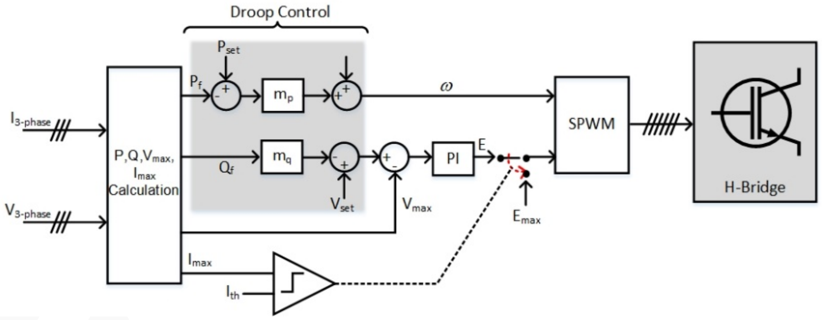
Task 4 – Overcoming Technical Challenges to Clean Resilience Nodes

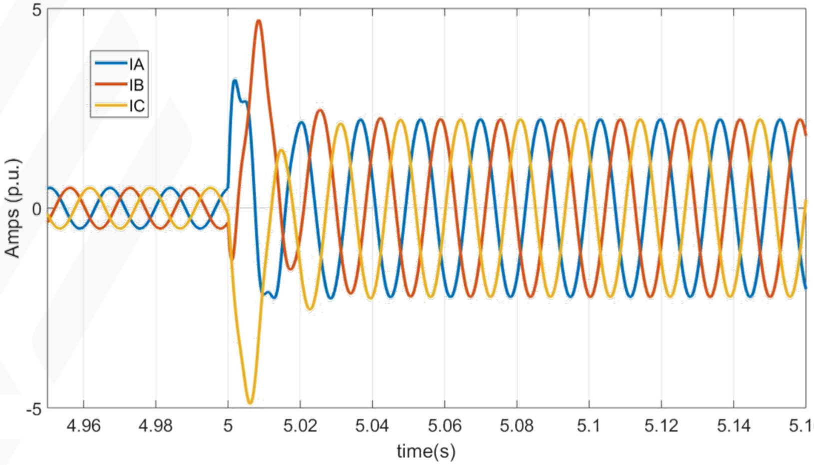
Designing Resilient Communities

Accomplishments – Task 4

Task 4 Accomplishments:

- Modeling of grid forming inverters for protection studies
  - Collaboration with New Mexico State University
- Installing, testing, and validating designs using PHIL
  - Demonstration at DETL
- Adaptive protection design
  - Collaboration with Clemson University
  - Demonstration at DETL





Publications:

- J. Hernandez-Alvidrez, A. Summers, M. J. Reno, J. Flicker, N. Pragallapati "**Simulation of Grid-Forming Inverters Dynamic Models using a Power Hardware-in-the-Loop Testbed**"," IEEE Photovoltaic Specialists Conference (PVSC), 2019.
- N. S. Gurule, J. Hernandez-Alvidrez, M. J. Reno, A. Summers, S. Gonzalez, and J. Flicker, "**Grid-forming Inverter Experimental Testing of Fault Current Contributions**," IEEE Photovoltaic Specialists Conference (PVSC), 2019.
- P. H. Gadde and S. Brahma, "**Realistic Microgrid Test Bed for Protection and Resiliency Studies**," North American Power Symposium (NAPS), 2019.

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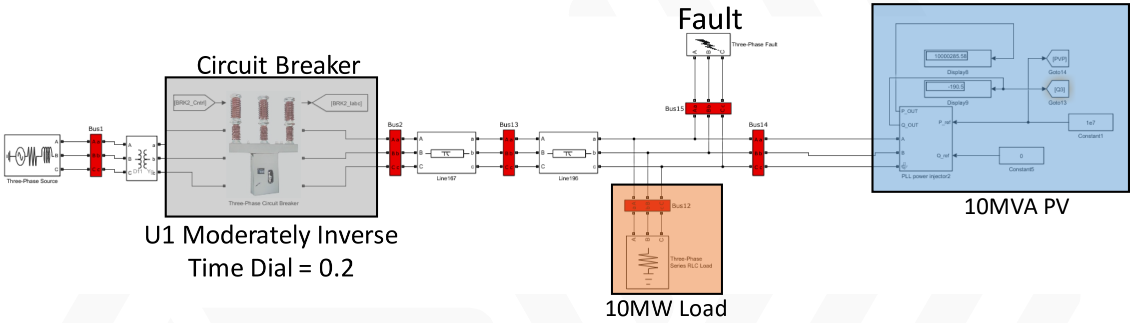
Accomplishments – Task 4

Designing adaptive protection schemes for inverter-dominated microgrids

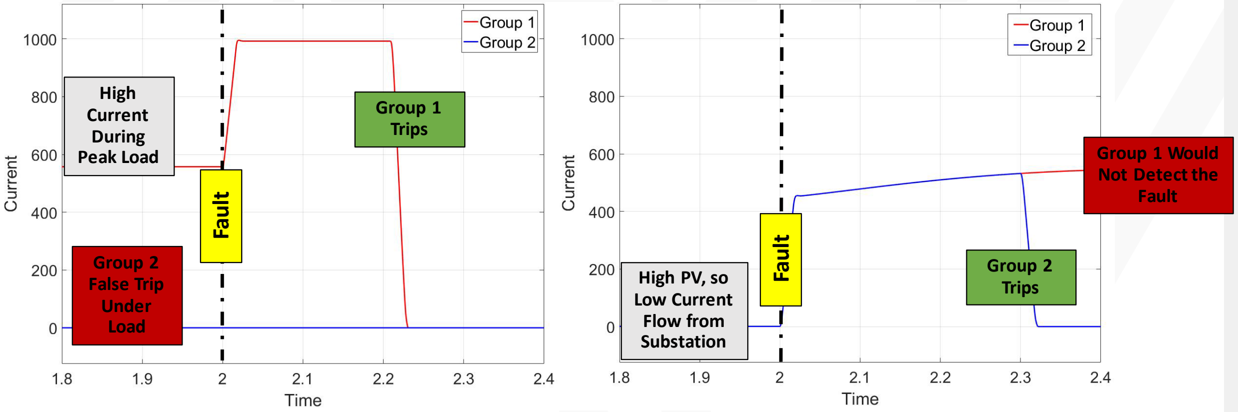

Fault

Circuit Breaker

U1 Moderately Inverse
Time Dial = 0.2

10MW Load

10MVA PV


High Current During Peak Load

Fault

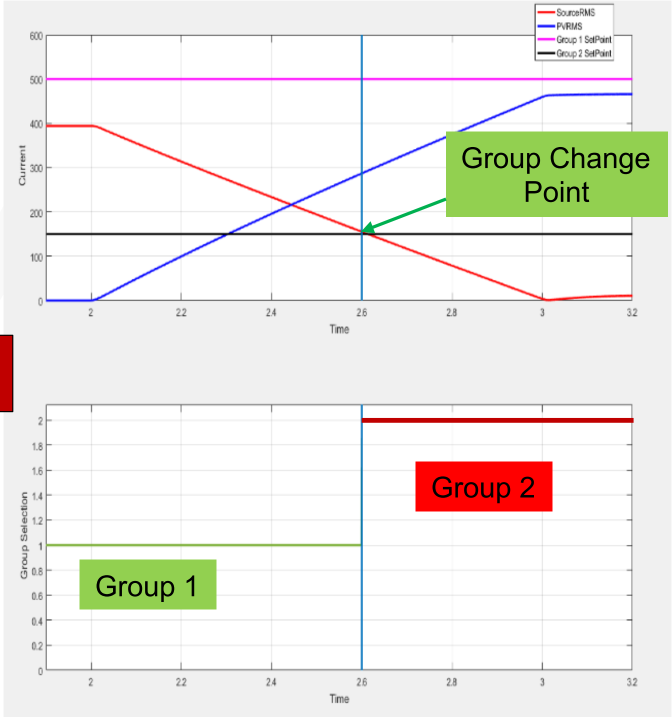
Group 1 Trips

Group 2 False Trip Under Load

High PV, so Low Current Flow from Substation

Group 2 Trips

Group 1 Would Not Detect the Fault


Group Change Point

Group 2

Group 1

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Accomplishments – Task 4

Task 4 – Hardware Demo of Adaptive Protection on a Resilience Node

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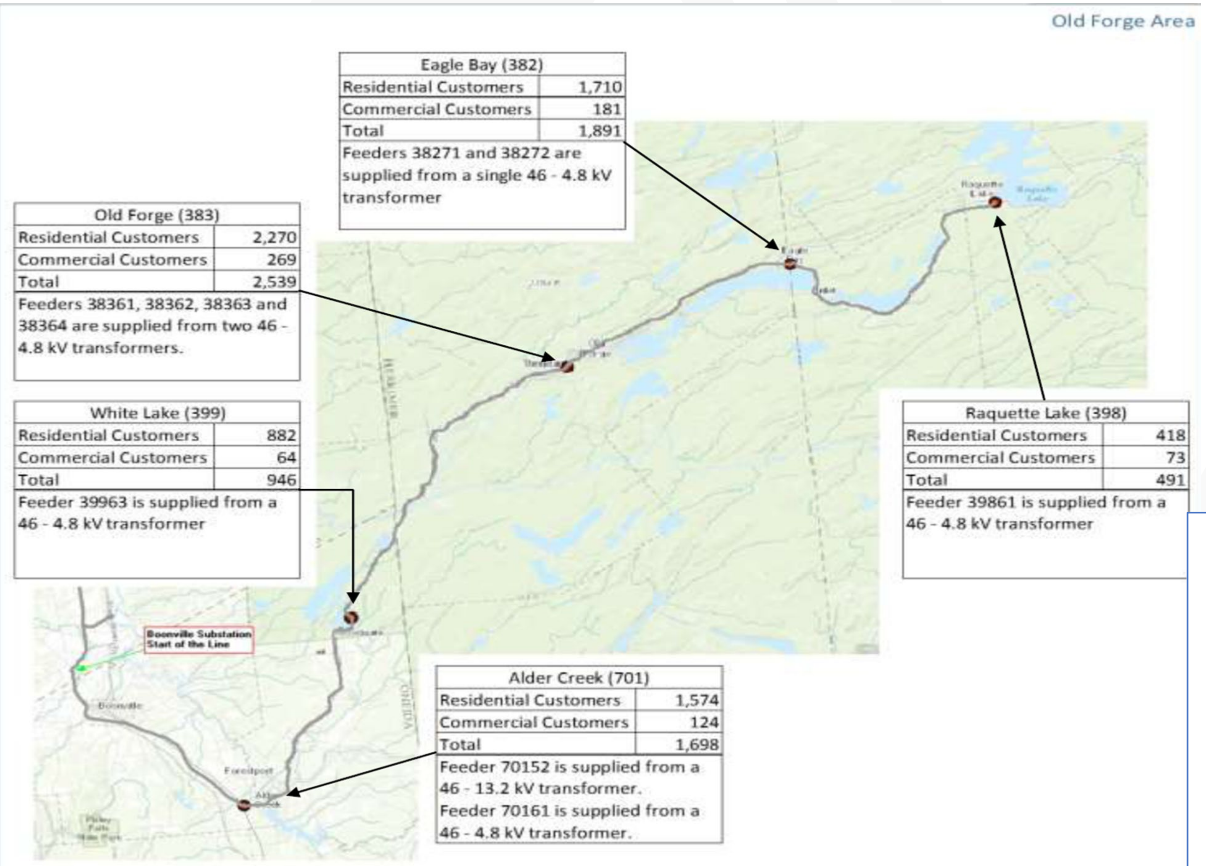
Accomplishments – Task 4

Old Forge Example: (reliability -> resilience)



Eagle Bay (382)	
Residential Customers	1,710
Commercial Customers	181
Total	1,891

Feeders 38271 and 38272 are supplied from a single 46 - 4.8 kV transformer

Old Forge (383)	
Residential Customers	2,270
Commercial Customers	269
Total	2,539

Feeders 38361, 38362, 38363 and 38364 are supplied from two 46 - 4.8 kV transformers.

White Lake (399)	
Residential Customers	882
Commercial Customers	64
Total	946

Feeder 39963 is supplied from a 46 - 4.8 kV transformer

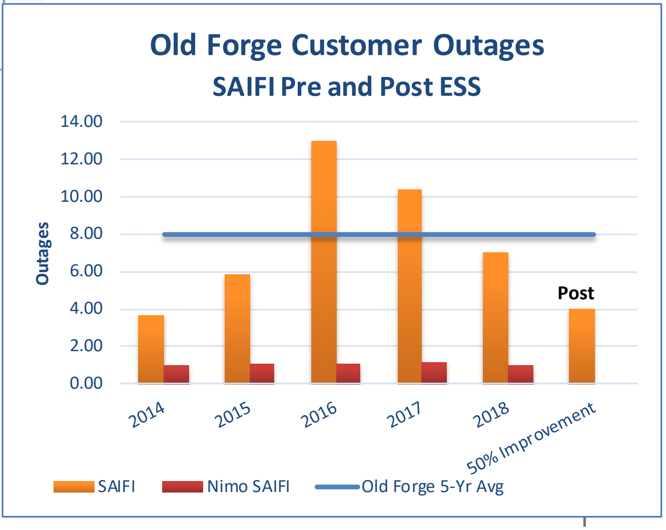
Raquette Lake (398)	
Residential Customers	418
Commercial Customers	73
Total	491

Feeder 39861 is supplied from a 46 - 4.8 kV transformer

Alder Creek (701)	
Residential Customers	1,574
Commercial Customers	124
Total	1,698

Feeder 70152 is supplied from a 46 - 13.2 kV transformer.
Feeder 70161 is supplied from a 46 - 4.8 kV transformer.

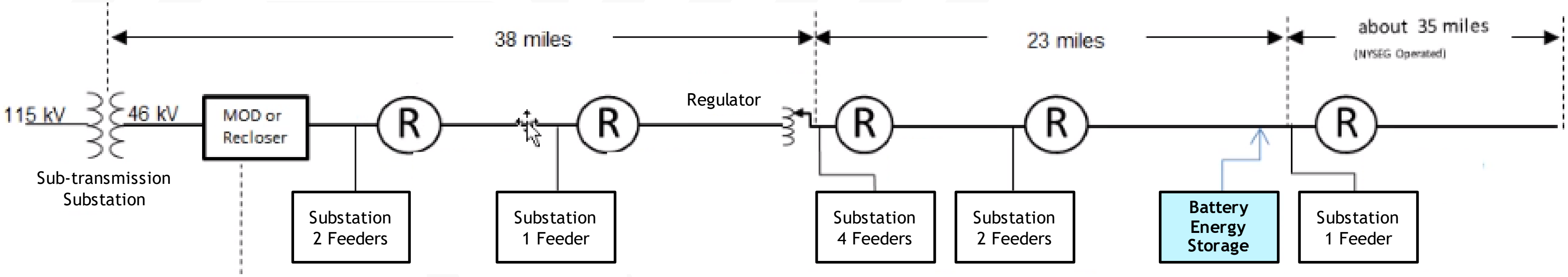
- $4 Million cost impact to customers per year over past 5 years for outages
- Old Forge customers were interrupted an average of 7.97 times per year for an average of 20.11 hours per year over the last five years – 10 times more than the NiMo average interruption duration of 2.52 hours



Designing Resilient Communities

Accomplishments – Task 4

- Working with National Grid for demonstration on a >70 mile microgrid
- Includes 5 substations in the microgrid, all connected with a 46 kV sub-transmission line
- Microgrid is powered by a large battery energy storage system (BESS)



38 miles

23 miles

about 35 miles

(NYSEG Operated)

115 kV

46 kV

Sub-transmission Substation

MOD or Recloser

Regulator

Substation 2 Feeders

Substation 1 Feeder

Substation 4 Feeders

Substation 2 Feeders

Battery Energy Storage

Substation 1 Feeder

Designing Resilient Communities

Discussion and Coordination

THANK YOU!

Bobby Jeffers (rfjeffe@sandia.gov)
Robert Broderick (rbroder@sandia.gov)

Designing Resilient Communities

Accomplishments – Task 3

Synapse
Energy Economics, Inc.

Topic 3 - Synapse Reports

Designing Resilient Communities

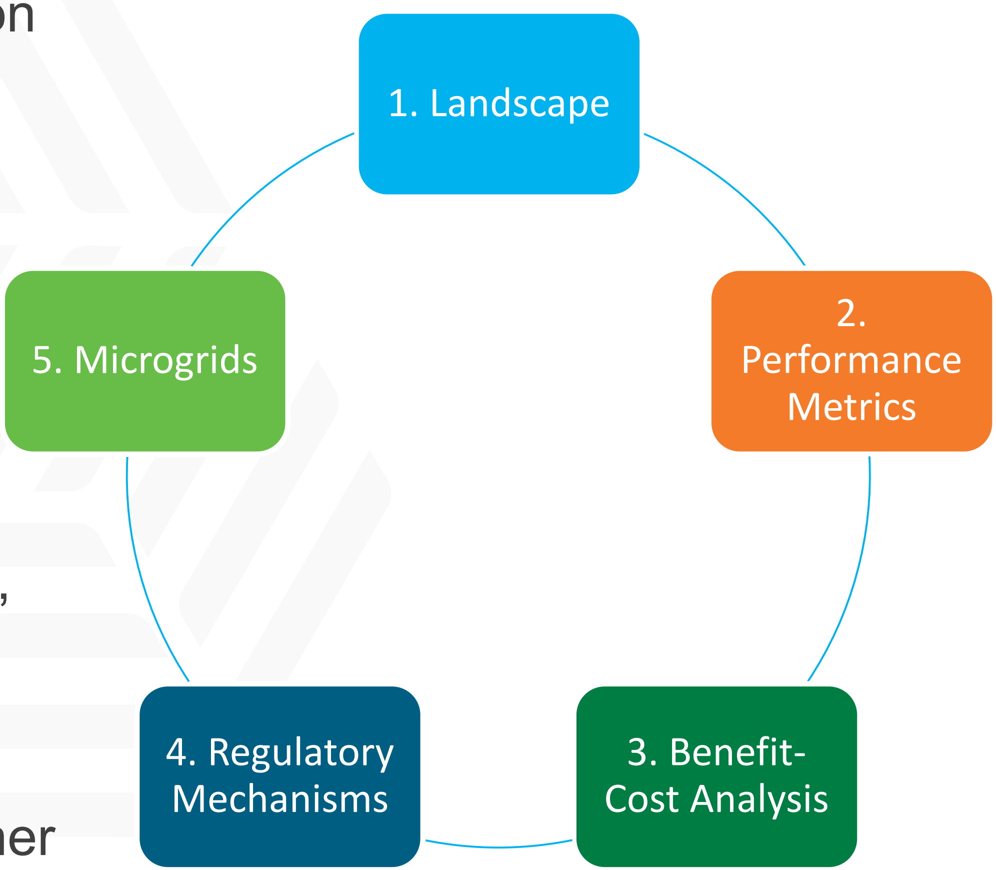
High-Level Project Summary

Five interrelated reports focused on important topic areas

Brief overview of each report

- Summary of purpose and key content
- Examples of key content

All reports discuss how regulators, utilities, communities, and other stakeholders can work together to advance investments that can achieve grid resilience, among other goals.



1. Landscape

2. Performance Metrics

3. Benefit-Cost Analysis

4. Regulatory Mechanisms

5. Microgrids

Landscape – Purpose and Key Content

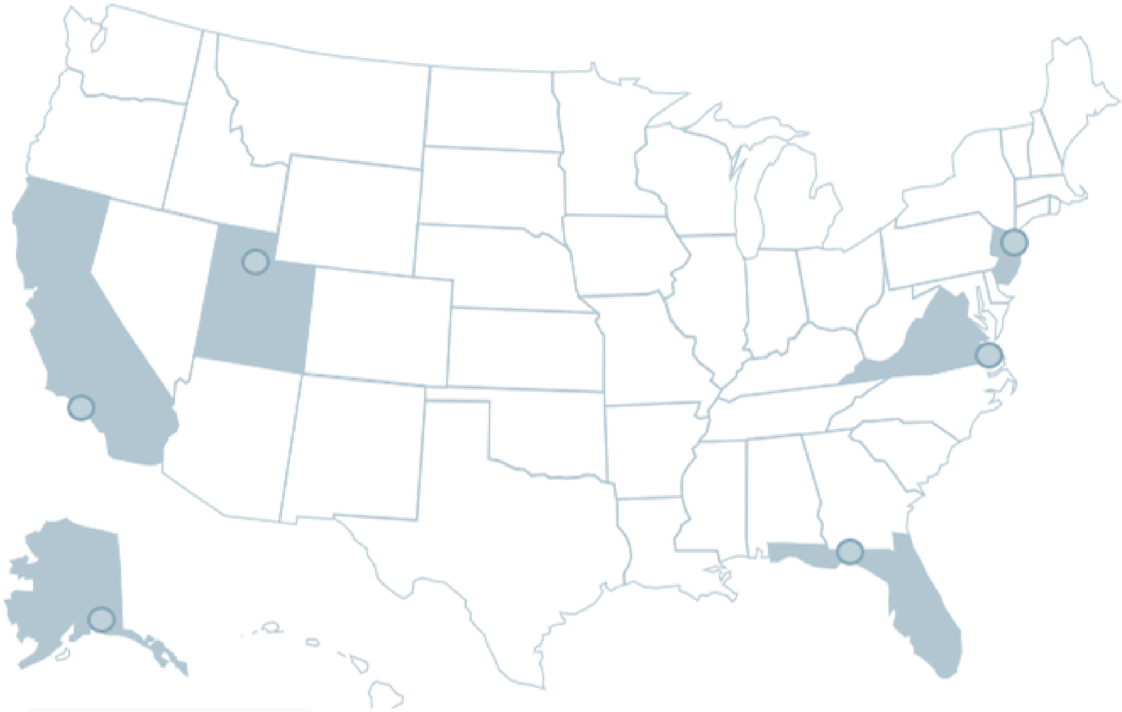
Purpose: To understand the challenges and opportunities experienced by communities and electric utilities in aligning their energy-related resilience efforts.

Key Content:

- a description of the approach to interviews of six community and utility pairs;
- case studies from the community and utility pair interviews;
- findings and opportunities identified from these interviews; and
- a summary of the conclusions.

Landscape – Case Studies

1. Hoboken, NJ/PSE&G
2. Norfolk, VA/Dominion
3. Salt Lake City, UT/Rocky Mountain Power
4. Tallahassee, FL/City of Tallahassee
5. Los Angeles, CA/LADWP
6. Cordova, AK/Cordova Electric Cooperative



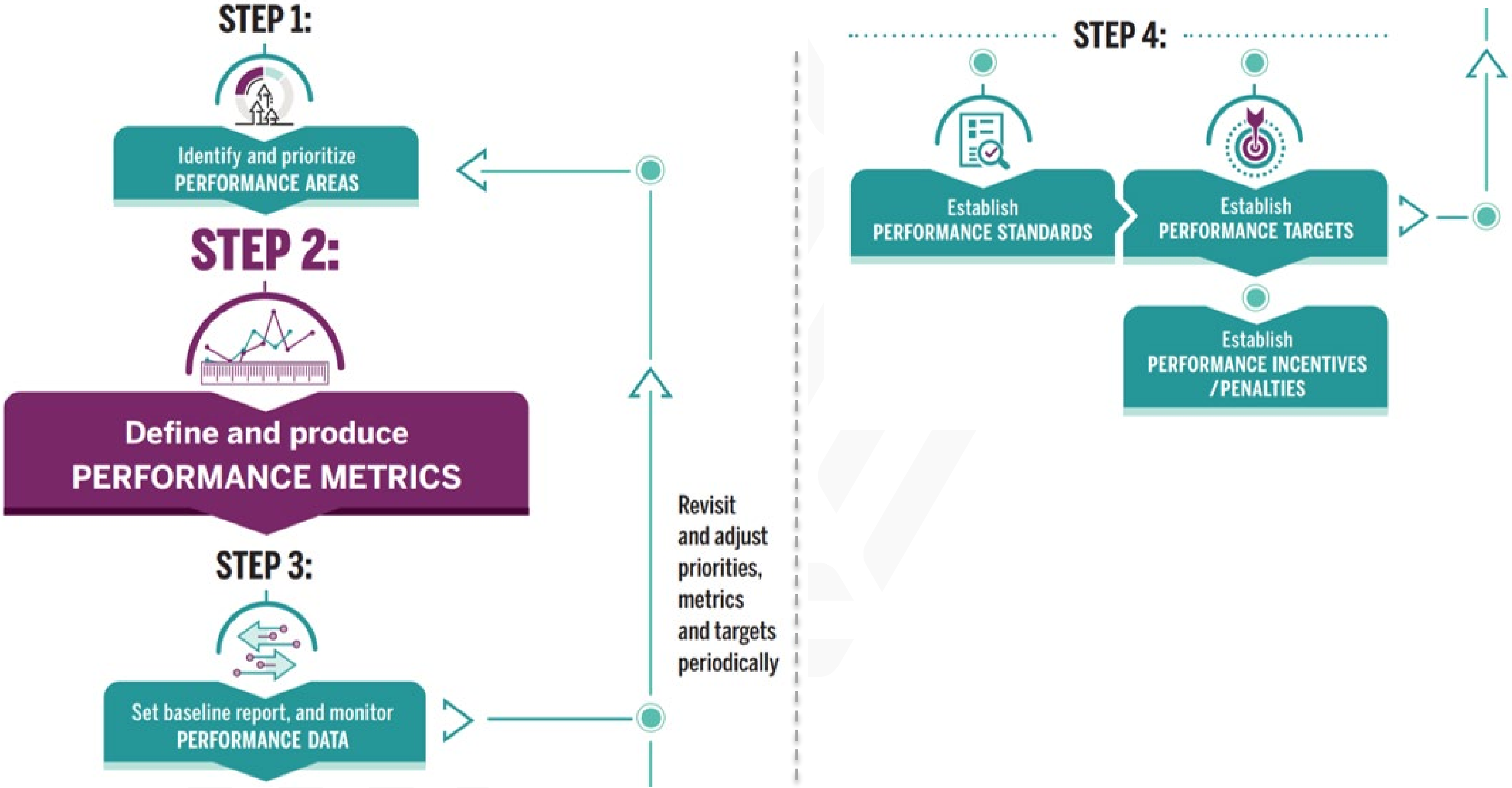
Performance Metrics – Purpose and Key Content

Purpose: To guide jurisdictions to take the important step of defining and establishing performance metrics for resilience

Key Content:

- A roadmap of the performance mechanism development process;
- A list and discussion of seven principles for developing well-designed performance metrics;
- A menu of performance metrics for grid resilience and associated discussion; and
- An Excel based tool visualizing these performance metrics in the form of reporting templates.

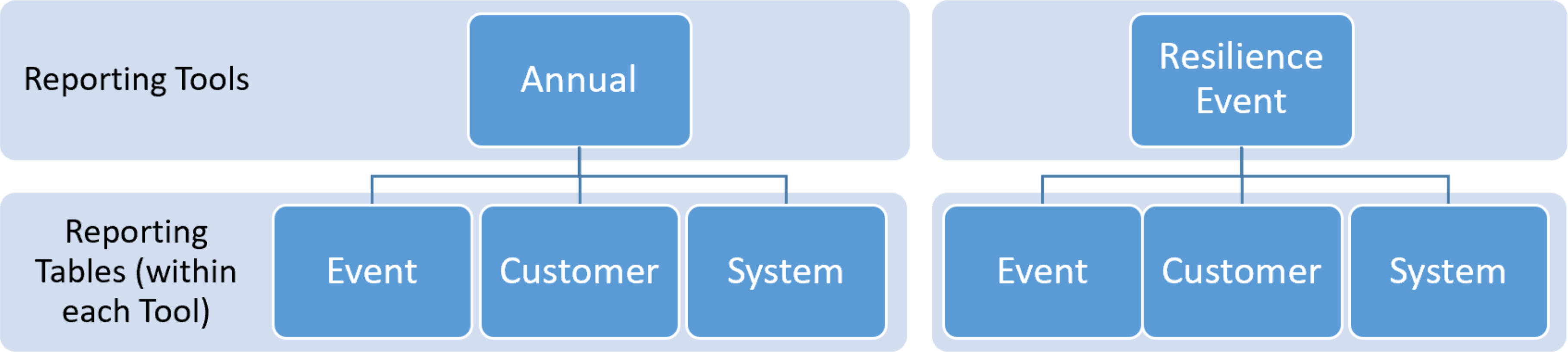
Performance Metrics – Development Process



Performance Metrics – Principles

1. Tied to goals
2. Clearly defined
3. Comparable
4. Calculated using readily available data
5. Objective and free from exogenous influences
6. Easily interpreted
7. Verifiable

Performance Metrics – Excel-Based Tool



Customer tiers:

- Critical community services
- Critical individual services
- Non-critical

System tiers:

- High consequence geographies
- Medium consequence geographies
- Low consequence geographies

Benefit-Cost Analysis – Purpose and Key Content

Purpose: Provides the first application of the framework developed in the *2020 National Standard Practice Manual for Benefit-Cost Analysis of Distributed Energy Resources* to grid resilience investments

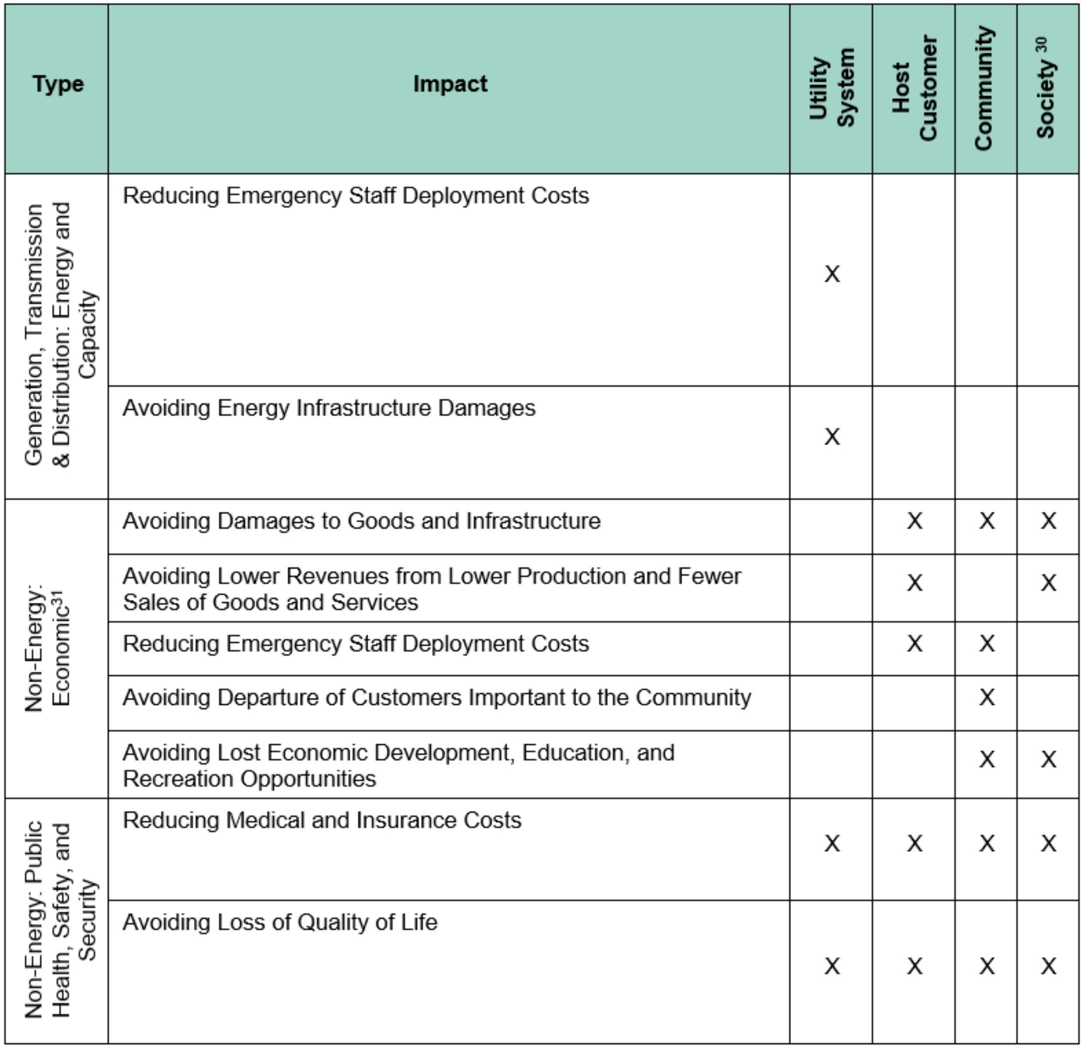
Key Content:

- Naming and definitions of costs and benefits relevant to grid resilience investments;
- A catalogue of grid resilience investments;
- An illustrative example of how to include these resilience impacts in a BCA;
- Other considerations that are relevant to BCA for grid resilience investments, including the probability of occurrence, temporal and locational variability, and interactive effects;
- A summary of metrics/data needed to quantify the costs and benefits of resilience; and
- Guidance on next steps for implementation of BCA for resilience investments.

Benefit-Cost Analysis – Naming and Definitions of the Costs and Benefits

Four perspectives:

- Utility system
- Host customer
- Community
- Society

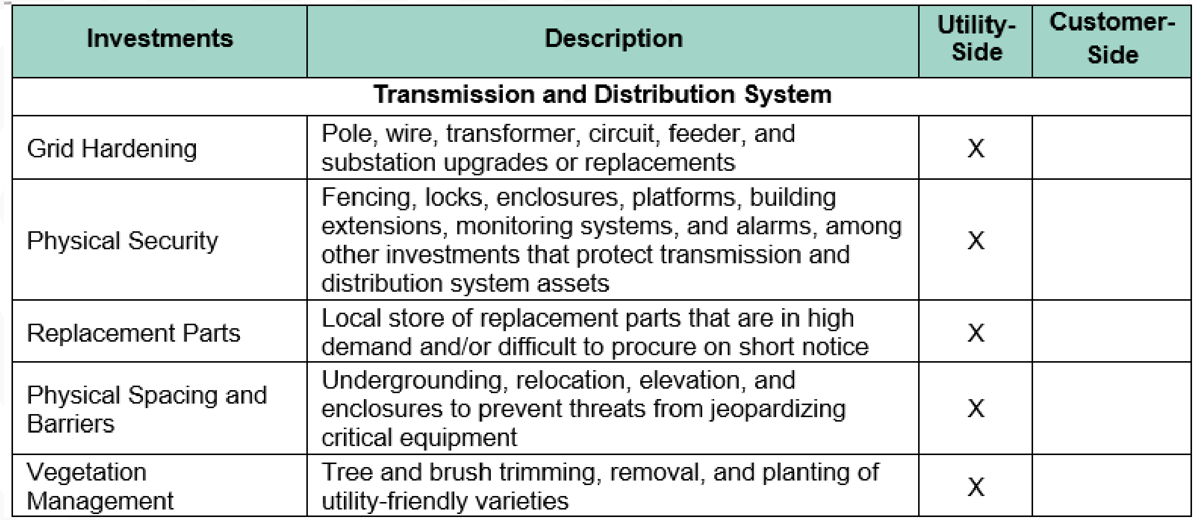


Type	Impact	Utility System	Host Customer	Community	Society[30]
Generation, Transmission & Distribution: Energy and Capacity	Reducing Emergency Staff Deployment Costs	X			
	Avoiding Energy Infrastructure Damages	X			
Non-Energy: Economic[31]	Avoiding Damages to Goods and Infrastructure		X	X	X
	Avoiding 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

Benefit-Cost Analysis – Catalogue of Grid Resilience Investments

Four categories:

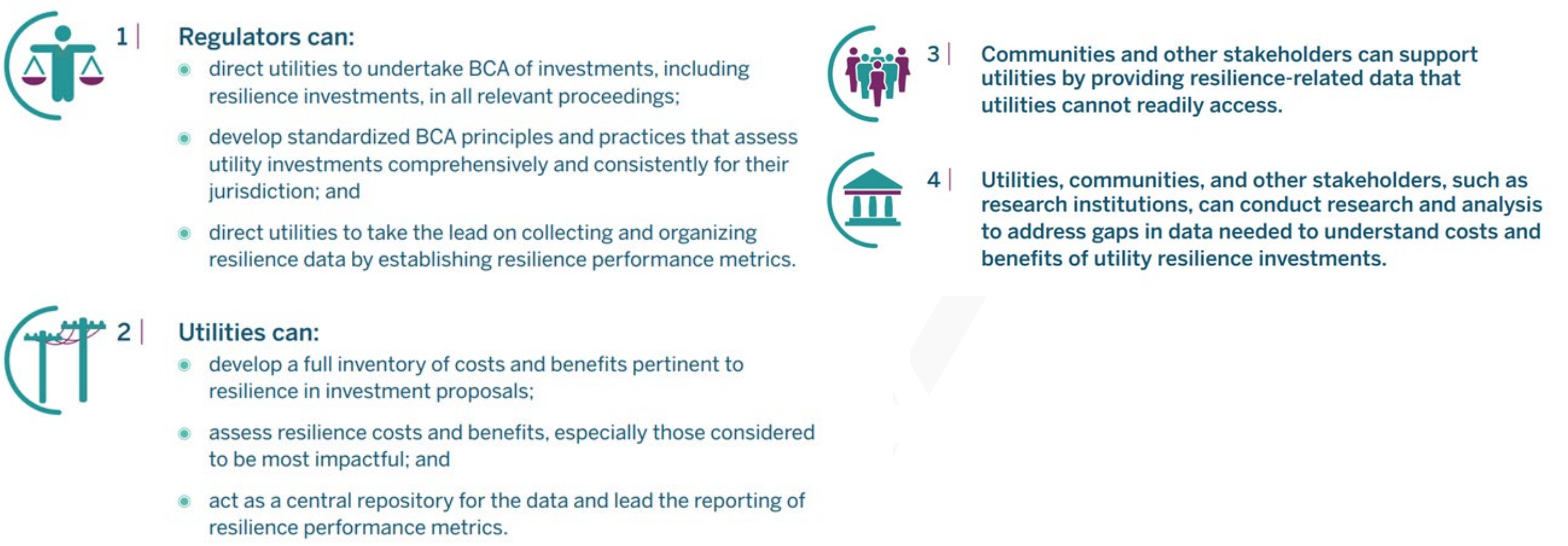
- Transmission and distribution system
- Generation
- Automation and controls
- Cross cutting



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	

Benefit-Cost Analysis – Guidance on Next Steps

REGULATORS, UTILITIES, COMMUNITIES, AND OTHER STAKEHOLDERS CAN WORK TOGETHER TO ADVANCE BCA PRACTICES FOR UTILITY RESILIENCE INVESTMENTS. EACH ENTITY HAS A ROLE TO PLAY



1 | **Regulators can:**

- direct utilities to undertake BCA of investments, including resilience investments, in all relevant proceedings;
- develop standardized BCA principles and practices that assess utility investments comprehensively and consistently for their jurisdiction; and
- direct utilities to take the lead on collecting and organizing resilience data by establishing resilience performance metrics.

2 | **Utilities can:**

- develop a full inventory of costs and benefits pertinent to resilience in investment proposals;
- assess resilience costs and benefits, especially those considered to be most impactful; and
- act as a central repository for the data and lead the reporting of resilience performance metrics.

3 | Communities and other stakeholders can support utilities by providing resilience-related data that utilities cannot readily access.

4 | Utilities, communities, and other stakeholders, such as research institutions, can conduct research and analysis to address gaps in data needed to understand costs and benefits of utility resilience investments.

Regulatory Mechanisms – Purpose and Key Content

Purpose: Identify regulatory mechanisms that electric utility regulators can use to align utility, customer, and third-party investments with regulatory, ratepayer, community, and other important stakeholder resilience interests and priorities.

Key Content:

- A characterization of regulatory objectives relevant to resilience;
- Identification of several regulatory mechanisms that are used or can be adapted to improve the resilience of the electric system;
- Case studies of each regulatory mechanism;
- A summary of findings by and across the case studies; and
- Suggestions of how these regulatory mechanisms might be improved and applied to resilience moving forward.

Regulatory Mechanisms – Regulatory Objectives Relevant to Resilience

1. Continuity of electric service
    - Provides uninterrupted electricity of sufficient quality and quantity.
2. Ensuring reasonable rates
    - Requires consideration of costs and benefits.
    - Considers all information reasonably known or knowable at the time that decisions are made.
    - Ensures the utility remains solvent without reaping excess profits.
3. Customer equity
    - Distributes costs among customers consistent with cost causation.
    - Recovers the cost of a capital investment over its useful life.
4. In the public interest
    - Promotes the well-being of the public more generally, and utility customers more specifically.

Regulatory Mechanisms – Regulatory Mechanisms and Case Studies

1. Performance-based regulation in Hawaii,
2. Integrated planning in Puerto Rico,
3. Tariffs and programs to leverage private investment and alternative lines of business for utilities in Vermont,
4. Enhanced cost recovery in New Jersey, and
5. Securitization in California.

Microgrids – Purpose and Key Content

Purpose: To identify the features of microgrids that are more likely to receive electric utility ratepayer funding.

Key Content:

- Identification of key regulatory objectives;
- Application of these objectives to define the term resilient public purpose microgrid;
- A characterization of five project types;
- A case study for each project type; and
- Findings and recommendations by and across project types.

Microgrids – Project Types and Case Studies

Microgrids providing critical community services

1. Emergency response - City of Portland, OR Fire Station
2. Emergency shelters - Rutland, VT High School and Red Cross Emergency Shelter
3. Defense infrastructure - Schofield Barracks Military Base in Oahu, HI
4. Essential public infrastructure - Inland Empire Utilities Agency Wastewater Facilities in San Bernardino County, CA

Microgrids providing critical individual services

5. Housing for less mobile populations - Marcus Garvey Apartments in Brooklyn, NY

Designing Resilient Communities

High-Level Project Summary

All reports available at: https://www.synapse-energy.com/project/improving-electric-utility-and-community-grid-resilience-planning

1. The Resilience Planning Landscape for Communities and Electric Utilities (available now)
2. Performance Metrics to Evaluate Utility Resilience Investments (available later this week)
3. Application of a Standard Approach to Benefit-Cost Analysis for Electric Grid Resilience Investments (available next week)
4. Regulatory Mechanisms to Align Utility Investments with Resilience (available in May)
5. Public Purpose Microgrids for Electric Grid Resilience: Considerations for Electric Utility Regulatory Approval (available in May)

Thank you!

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Estimating the social burden of attaining critical services following major power disruptions

SARA PETERSON[1], SUSAN SPIERRE CLARK[1], BOBBY JEFFERS[2], MIKE SHELLY[1]
[1]UNIVERSITY AT BUFFALO
[2]SANDIA NATIONAL LABORATORIES

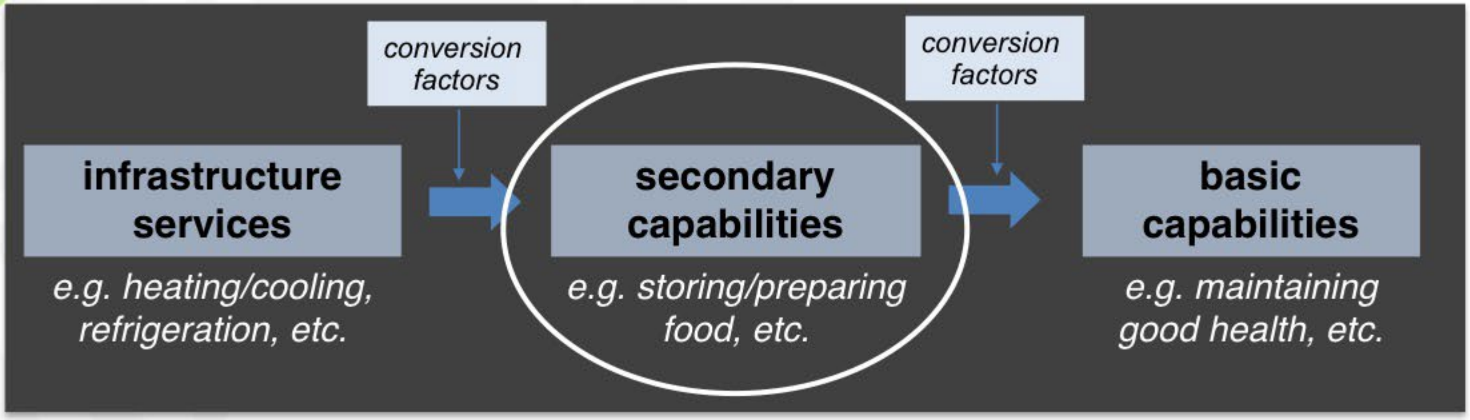
April 27, 2021

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology and Engineering Solutions of Sandia LLC, a wholly owned subsidiary of Honeywell International Inc. for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Objective: *Develop and validate a resilience metric quantifying the social burden of energy loss across different types of communities*

***Capabilities Approach** for measuring human wellbeing*

(capabilities + choice = wellbeing)



infrastructure services

e.g. heating/cooling, refrigeration, etc.

secondary capabilities

e.g. storing/preparing food, etc.

basic capabilities

e.g. maintaining good health, etc.

Caño Martín Peña Research

1 Develop Initial Questionnaire & Focus Group Materials

2 Conduct Focus Groups

3 Refine Online Questionnaire

4 Implement Questionnaire in Community

- *Emphasis on distance and money as burden proxies*

- *Conducted focus groups & pilot tests with G8 Community Leaders*
- *Key component:*
  - *Demographics*
  - *Experience*
  - *Social capital*

- *Created online survey to continue research during COVID*
- *Revised questions & format*

- *Multiple outreach approaches*
- *Ongoing research*

G8

PROYECTO
ENLACE
DEL CAÑO
MARTÍN PEÑA

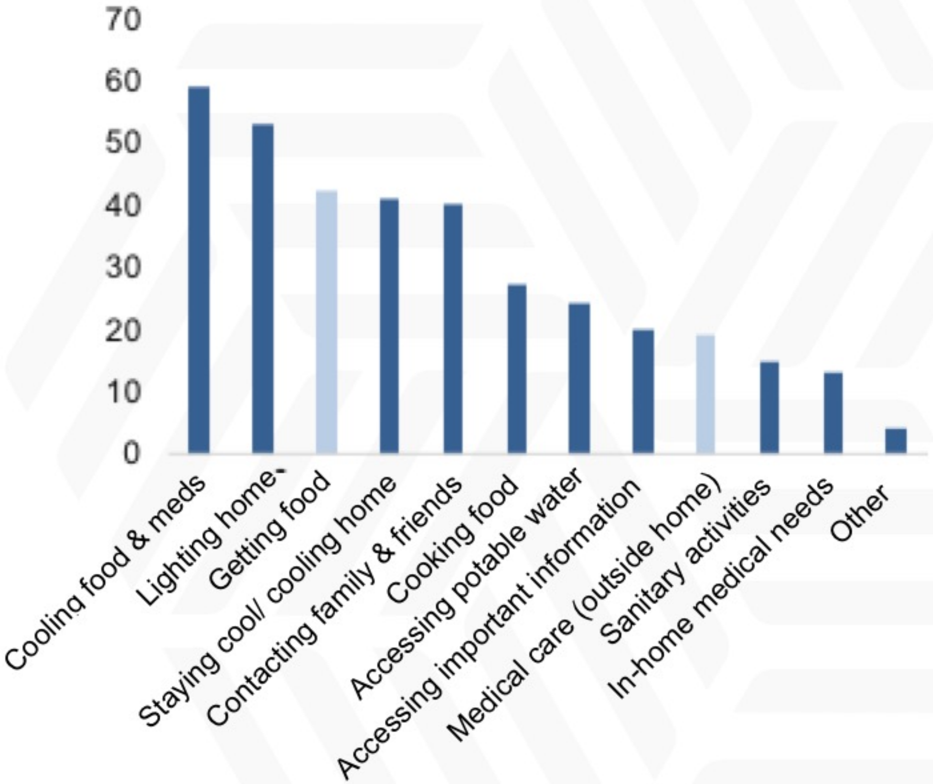
FIDEICOMISO
DE LA TIERRA
CAÑO MARTÍN PEÑA

Preliminary Results

102 El Caño Households

Outages Disrupted Basic Household Activities

All Disrupted Activities



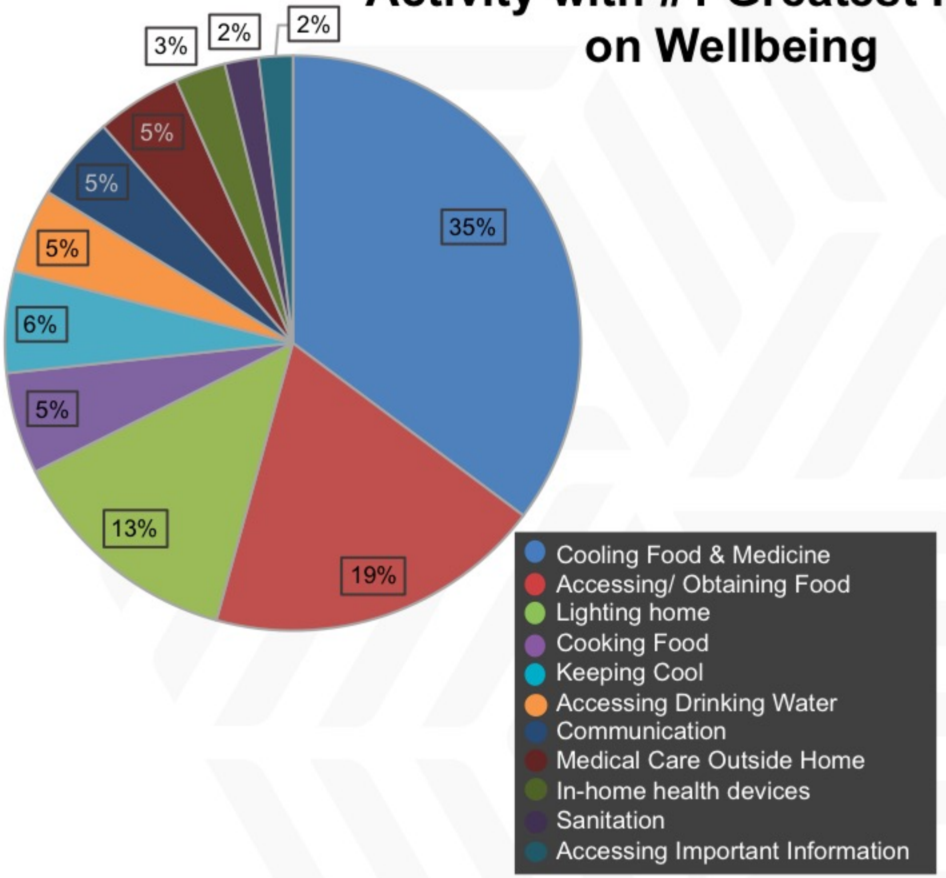
● Top Disrupted Activities inside Home

- keeping food and medicine cold
- lighting home
- staying cool or cooling their home
- cooking food

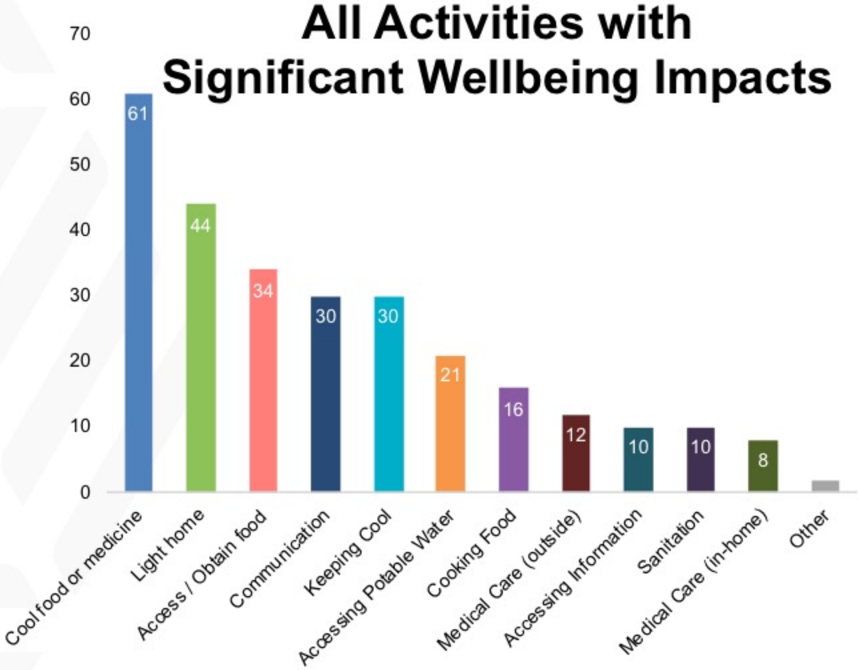
● Top Disrupted Activities outside Home

- accessing or obtaining food
- accessing medical care outside their home

Greatest Wellbeing Impact: Loss of Refrigeration



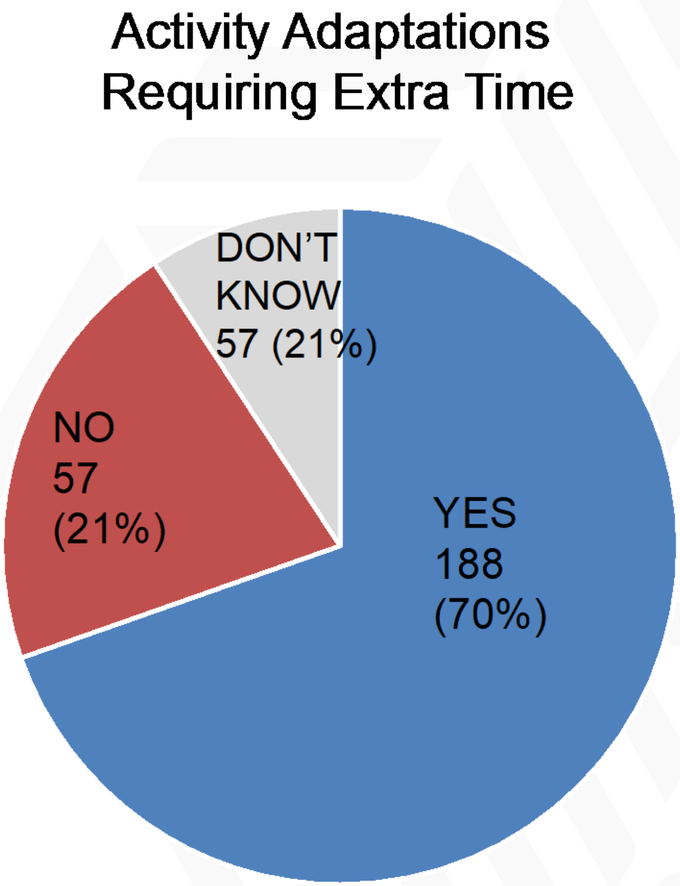
Activity with #1 Greatest Impact on Wellbeing

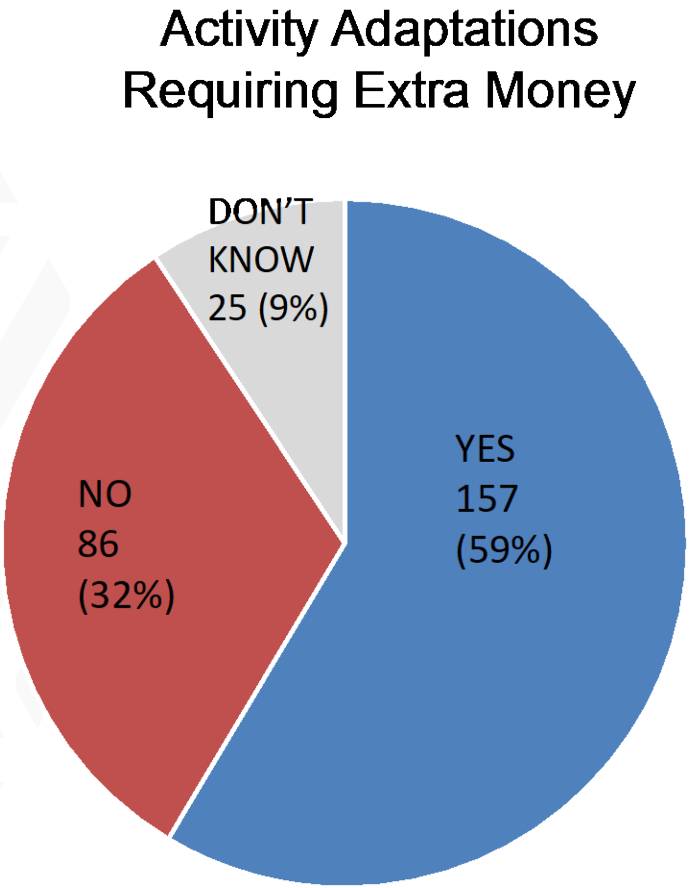


All Activities with Significant Wellbeing Impacts

Infrastructure disruptions cost households both time and money

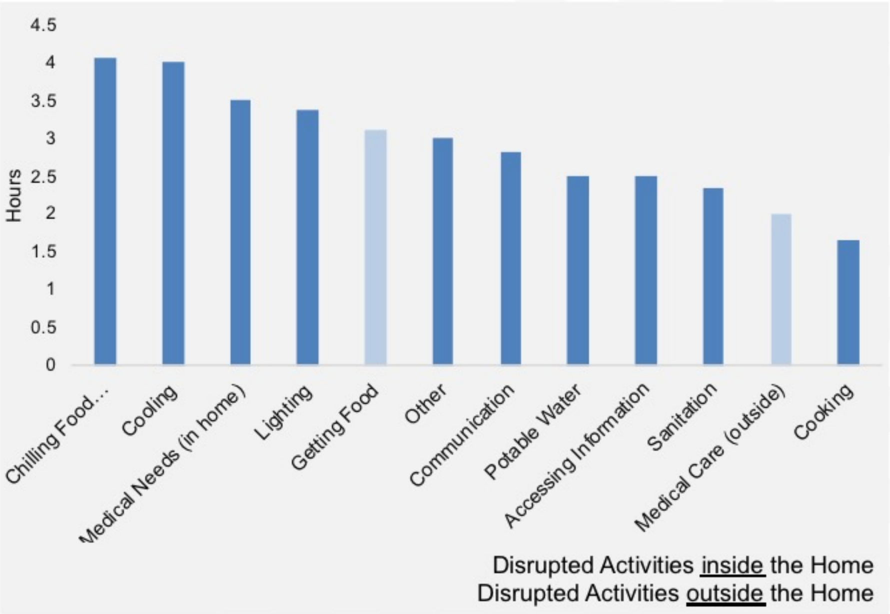
GRID MODERNIZATION INITIATIVE
U.S. Department of Energy



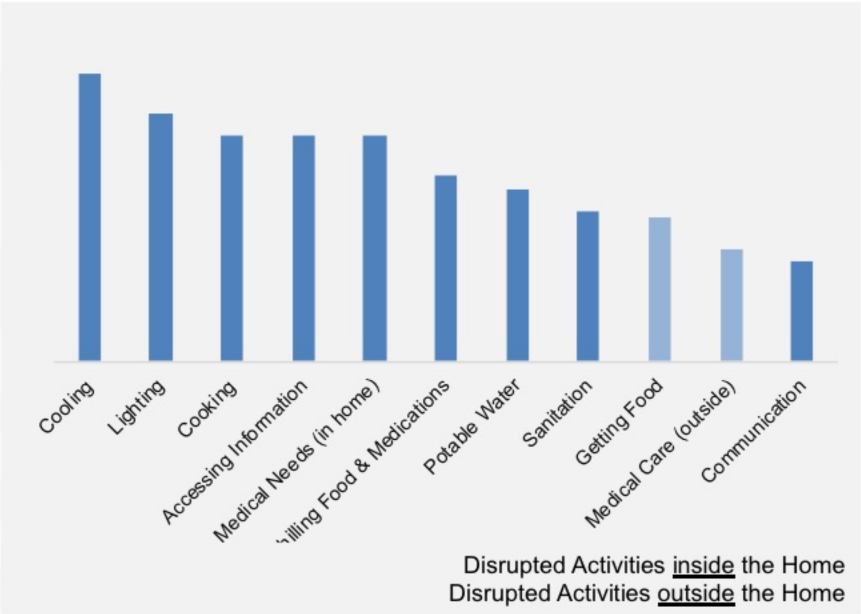


Reported Costs of Adaptations

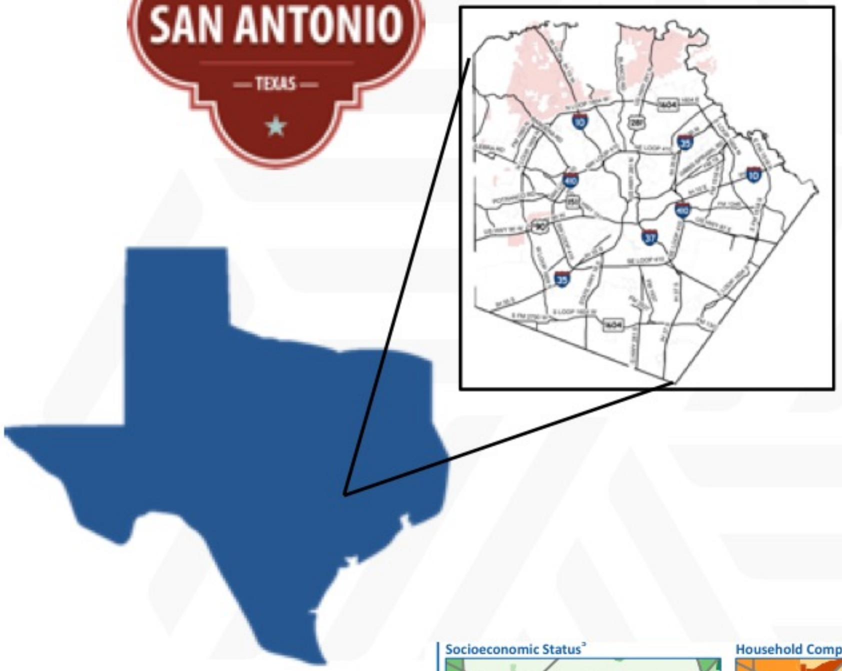
Average Additional Hours Per Week



Average Additional Costs Per Week



Next Case Study: Studying Burden in San Antonio, TX

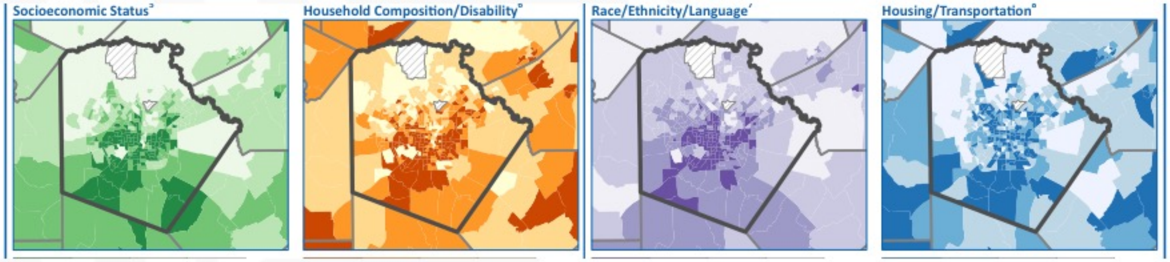


Questionnaire Deployment in San Antonio

- Representative, city-wide study administered by QUALTRICS (n=500 households)
- Refining Puerto Rico implement; working with City of San Antonio to address context-specific considerations

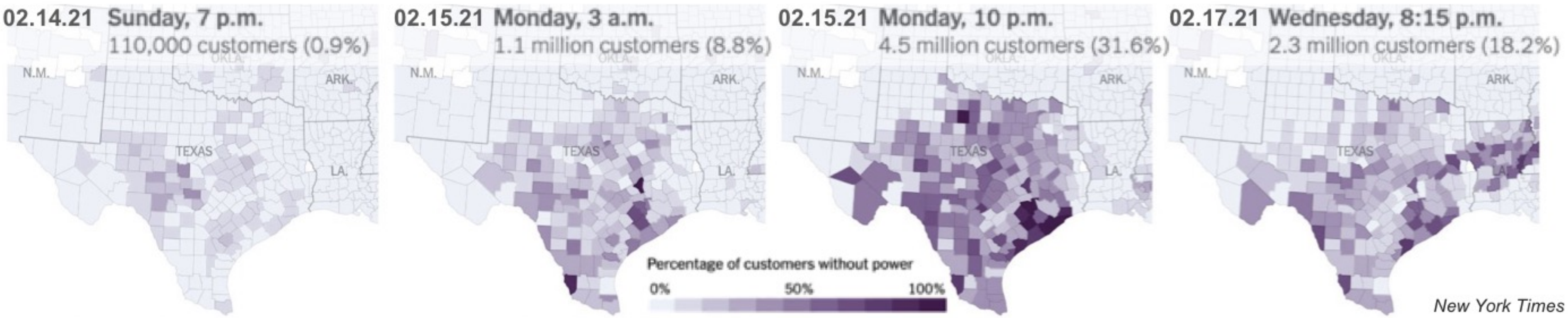
Future Research Opportunities & Directions

- Collaboration with Office of Equity & community organizations for more extensive research in vulnerable communities



RAPID Research: Texas' Social Burden During Winter Storm Uri

WINTER STORM URI OUTAGES: 02.14.21- 02.17.21



New York Times

NSF RAPID FUNDING: for data collection with 'severe urgency,' including natural disasters & unexpected events

Operationalizing the Capabilities Approach in the Context of Disaster Resilience: Measuring the Social Burden of Infrastructure Disruptions in Texas

- 1000 household study across ERCOT service area
- Household-level study of interrupted activities and mitigation costs
- Key areas of exploration:
  - *Role of outage duration on burden*
  - *Variation of burden across sociodemographic groups*
  - *Role of prior experience in mitigating burden*

Designing Resilient Communities

Discussion and Coordination

THANK YOU!

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Behind-the-meter Resilience Planning: Locating and Designing Resilience Nodes for Maximum Community Benefit

Bobby Jeffers, Amanda Wachtel, Jimmy Quiroz, Holly Eagleston, Daniel Villa, Will Peplinski
SANDIA NATIONAL LABS

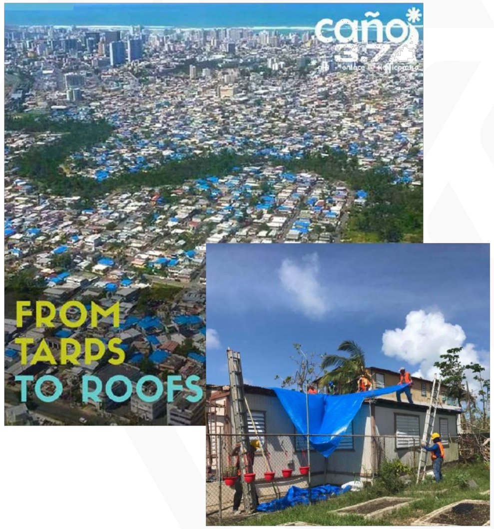
Efrain O'Neill-Carrillo
UNIVERSITY OF PUERTO RICO AT MAYAGUEZ

El Caño Martin Peña, PR

Case Study

El Caño Martín Peña:

- 3.75 mile tidal channel
- Connects Bahia de San Juan to Laguna San Jose (critical connection for both systems)
- Citizens without sanitary sewer (~30%)
- Citizens with blue tarp roofs
- Strong local governance
- Comprehensive dev. Plan
- EPA Urban Waters Partner



El Caño Martin Peña, PR

Case Study

Creating representative microgrid “conceptual designs.”

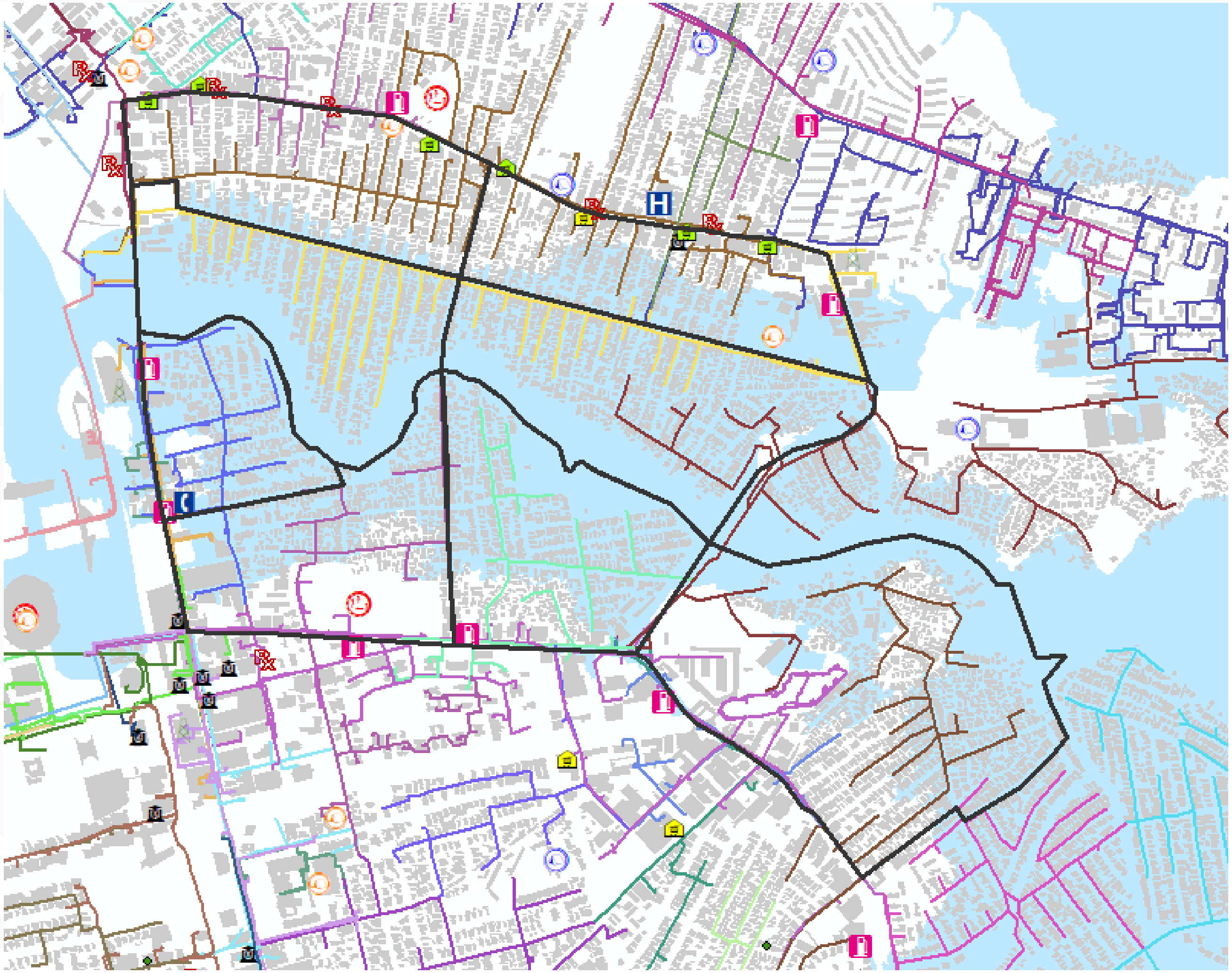
1. What types of microgrids best support community resilience for a given investment?
    a. Critical infrastructure microgrids (grocery, drainage pumps, etc.)
    b. Dense housing microgrids (apartments, townhomes, etc.)
    c. Institutional microgrids (community centers, schools, etc.)
2. What are the design considerations for each of these types of microgrids?
3. What types of microgrids are most readily financed and implemented?

Where can microgrids benefit?

ReNCAT analysis

Infrastructure and Flooding

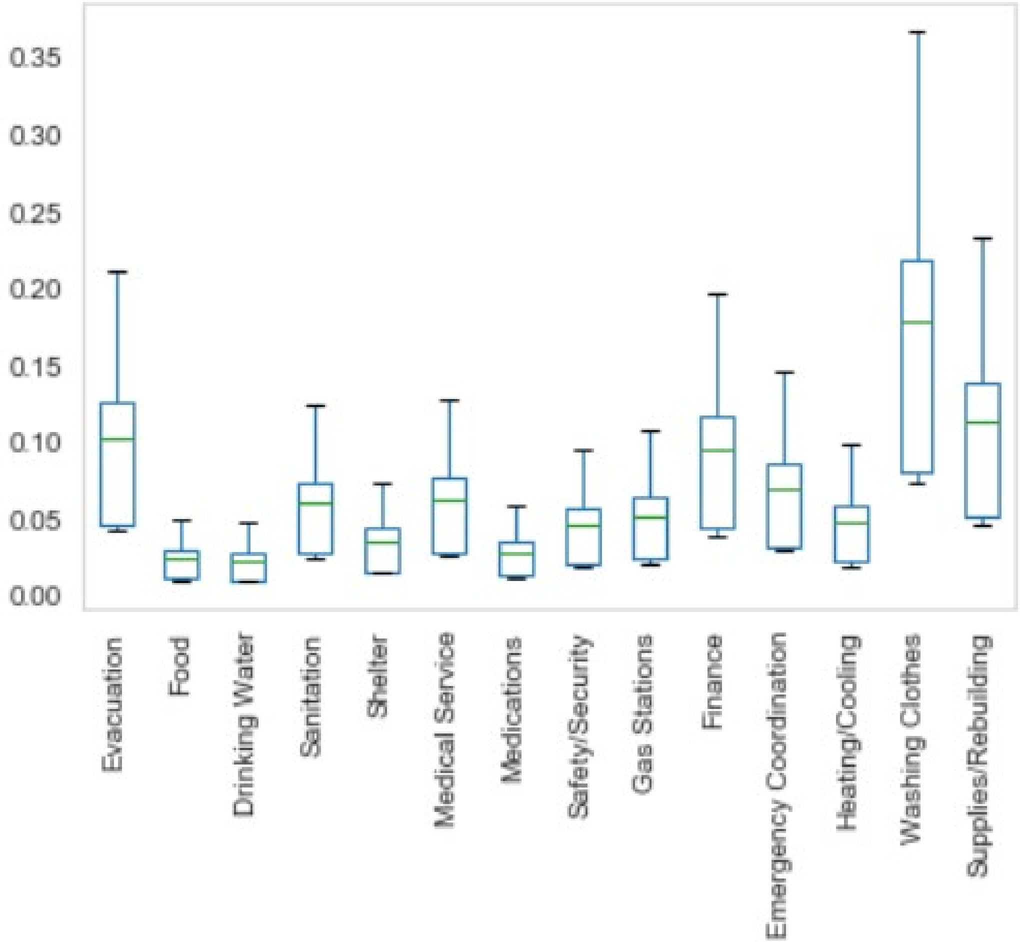
- This information is input to the Resilience Node Cluster Analysis Tool (ReNCAT) to aid in locating resilience nodes.
- We determine a baseline (do nothing) and several alternative (investment) social burden score across several infrastructure service categories.



Baseline Social Burden

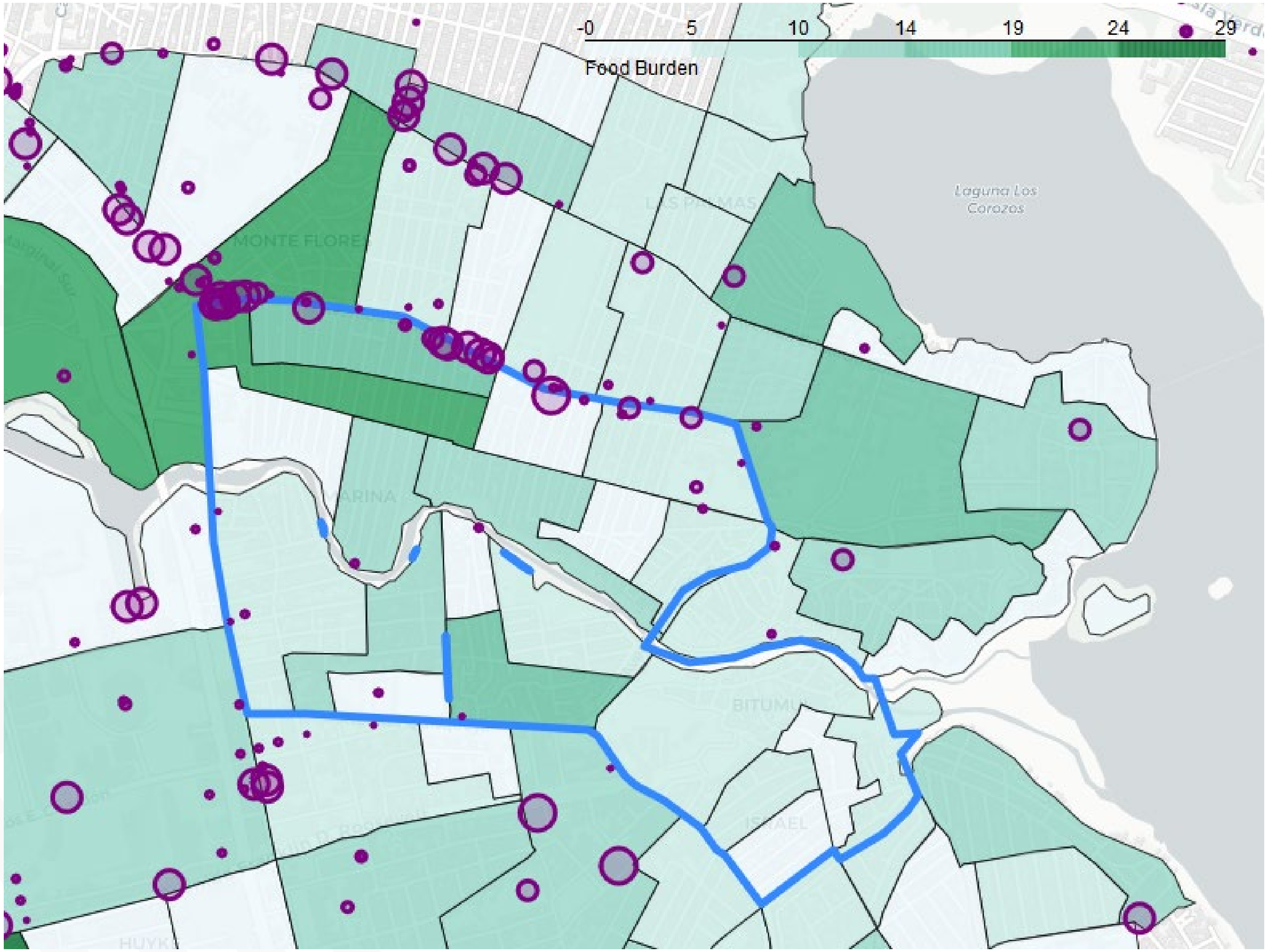
Leveraging U Buffalo Work

"Blue Sky" Social Burden (No Disruption)



Food Burden Example

Interactive Map



Total Social Burden

Minimize this through microgrid locations

Microgrid Conceptual Design

Co-optimization Process

Identify potential resilience node

Initial:
- Former GSA development

Following:
- Other housing redev
- Institutional devs
- Critical infrastructure clusters

Establish goals and metrics

Affordability:
- Net Present Value of all energy-related expenditures

Sustainability:
- Energy-associated GHG

Resilience:
- Energy availability (probability of service) to critical loads during projected design basis threats

Establish and characterize design basis threats

Storms, earthquakes

Project load (blue and black sky)

Blue sky load:
- 8760 hour profile broken out by each building that is potentially served by microgrid

Black sky load:
- 8760 profile for each building, further decomposed into criticality tiers

Optimize design for blue sky

MDT - MSC

Optimize design for black sky

MDT - PRM

Iterate to converge final conceptual design

Housing Redevelopment Microgrid

Background

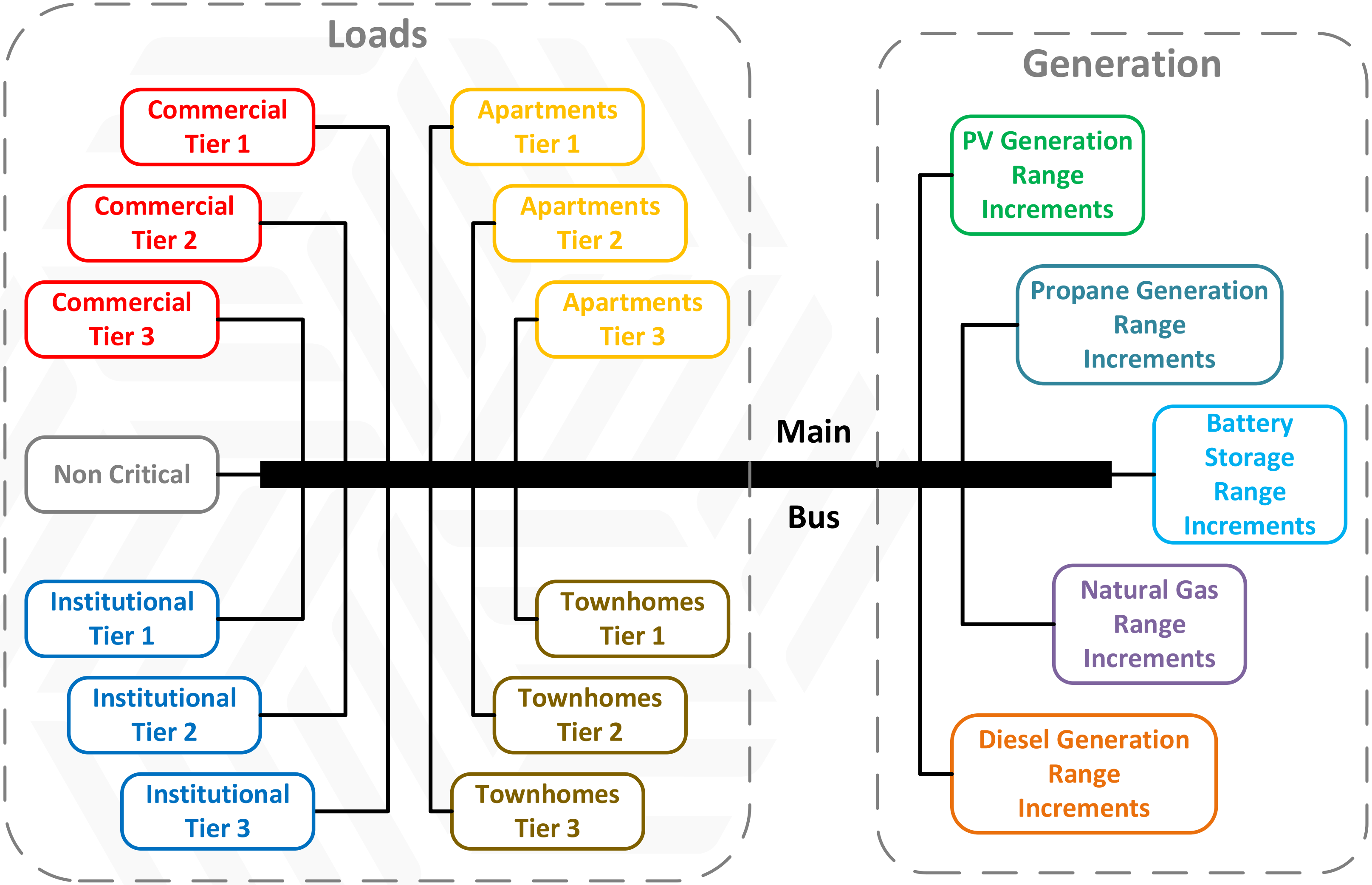
Former General Services Administration (GSA) Area

Microgrid Design Toolkit (MDT) Analysis

- 206 Units
  - 65-70% Town Homes
  - 30-35% Apartments
  - Carve-outs for elderly and disabled
- Commercial on first floor along Hwy 27
- Institutional buildings on north and south ends
- Public park on east side (not modeled)

Housing Redevelopment Microgrid

Conceptual Model



Tiered Load Analysis

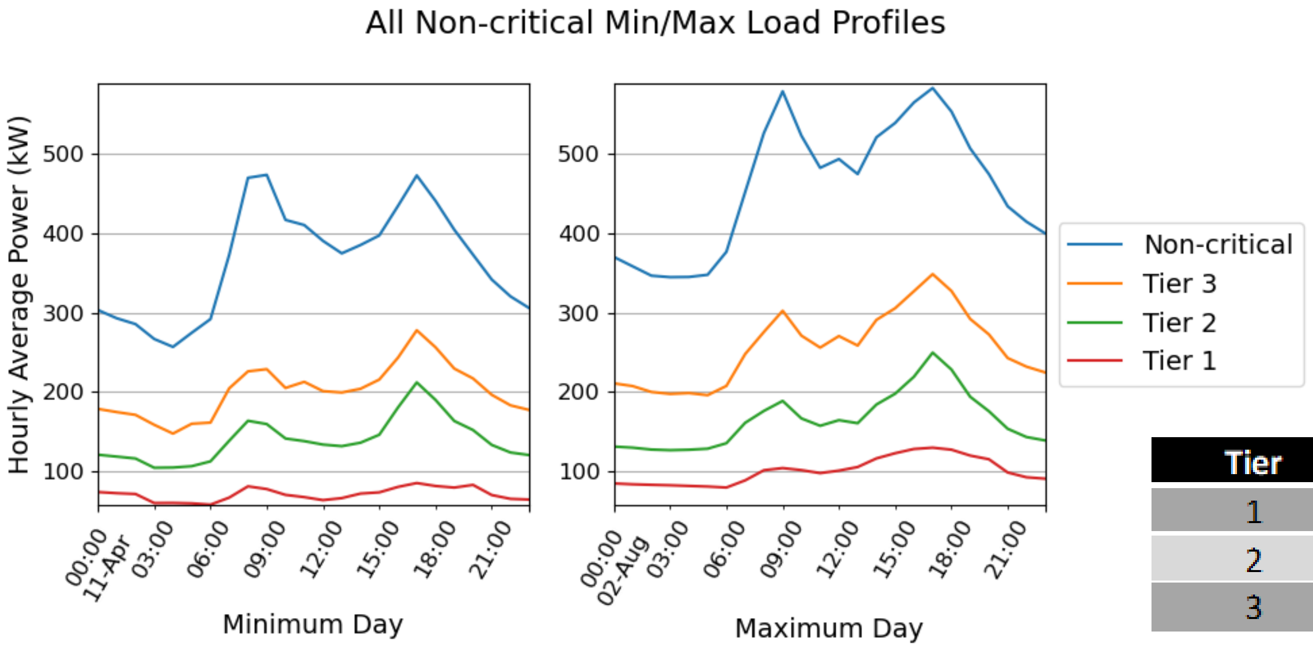
Using TEB toolkit

Type	Non-critical	Tier 3	Tier 2	Tier 1
Residential	1) Clothes dryers and washing machine, 2) Wall AC units, 3) 5 interior light fixtures, 4) Central AC, 5) All other plug loads 6) Ceiling fans	1) EV charging, 2) TV, 3) Microwave 4) 5 Interior light fixtures	1) Home Mobility Scooter Battery Charging (select units), 2) Laptop Charging, 3) Stove range 4) 8 interior light fixtures	1) Cell phone charging, Internet Wifi, 2) Medical Equipment (select units), 3) Refrigerator, 4) Wall AC for Home Medical (select units) 5) 1 plug in fan per bedroom 6) 3 interior and 1 exterior light fixture
Commercial	1) Cooking 2) Non-critical computers 3) Heating/drying devices 4) Hot water 5) ½ Checkout computers 6) 1 Plug in fan per store 7) Mini-Fridges 8) Closed commercial fridges (beverage cooling) 9) 220 interior light fixtures and 100 exterior (all stores)	1) TV's and Displays 2) Microwaves 3) Central AC 4) 3 ceiling fans per store 5) 220 interior light fixtures and 100 exterior (all stores)	1) Laptop and battery charging 2) 3 ceiling fans per store 3) Non-critical Closed freezers 4) 220 interior light fixtures and 100 exterior	1) Cell phone charging 2) 1 Plug in fan per store 3) Full size fridges 4) Critical Closed freezers 5) 70 interior light fixtures and 20 exterior

Tiered Load Analysis

Results

GSA Redevelopment DRAFT load profiles (Tiered Load Analysis)



Tier	Limit	Objective
1	99%	99.5%
2	95%	95.5%
3	80%	85%

Generation Options

Blue and Black Sky Parameters

Asset Type:	Range:	Increments:	MTBF (h):	MTTR (h):	Capital Cost:
PV	50kW-1MW	50/100/500kW and 1MW	8468	55	$1800/kW
Lithium-Ion Batteries	50-500 kW	50/100/500 kW (4-hour batteries)	8000	168	$2604/kW
Diesel Generators	50kW-1MW	50/100/500kW and 1MW	10,500	37	$850/ kW
Natural Gas Generators	1MW	1MW	30000	6	$1000/kW
Propane Generators	50kW-1MW	50/100/500kW and 1MW	30000	6	$2750/kW

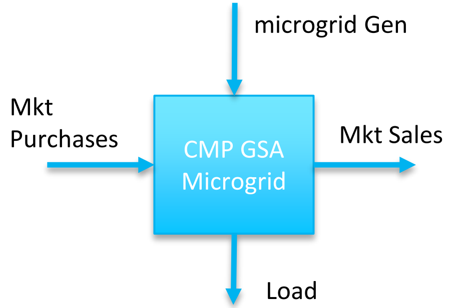
Blue Sky Optimization

MDT - MSC

Optimal Blue-Sky Installation is: 2,296 kW-AC rooftop PV

- Current microgrid ruling:
  - 25% of gen annually – max – from fossil
  - No leasing of PREPA conductor
- Retail rates - Mid $0.2242/kWh
  - No demand charges
  - No TOU
  - Net Metering (end-of-year true-up)
  - EOY surplus paid @ $0.07/kWh

- Discount rate = 6.5% (Olin using 7%)
- Effective "PREPA Efficiency" = 0.264
  - Defined as the efficiency of PREPA if it were assumed to be one big natural gas generator
  - Includes T&D losses
- Time horizon: 20 years



Investment Annual Cash Flows		
Fuel Cost	$	-
O&M Cost	$	(43,150)
CO2 Charges	$	-
Energy Purchases	$	(435,830)
Energy Sales (at 0.224)	$	435,830
Energy Sales (at 0.07)	$	33
Demand Charges	$	-
Net Annual Cash Flow	**$**	**(43,117)**
Carbon Emissions (tonne/yr)		
Local CO2 Emissions		0.0
Utility CO2 Emissions		1374.6
Offset CO2 Emissions		-1374.9
Net CO2 Emissions		**-0.3**

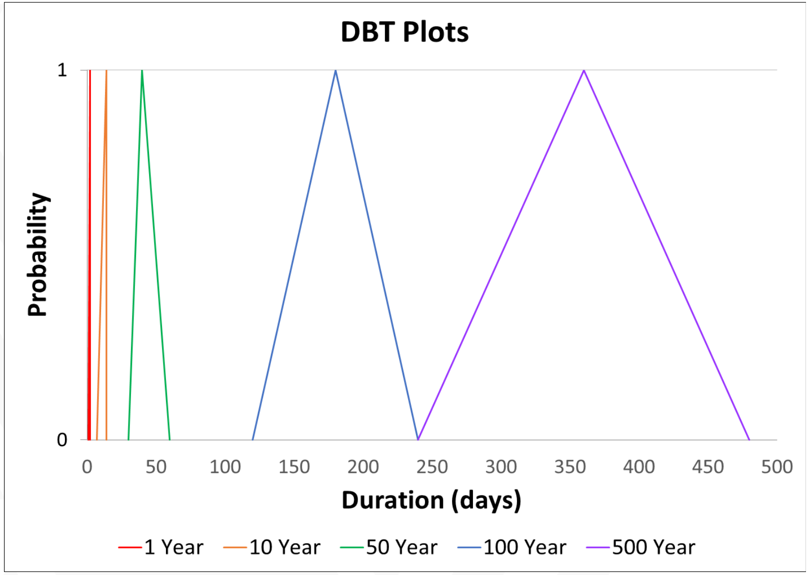
Baseline Annual Cash Flows		
Fuel Cost	$	-
O&M Cost	$	-
CO2 Charges	$	-
Energy Purchases	$	(802,049)
Energy Sales (at 0.224)	$	-
Energy Sales (at 0.07)	$	-
Demand Charges	$	-
Net Annual Cash Flow	**$**	**(802,049)**
Carbon Emissions (tonne/yr)		
Local CO2 Emissions		0.0
Utility CO2 Emissions		2529.7
Offset CO2 Emissions		0.0
Net CO2 Emissions		**2529.7**

Net Present Value of Investment		
NPV of Baseline Cash Flows	$	(8,837,387)
NPV of Investment Cash Flows	$	(475,090)
NPV Annual Cash Flow v. Base	**$**	**8,362,297**
CapEx of Investment	$	(4,132,800)
NPV of EOL Salvage Investment	$	234,575
Total CapEx	**$**	**(3,898,225)**
Net Benefit v. Baseline	**$**	**4,464,072**
CO2 Emissions v Baseline (tonne/yr)		**-2530.0**

Black Sky Optimization

MDT-PRM

Design Basis Threats



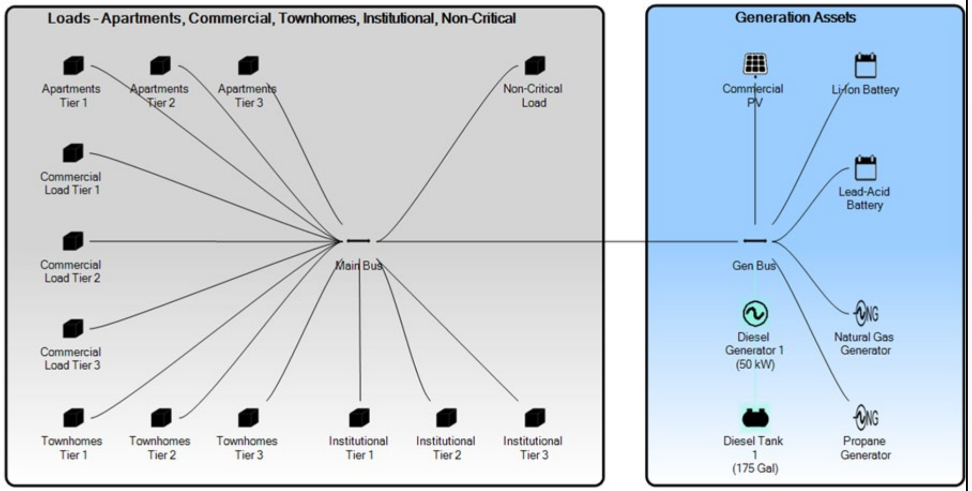
DBT Frequency (yrs)	Duration (days)	Duration Range	1000 Year Sim Occurences	Total Sim Outage Duration (days)	Percent of Total Sim Time
1	2	1-2 days	1000	2000	0.55%
10	14	7-14 days	100	1400	0.38%
50	40	30-60 days	20	800	0.22%
100	180	4-8 months	10	1800	0.49%
500	365	8-16 months	2	730	0.20%
		Totals:	**1132**	**6730**	**1.84%**

Black Sky Optimization

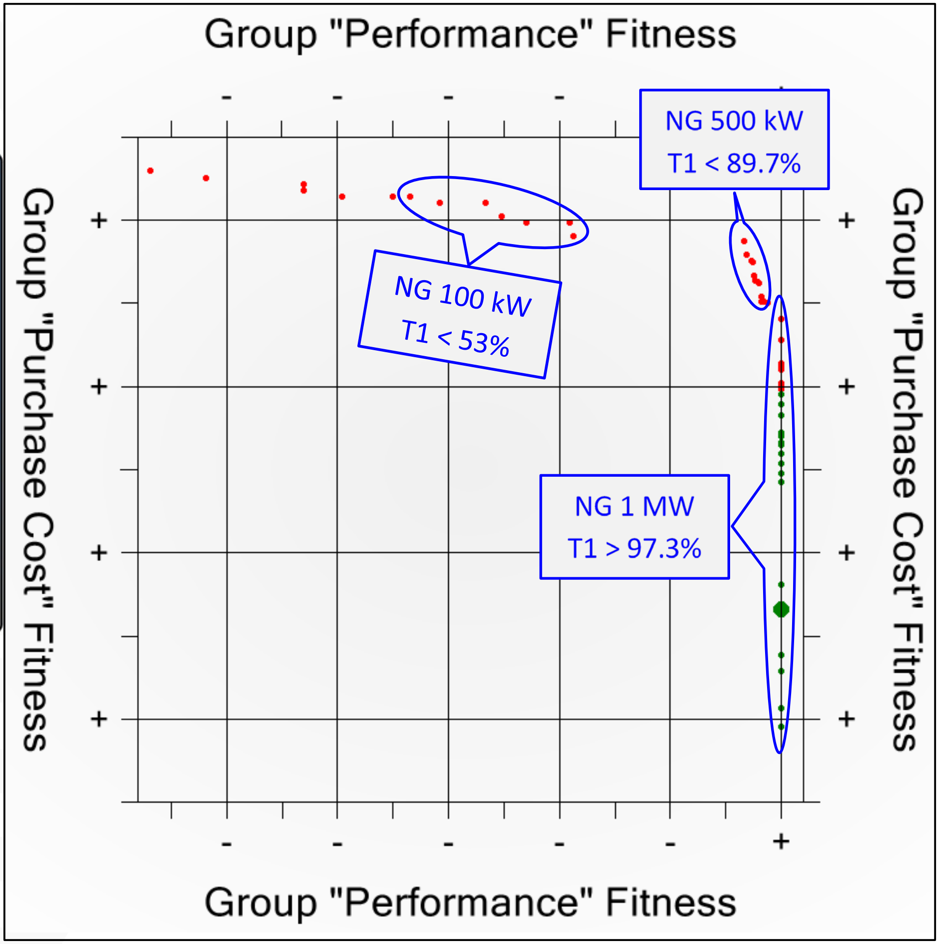
No Blue-Sky Consideration

MDT-PRM (Black Sky)

Case 1 – no fixed assets



Total Solutions:	Feasible:	Infeasible:
53	19	34



NG 500 kW
T1 < 89.7%

NG 100 kW
T1 < 53%

NG 1 MW
T1 > 97.3%

Results Are Under Review

Converging Solutions

Black and Blue-sky optimal

Case 2 – co-optimization with blue sky solution

- 2,300 kW-AC rooftop PV – “locked in”
- Allow PRM to optimize “on top of” the blue-sky solution
  - This approach is only recommended in special cases
- Recall peak hour loads:
  - T1: 130 kW T2: 120 kW T3: 90 kW Rem non-crit: 220 kW
  - TOTAL PEAK: 580 kW

PV Fixed 2300 kW, All Others Variable											
Config#	**Availability**				**Variable Selections (kW)**					**Total Installed Capacity (kW)**	**Total Purchase Cost ($M)**
	Tier 1	**Tier 2**	**Tier 3**	**NC**	**PV**	**Li-Ion Battery**	**Natural Gas**	**Diesel**	**Propane**		
2305	99.1%	98.9%	99.1%	98.2%	2300	0	500	50	0	2850	$4.686M
1817	99.8%	99.8%	99.8%	99.7%	2300	0	500	0	50	2850	$4.778M
2201	99.9%	99.8%	99.8%	99.8%	2300	50	500	50	0	2900	$4.816M
1687	99.9%	99.9%	99.9%	99.9%	2300	100	500	50	0	2950	$4.946M
1361	99.9%	99.9%	99.9%	99.9%	2300	0	1000	0	0	3300	$5.14M

Results Are Under Review

El Caño Martin Peña, PR

Conclusions

1. A combination of factors leads to only PV (and efficiency) being blue-sky optimal for behind-the-meter microgrid investment
    a. Net metering
    b. Lack of TOU rates
    c. Lack of demand charges
    d. Microgrid Ruling (>75% renewable on annual energy)
2. Black-sky (resilience) optimal investment requires additional flexible (dispatchable) generation *on top of* the PV
    a. Combination of battery storage and fossil generation – redundancy and flexibility for longer-duration outages
    b. None of these technologies – even battery storage – can be utilized economically during normal operations
    c. Currently not seeing solutions that heavily utilize the load tiering / microgrid load shed scheme
3. With follow-on analysis, we believe similar conclusions can be developed to represent most behind-the-meter microgrid cases in PR
    a. Currently supported by DOE/FEMA recovery efforts

Designing Resilient Communities

Discussion and Coordination

THANK YOU!

Bobby Jeffers (rfjeffe@sandia.gov)
Robert Broderick (rbroder@sandia.gov)

Evaluating Resilience Nodes Using a Framework and Integrating Electrified Transportation

Bobby Jeffers, Darryl Melander, Samantha Horn, Emily Moog, Holly Eagleston, Brooke Garcia

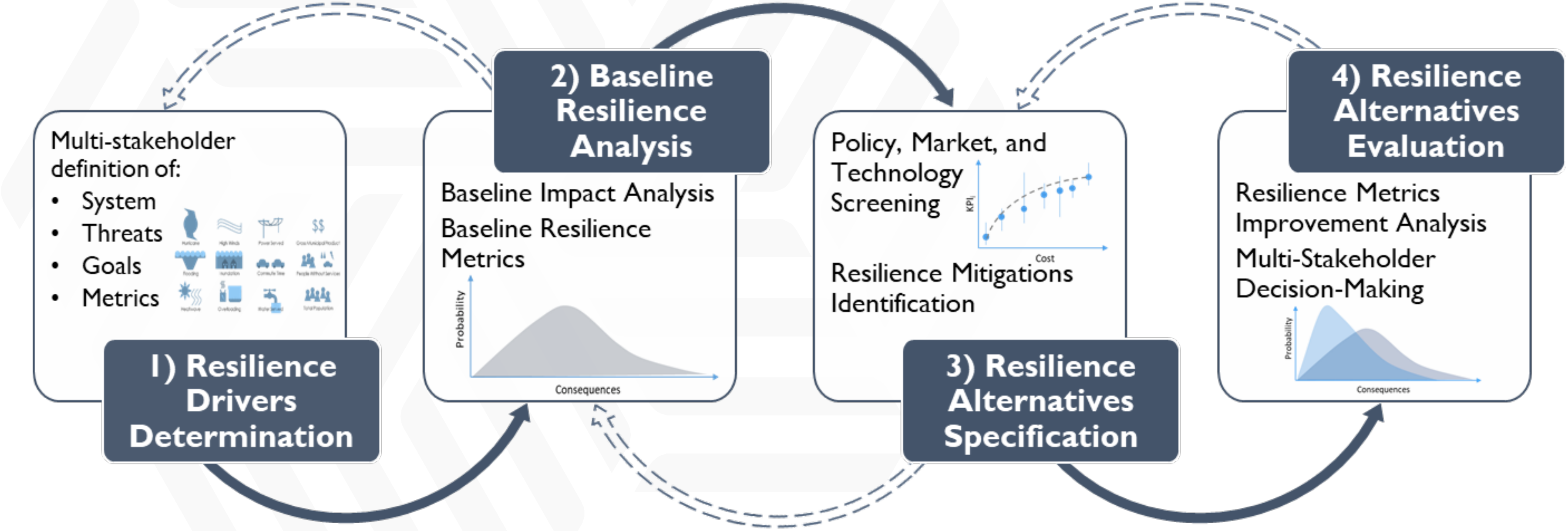
With Support from CPS Energy and the City of San Antonio

Brooks City Base

San Antonio, TX

Brooks City, Using the Framework

- **Demonstration, verification, and validation of the framework as applied to various community/utility constructs -** Analysis of microgrid siting and sizing to provide community resilience in a future with high EV penetration



1) Resilience Drivers Determination

Multi-stakeholder definition of:
- System
- Threats
- Goals
- Metrics

2) Baseline Resilience Analysis

Baseline Impact Analysis

Baseline Resilience Metrics

3) Resilience Alternatives Specification

Policy, Market, and Technology Screening

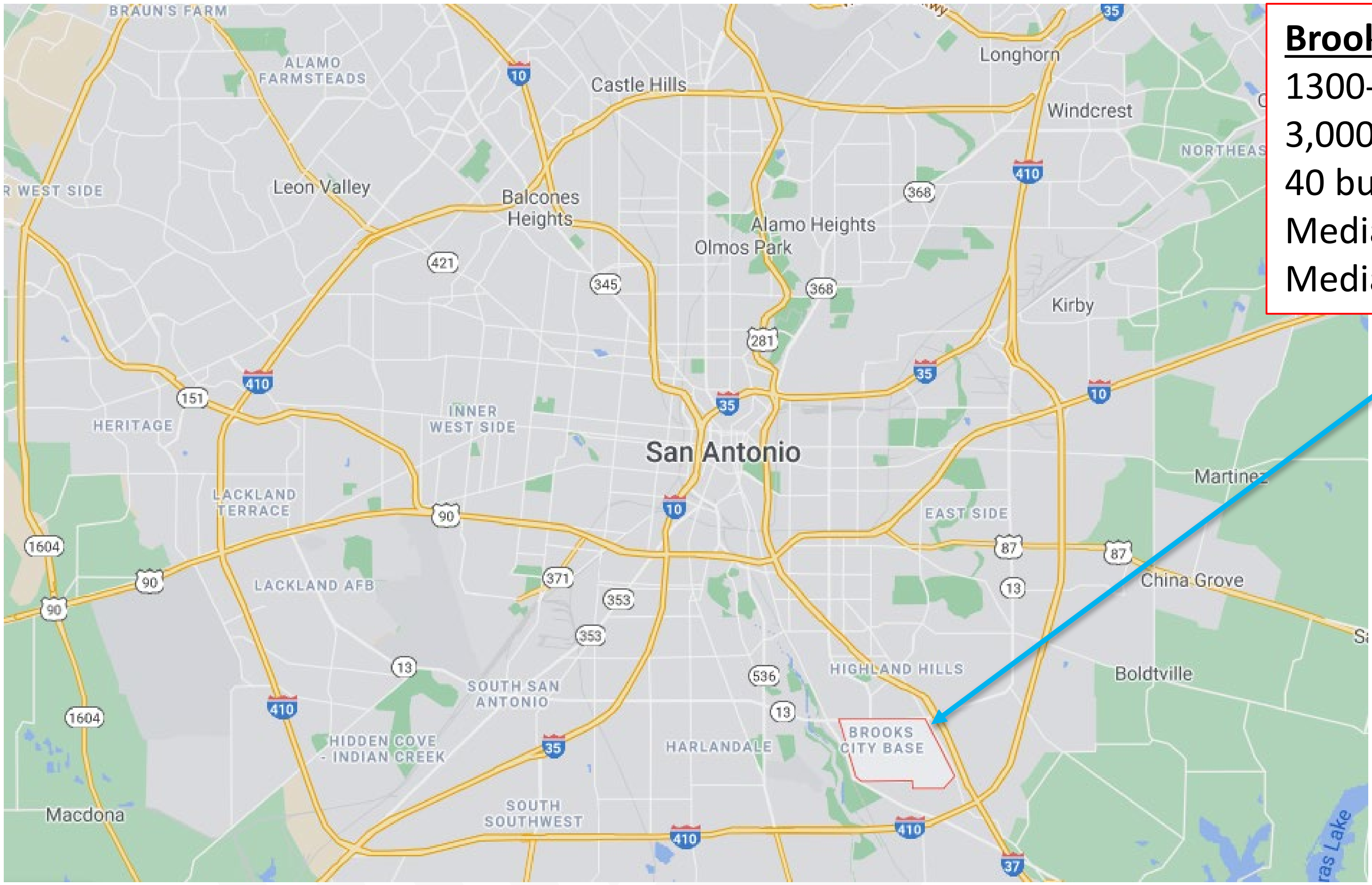
Resilience Mitigations Identification

4) Resilience Alternatives Evaluation

Resilience Metrics Improvement Analysis

Multi-Stakeholder Decision-Making

San Antonio and Brooks City



Brooks City

1300-acres

3,000 residents

40 businesses

Median income ~$50k

Median age ~22

Brooks City Scenario Development

What happens to if?

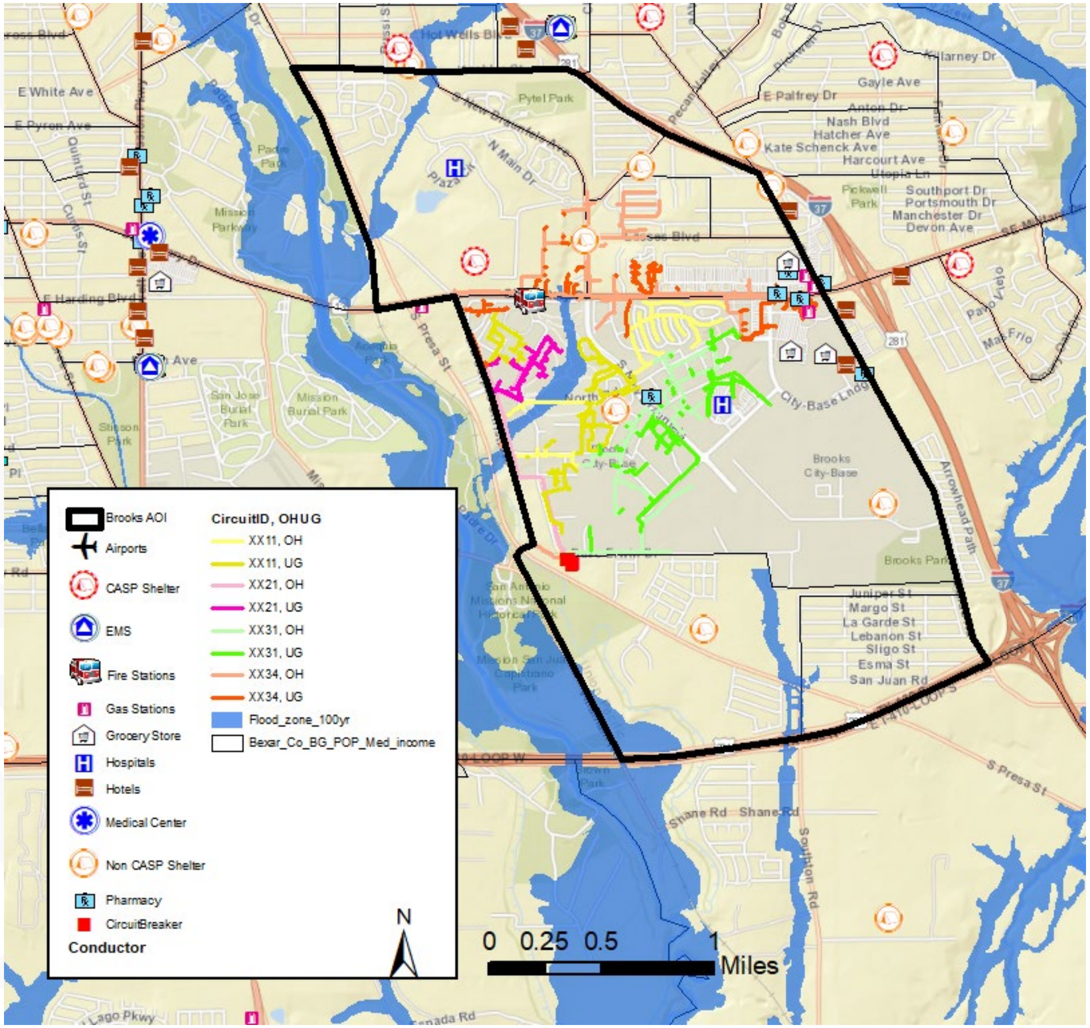
1) Coastal evacuation,

AND

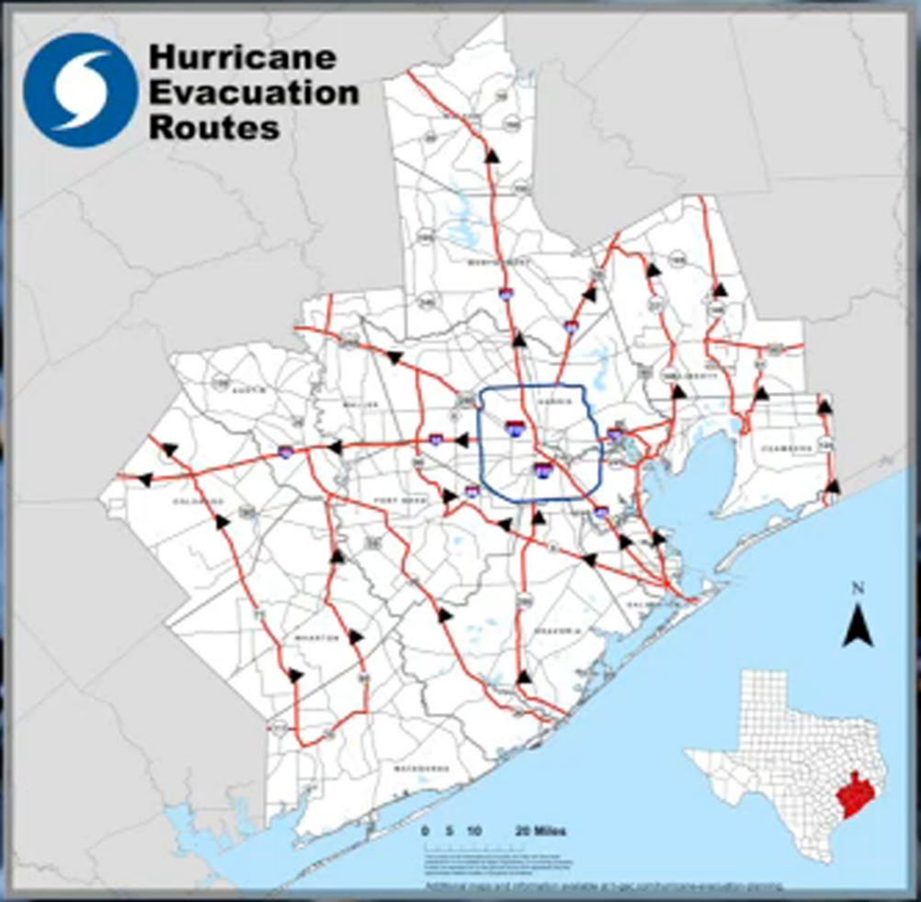
1) Extended power outage

Key considerations:

- Evacuation patterns during large scale disruptions
- Forecast for EV adoption
- Critical Infrastructure, existing system characterization



Threat Definition- Coastal Evacuation



- Study years: 2030 and 2040
- Estimate **approximately 2000 evacuees** are housed in Brooks City during evacuations.
- Using current rates projected for EV adoption:
  - Estimate **200 EVs (146 Residents, 54 Evacuees)**

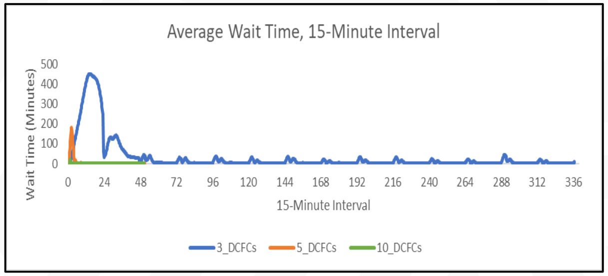
Reference: http://www.gis.hctx.net/evacuationmap/

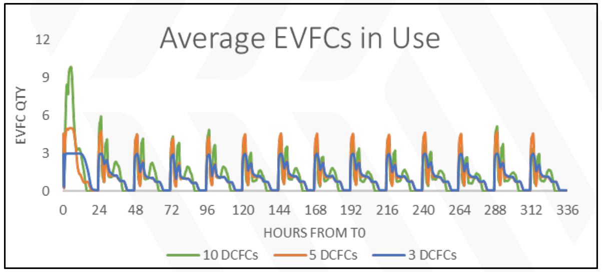
Goals – Minimize Burden/Maximize Investment

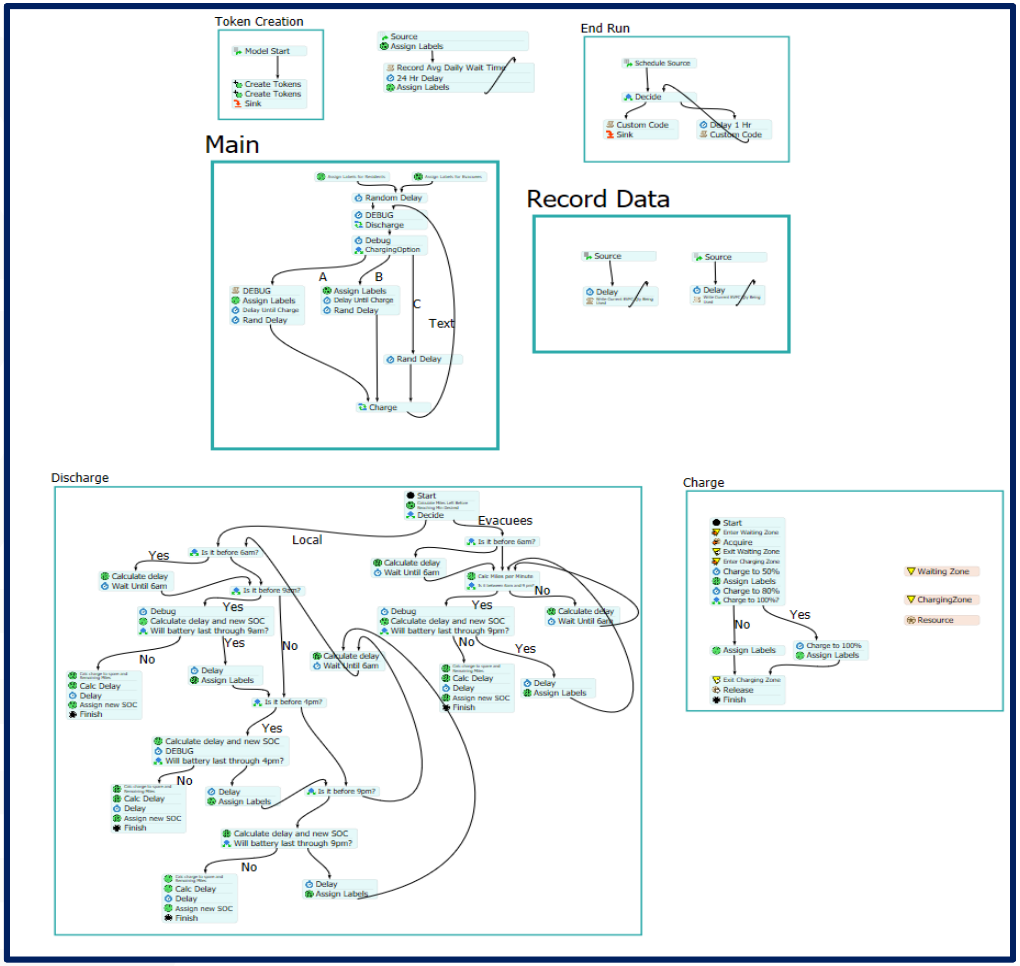
Baseline Queueing Model Developed using FlexSim

Objective: Develop a discrete-event simulation representing Electric Vehicle (EV) charging patterns during an outage in order to:

- Correlate the # of public EV chargers with queueing times during an event

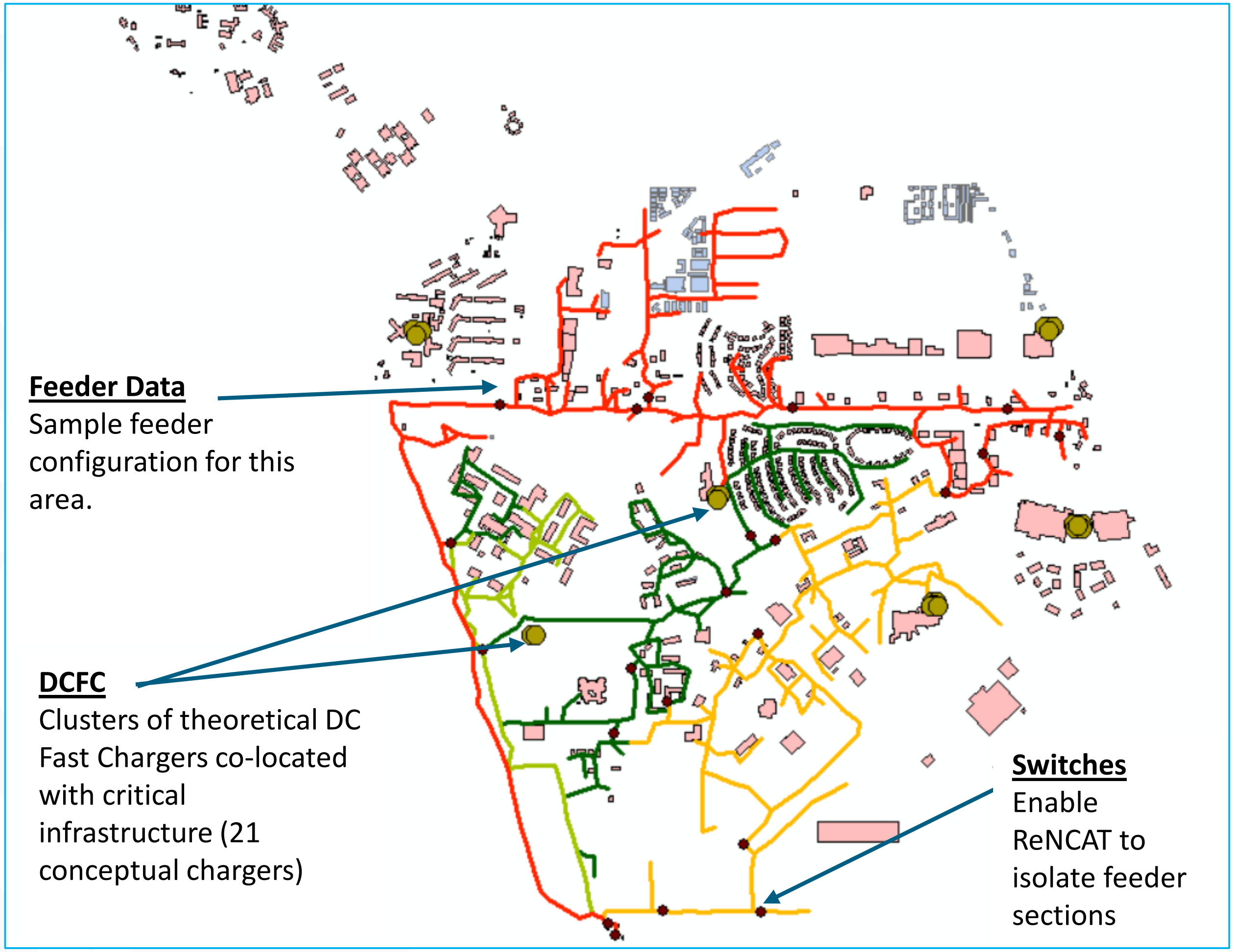






ReNCAT Input Data

- Place **candidate DCFC's** and **switches** throughout Brooks City to allow ReNCAT to optimize against other critical infrastructure on the same feeder.



Feeder Data
Sample feeder configuration for this area.

DCFC
Clusters of theoretical DC Fast Chargers co-located with critical infrastructure (21 conceptual chargers)

Switches
Enable ReNCAT to isolate feeder sections

Designing Resilient Communities

Accomplishments – Task 2

ReNCAT Input

Current Grid Topology and Load Data

Switch Locations

Proposed Charging Station Locations

Charging Station Analysis

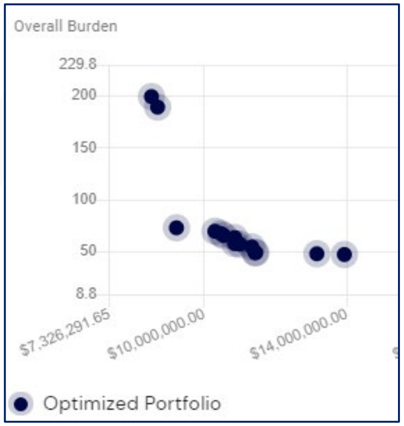
Run ReNCAT

Design metrics used by ReNCAT to evaluate microgrid locations specific to:

- **Cost**
- **Social Burden**
- **Traffic impact (queueing)**
- **EVs location and count**

Analyze Results

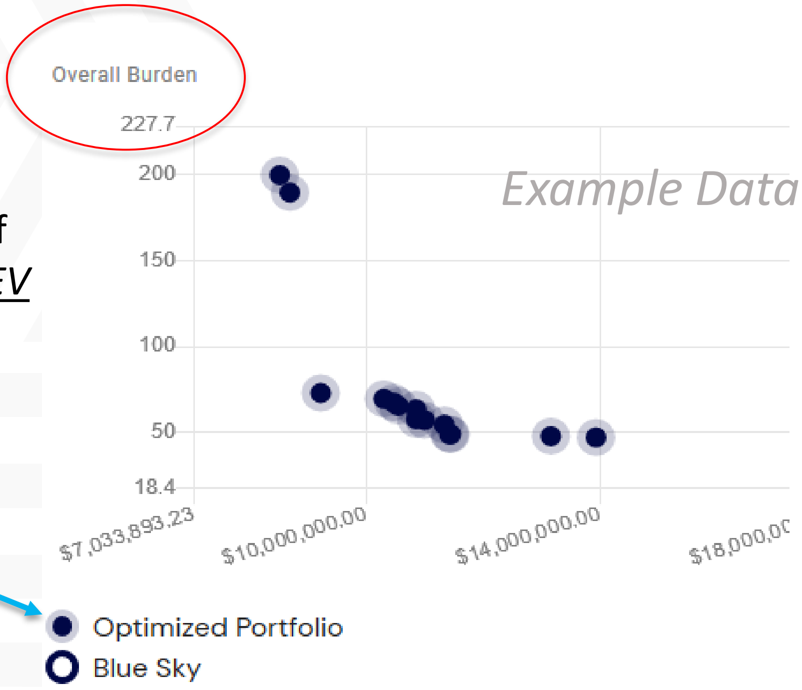
Multiple proposed new grid designs, each with a different balance of design metrics



Remaining Steps

Complete ReNCAT Analysis – produce a pareto frontier that shows burden reduction with respect to cost of investment.

Evaluate microgrid portfolios as a function of cost and social burden, *which now includes EV infrastructure as a critical asset*, which influences the *effort* required to meet basic human needs.



Designing Resilient Communities

Discussion and Coordination

Thank you!

Brooke Marshall Garcia, PE
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GMLC 1.5.06 - Designing Resilient Communities: A consequence-based approach for grid investment

MATTHEW RENO
SANDIA NATIONAL LABORATORIES

4/27/2021

Designing Resilient Communities

High-Level Project Summary

Project Description
The high-level goal of this project is to demonstrate an actionable path toward designing resilient communities through: (1) consequence-based approaches to grid planning and investment; **(2) field validation of technologies with utility partners that enable distributed, clean resources to improve community resilience.**

Value Proposition

- ✓ Incorporating community resilience within electric utility investment planning
- ✓ Examining the impact of alternative regulatory frameworks and utility business models to incentivize resilience
- ✓ **Demonstrating that a community resilience node can be implemented through clean, renewable technologies via inverter-dominated island protection and control**

Project Objectives

- ✓ Form and hold national outreach meetings with a Stakeholder Advisory Group (SAG) that will inform the technical and policy solution space
- ✓ Design and implement (with two city/utility pairs) a widely-applicable framework that aligns grid investment planning with community resilience planning
- ✓ **Design, implement, and field validate at a utility scale resilience nodes implemented predominately using clean distributed energy technologies**

PROJECT FUNDING

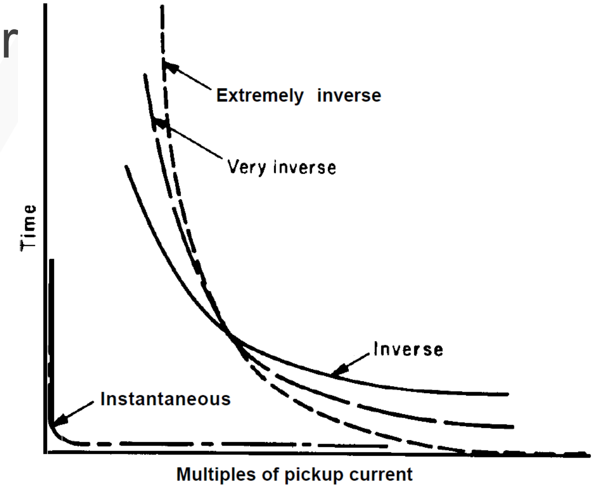
Lab	YR1 $	YR2$	YR3$
Sandia	1,500	1,500	1,500
100RC*	50	50	50
CPS Energy*	200	200	260
National Grid*	50	125	125
* = all cost share			

Task 4 – Overcoming Technical Challenges to Clean Resilience Nodes

- Clearing hurdles for inverter-dominated microgrids
- Resilient nodes are becoming less reliant on backup synchronous generation, and instead leveraging inverter-based distributed energy resources
  - Decreasing costs of PV and batteries
  - Decarbonization efforts, including city emission standards
  - Stacking benefits of energy storage during normal operations
- Inverter-based generation can create new problems for the grid, especially around power system protection

Power System Protection

- The protection system and equipment is designed to maintain safe operation of the grid and reliable service
  - Must rapidly and automatically disconnect the faulty sections of the power network
  - Minimize the disconnection of customers
- Conventional power system protection design may not work for high penetrations of inverter-based PV generation
- Traditional protection systems are designed for synchronous and induction machines
  - Short-circuit modeling and protection of traditional systems is well established
  - *Increasing penetration of inverter-interfaced resources underscore the need of inverter models for short circuit studies*

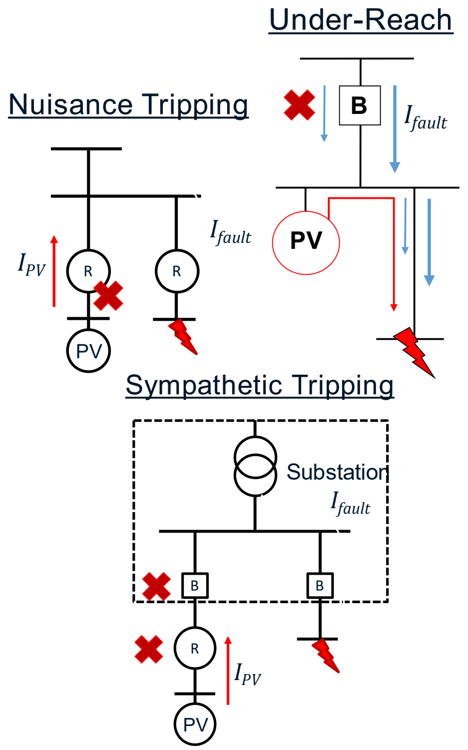


Inverter-Based DG Impacts on Protection

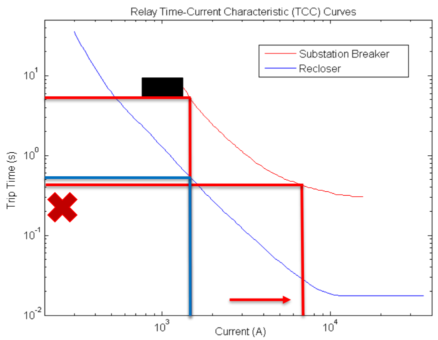
- The legacy protection was not designed for the presence of inverter-based DG

Common Protection Issues and Impacts:

- ✓ Reverse power flow and multiple injection points of fault current
- ✓ Loss in coordination between protection devices
- ✓ Relay desensitization
- ✓ Transfer trip strategies
- ✓ Anti-islanding detection
- ✓ Open-phase detection
- ✓ Interconnection transformer winding configuration and grounding
- ✓ Load rejection transient over-voltage

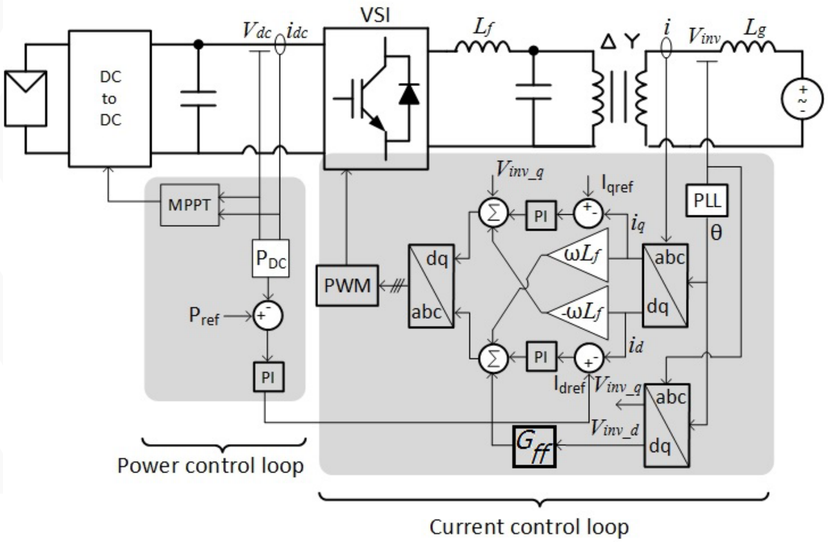


Coordination Loss



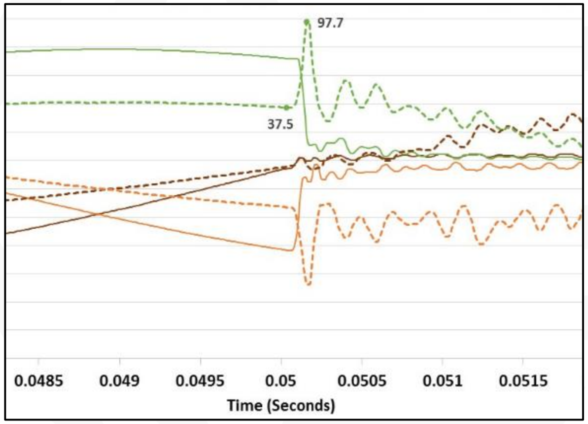
100% Inverter-Based System Protection Challenges

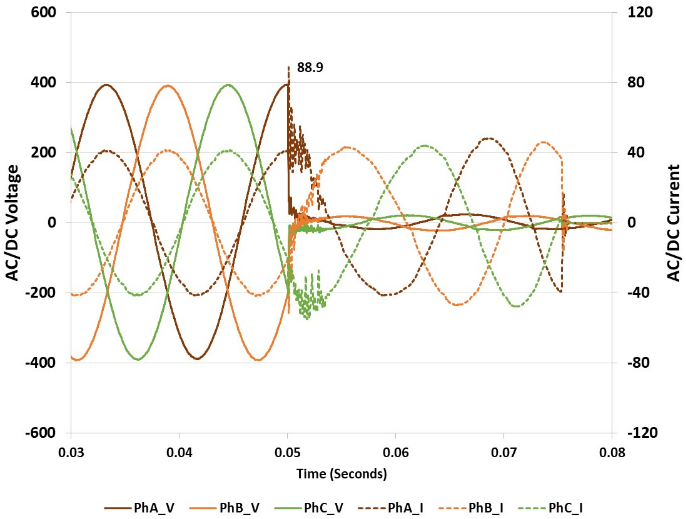
- 100% inverter-based systems present a new set of challenges for protection
- Inverters do not provide significant current during faults
  - Overcurrent protection schemes might not detect the fault
  - Fault currents can look similar to motor starts or inrush
  - With low fault currents, the fault currents are more sensitive to generation dispatch, complicating coordination



Inverter Response to Faults

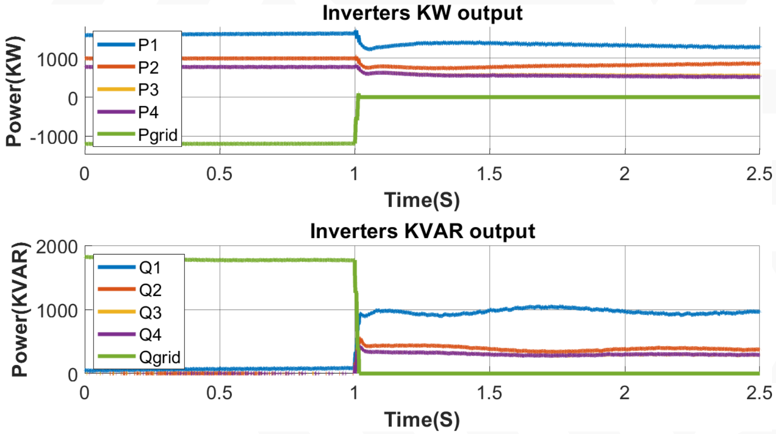
- ►Inverters have a unique dynamic response to faults
  - ■Initial spike (~0.1ms) depends on filter cap, system impedance, and pre-fault condition
  - ■Transients during control actions, lasting 2-8ms
  - ■Steady-state fault current based on the current limiter
- ►Common utility planning software for protection (such as CAPE or ASPEN) cannot model those dynamics, especially for islanded systems
  - ■Advantage of electromagnetic transient (EMT) simulations
  - ■Advantage of doing hardware-in-the-loop testing
  - ■Demonstration of resilient nodes based on the framework
  - ■Initial demonstration using PHIL at Sandia DETL

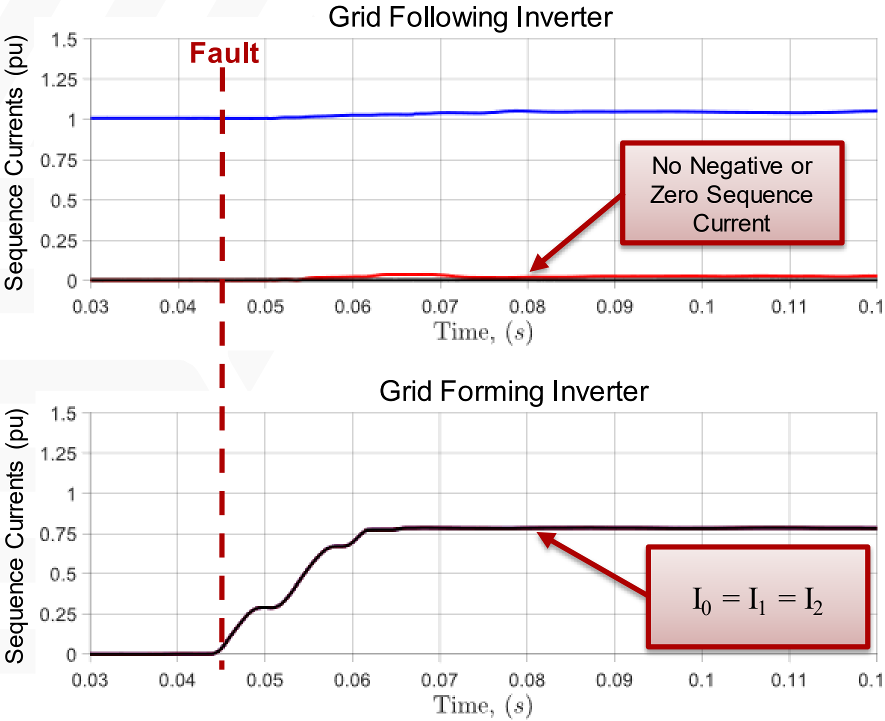




Inverter Response to Faults

- Grid-forming inverters (GFMI) have been integrated into DETL for demonstration
- This collection of six different vendors allows us to demonstrate different systems and test how various inverter designs will perform
- Modeling of grid forming inverters during transition from grid connected to islanded mode. System is islanded at t=1s. Grid is disconnected and the grid-forming inverter (Inverter 1) provides the frequency reference, reactive power, and negative and zero sequence necessary to maintain the grid



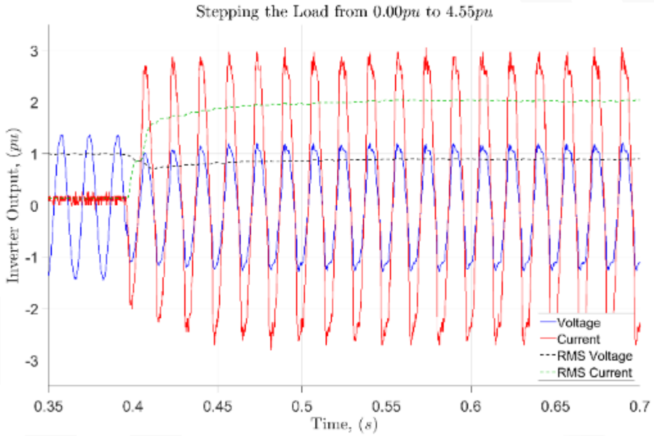


No Negative or Zero Sequence Current

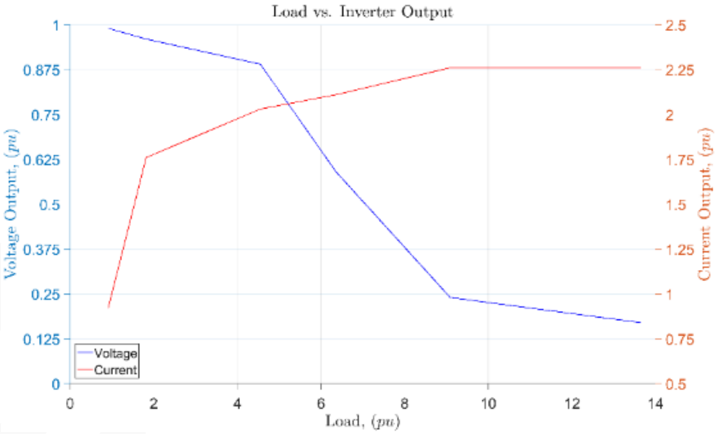
$I_0 = I_1 = I_2$

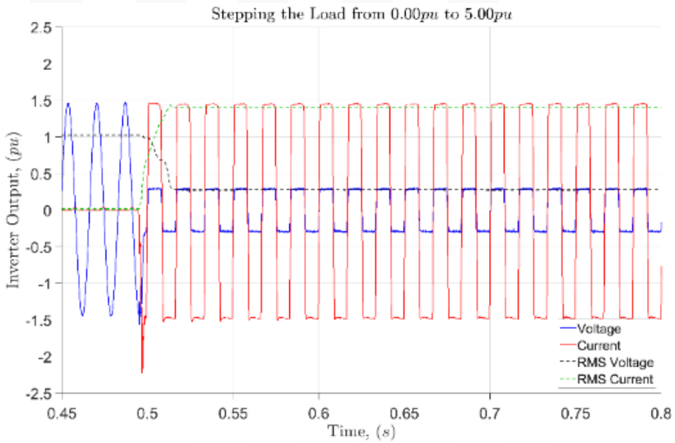
Inverter Response to Faults

Testing and characterization of grid forming inverters at lab scale

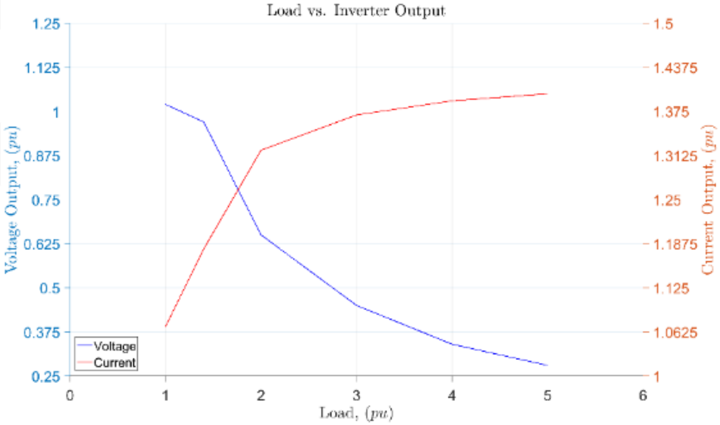


Inverter 1





Inverter 2



Designing Resilient Communities

Task 4 - Demonstration

Upstate NY:

National Grid’s current proposed resilience planning methodology

System: Distribution system for weather events

- Planning process:
  - A resiliency project shall be developed for 15 kV class feeders and stations that have one or more protection devices with a total seven-year CHI (Customer Hours Interrupted) event outage value of greater than X CHI Outage Limits for major and minor storm events lasting greater than 12 hours
  - A station flood mitigation analysis shall be conducted for stations that are within the 100-year flood zone
  - Both criteria above are conditional upon a separate violation of a planning criteria element, i.e., load relief, reliability, asset condition etc.

Threats

- Weather impacts and trending towards longer duration and more frequent events
- Other company resiliency elements currently considered independently but not yet in an integrated fashion:
  - Physical attacks, Cyber security
  - Transmission: identification of weak topologies and high-risk contingencies

Goals

- Implement Resiliency projects to bring areas over CHI metric back within criteria Solutions to consider the following time periods (IEEE PES-TR65): Manage disruption, Quickly respond, Fully recover and adapt
- Improve customer experience and satisfy increasing expectations

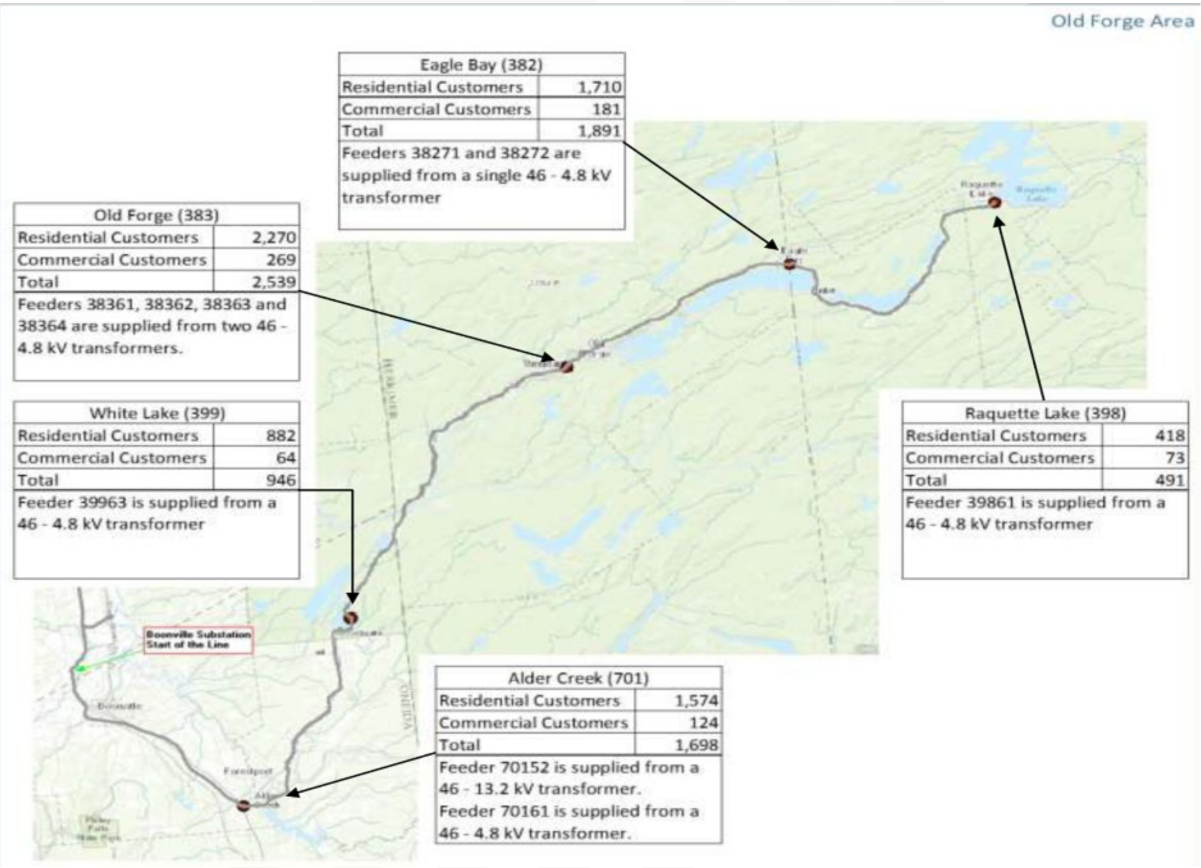
Metrics

- CHI metric confirmed via historical lookback and probabilistic simulations
- Benefit Cost Analysis

Designing Resilient Communities

Task 4 - Demonstration

Old Forge Example: (reliability -> resilience)



Eagle Bay (382)	
Residential Customers	1,710
Commercial Customers	181
Total	1,891

Feeders 38271 and 38272 are supplied from a single 46 - 4.8 kV transformer

Old Forge (383)	
Residential Customers	2,270
Commercial Customers	269
Total	2,539

Feeders 38361, 38362, 38363 and 38364 are supplied from two 46 - 4.8 kV transformers.

White Lake (399)	
Residential Customers	882
Commercial Customers	64
Total	946

Feeder 39963 is supplied from a 46 - 4.8 kV transformer

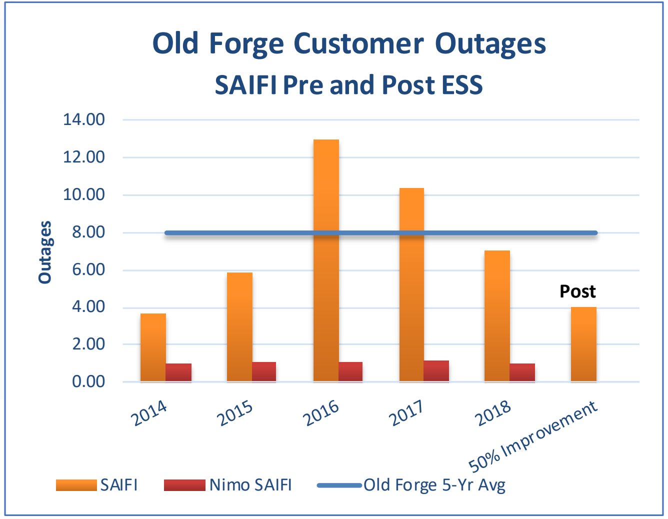
Raquette Lake (398)	
Residential Customers	418
Commercial Customers	73
Total	491

Feeder 39861 is supplied from a 46 - 4.8 kV transformer

Alder Creek (701)	
Residential Customers	1,574
Commercial Customers	124
Total	1,698

Feeder 70152 is supplied from a 46 - 13.2 kV transformer.
Feeder 70161 is supplied from a 46 - 4.8 kV transformer.

- $4 Million cost impact to customers per year over past 5 years for outages
- Old Forge customers were interrupted an average of 7.97 times per year for an average of 20.11 hours per year over the last five years – 10 times more than the NiMo average interruption duration of 2.52 hours



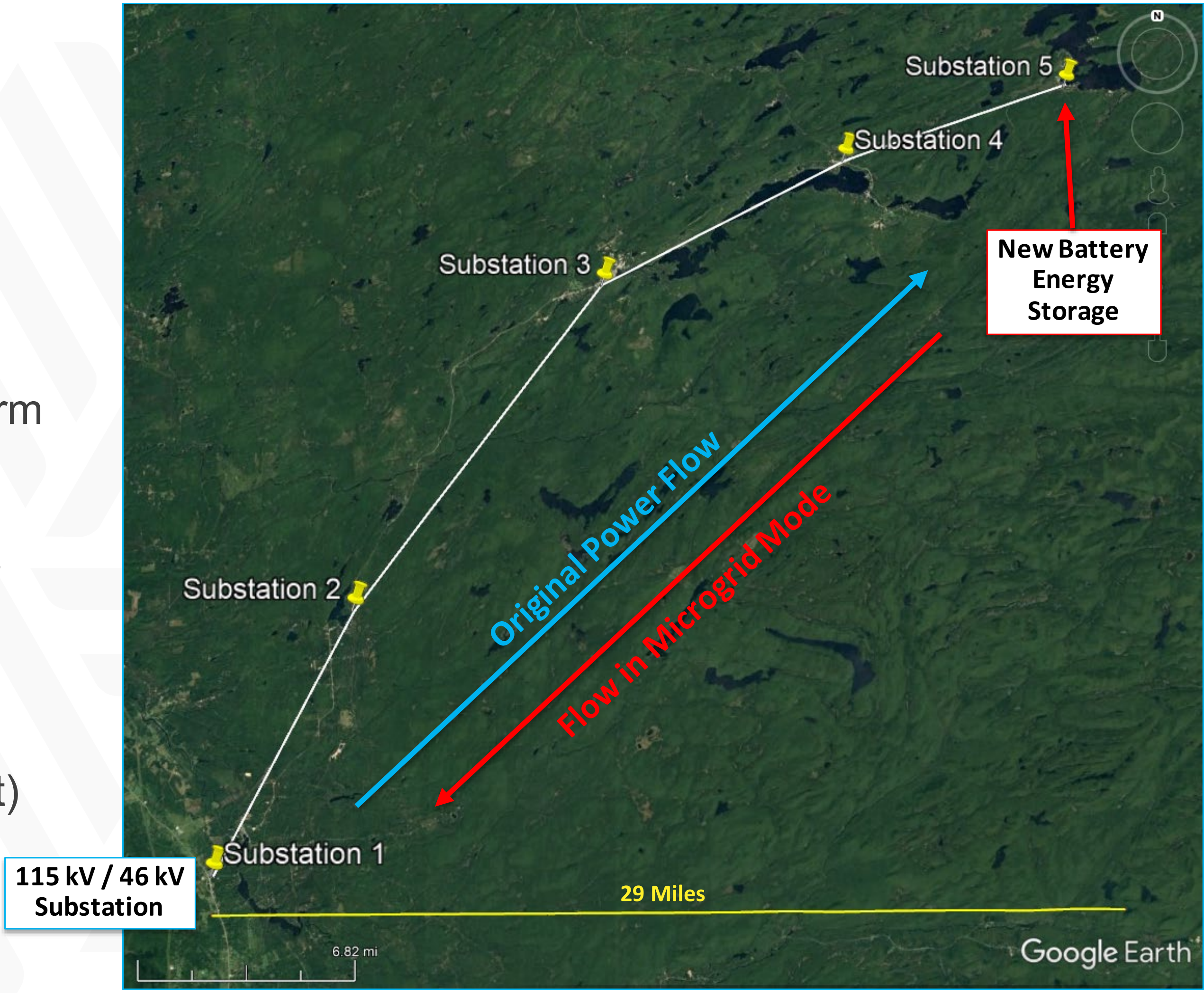
Old Forge Customer Outages

SAIFI Pre and Post ESS

Designing Resilient Communities

Task 4 - Demonstration

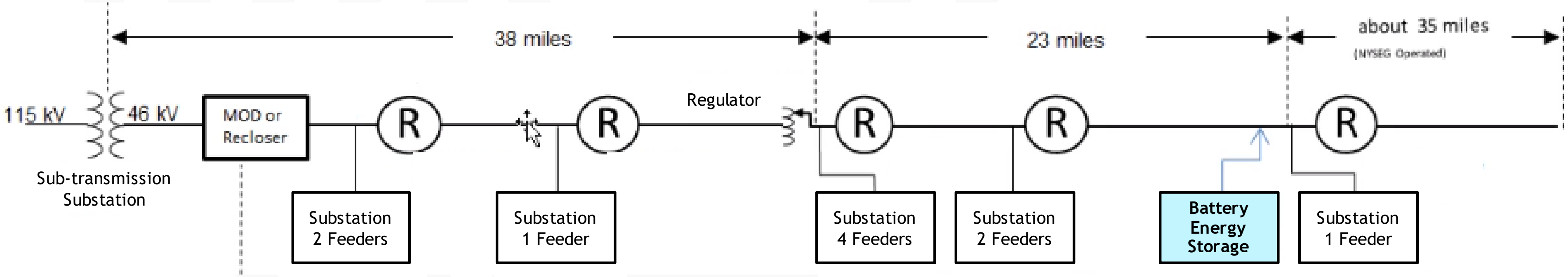
- Solution - Installing new battery energy storage at substation 5
- Improves system reliability and resilience
- The whole system (5 substations, 46 kV sub-transmission line, and 10 feeders) can separate to form an island supplied by the battery
- Sub-transmission system is generally fed from the left (West) from a 115 kV substation. In island mode, the system will be fed from the BESS on the right (East) side of the microgrid



Designing Resilient Communities

Task 4 - Demonstration

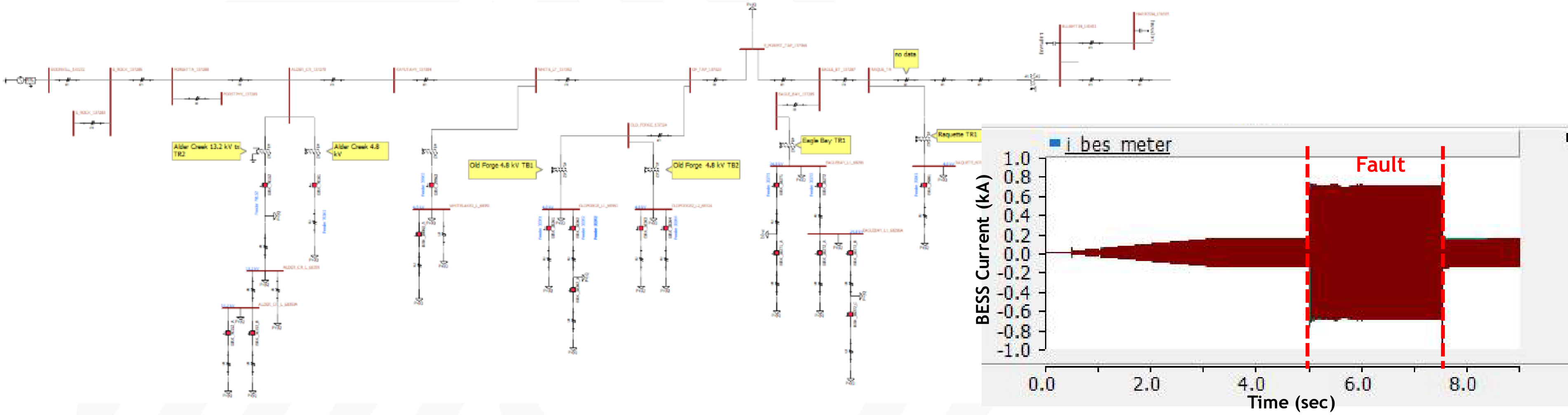
- During the microgrid mode transition the current flow direction and the fault current magnitudes will change
  - All protective devices will change settings – Adaptive Protection
- Modeling the Clean Energy Resilient Node
  - Initial National Grid protection models in ASPEN (phasor domain short circuit study analysis). This did not allow for studying the microgrid in island mode or to capture any inverter dynamics
  - Sandia has created a PSCAD model of the microgrid for EMT analysis. Working directly with inverter manufacturers to get accurate models of their inverter in grid-following and grid-forming mode



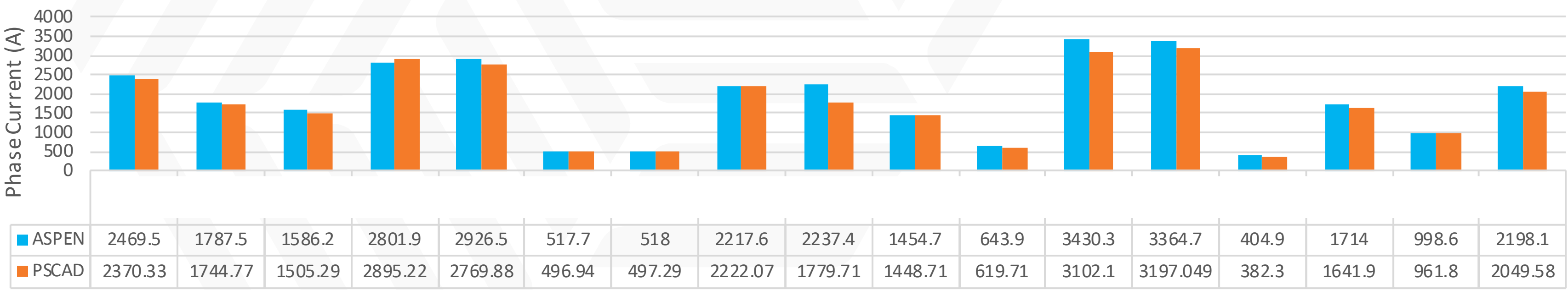
Designing Resilient Communities

Task 4 - Demonstration

- EMT simulation validated to match National Grid PSS/E and ASPEN simulation, but provides more detailed unbalanced waveform data



3 LG Fault Current Comparisons (ASPEN vs PSCAD)

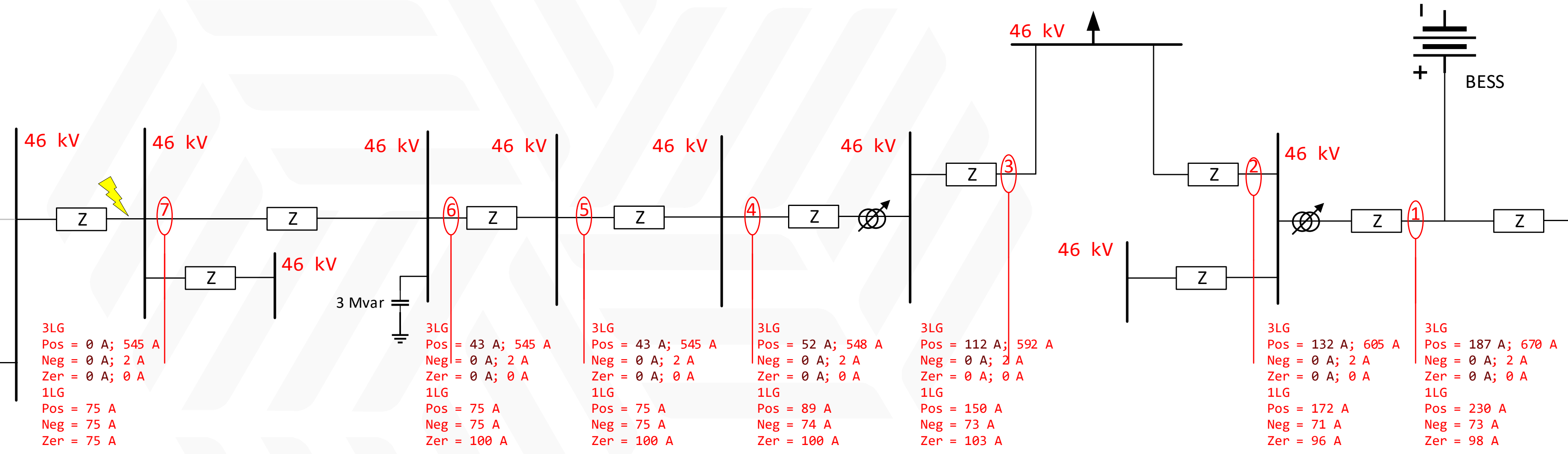


ASPEN	2469.5	1787.5	1586.2	2801.9	2926.5	517.7	518	2217.6	2237.4	1454.7	643.9	3430.3	3364.7	404.9	1714	998.6	2198.1
PSCAD	2370.33	1744.77	1505.29	2895.22	2769.88	496.94	497.29	2222.07	1779.71	1448.71	619.71	3102.1	3197.049	382.3	1641.9	961.8	2049.58

Designing Resilient Communities

Task 4 - Demonstration

- Simulations study what each relay will see during different faults
- For example, for a fault on the left side, the voltage and current through each relay is shown. Ensure that the protection system operates correctly for each contingency



3LG
Pos = 0 A; 545 A
Neg = 0 A; 2 A
Zer = 0 A; 0 A
1LG
Pos = 75 A
Neg = 75 A
Zer = 75 A

3LG
Pos = 43 A; 545 A
Neg = 0 A; 2 A
Zer = 0 A; 0 A
1LG
Pos = 75 A
Neg = 75 A
Zer = 100 A

3LG
Pos = 43 A; 545 A
Neg = 0 A; 2 A
Zer = 0 A; 0 A
1LG
Pos = 75 A
Neg = 75 A
Zer = 100 A

3LG
Pos = 52 A; 548 A
Neg = 0 A; 2 A
Zer = 0 A; 0 A
1LG
Pos = 89 A
Neg = 74 A
Zer = 100 A

3LG
Pos = 112 A; 592 A
Neg = 0 A; 2 A
Zer = 0 A; 0 A
1LG
Pos = 150 A
Neg = 73 A
Zer = 103 A

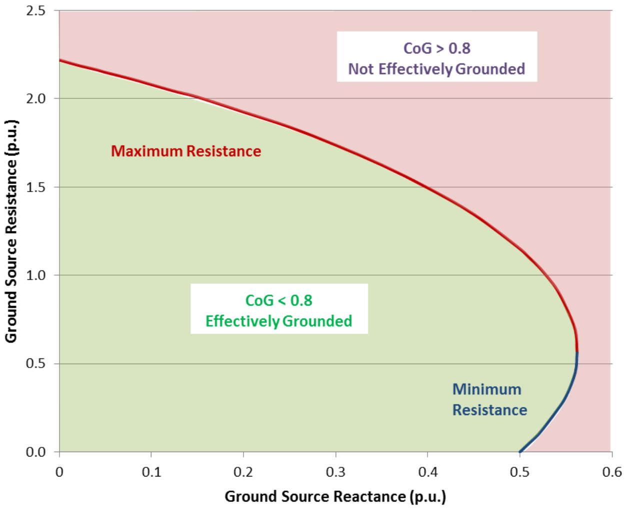
3LG
Pos = 132 A; 605 A
Neg = 0 A; 2 A
Zer = 0 A; 0 A
1LG
Pos = 172 A
Neg = 71 A
Zer = 96 A

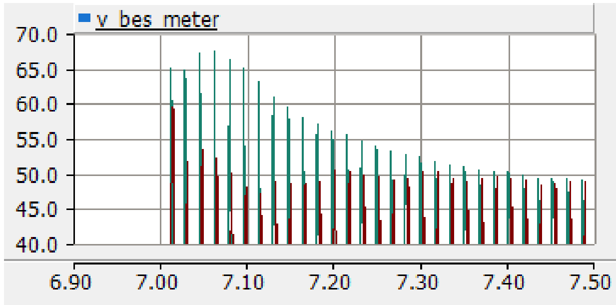
3LG
Pos = 187 A; 670 A
Neg = 0 A; 2 A
Zer = 0 A; 0 A
1LG
Pos = 230 A
Neg = 73 A
Zer = 98 A

Designing Resilient Communities

Task 4 - Demonstration

- Grounding is important for protecting the microgrid, preventing damage to equipment, and detecting faults
- Under normal operations, grounding is provided by the 115 kV substation, so in island mode, a different grounding source is required.
  1. Option 1 – ground the battery transformer
  2. Option 2 – switch grounding in/out depending on microgrid mode
- Changing the ground resistance and reactance impacts the temporary overvoltages (that can damage equipment) and the ground currents during the fault (that determines the ability to detect the fault).
- Effective grounding calculations are more straightforward for synchronous generation, we can determine the correct size and model the impacts for the inverter-based microgrid using EMT simulations





Conclusions

- Working with National Grid, we are working to overcome some of the barriers to clean resilience nodes – including adaptive protection, grounding studies, and protection schemes for inverter-based systems
- This demonstration uses a very large battery that can provide power to the entire area and significant fault current. For next steps:
  - Can we provide similar resilience with advanced protection methods and load shedding schemes based on customer criticality that may not require as large of a battery?
  - Can we integrate some of the customer owned backup generation into the microgrid controls and protection?
  - What are the best types of inverter controls and the requirements for percentage of grid-forming inverters in an inverter-based microgrid?
  - How do we incorporate clean resilience nodes into meshed systems like downtown secondary networks?
- Currently we are building the entire microgrid into a digital twin at Sandia's DETL facility for real-time hardware-in-the-loop testing
  - Using battery energy storage grid-forming inverters and relays with the same configuration and settings as the National Grid microgrid
  - Test a range of resilience scenarios and contingency cases

Thank You

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Thank You

GMLC Designing Resilient Communities WEBINAR

Sandia National Labs, Converge Strategies, Synapse, and Partners

April 27, 2021