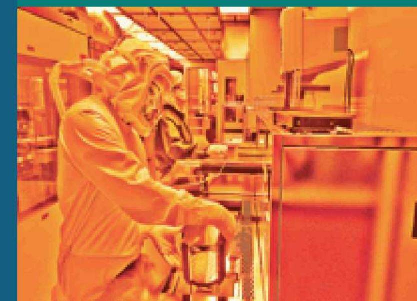
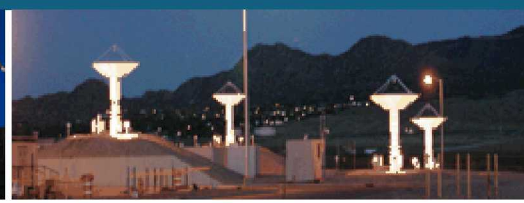
SAND2019-10508PE

Overview of Resilience Planning Framework





PRESENTED BY

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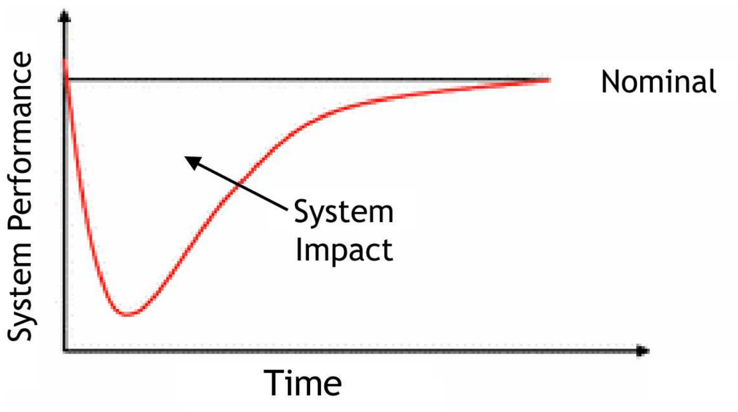
What is Resilience?



Ability to Prepare for, Withstand, and Recover from disruptions caused by major Accidents, Attacks, or Natural Disasters.

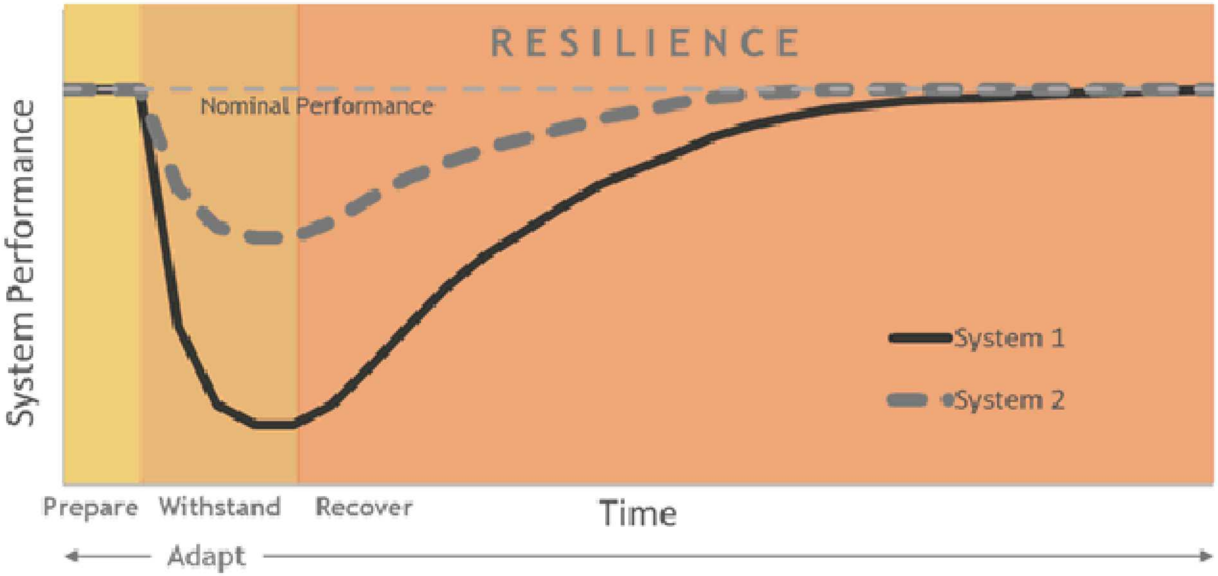
1. Resilience is contextual – defined in terms of threats or hazards
   - A system resilient to hurricanes may not be resilient to earthquakes
2. Includes hazards with low probability but potential for high consequence
   - Naturally fits within a risk-based planning approach…
   - …but difficult to capture this type of risk with high confidence

What is Our Goal?

We want to improve resilience, efficiency (cost-effectiveness), and sustainability of our energy systems. We want to consider these goals concurrently.

To increase the resilience of our system through energy master planning our system should: prepare, withstand, recover, and adapt.

We must be able to *quantify* the improvement.



System 1 and System 2 are two alternative designs of the same energy system experiencing the same disruption. System 2 represents our desired outcome after the EMP process.

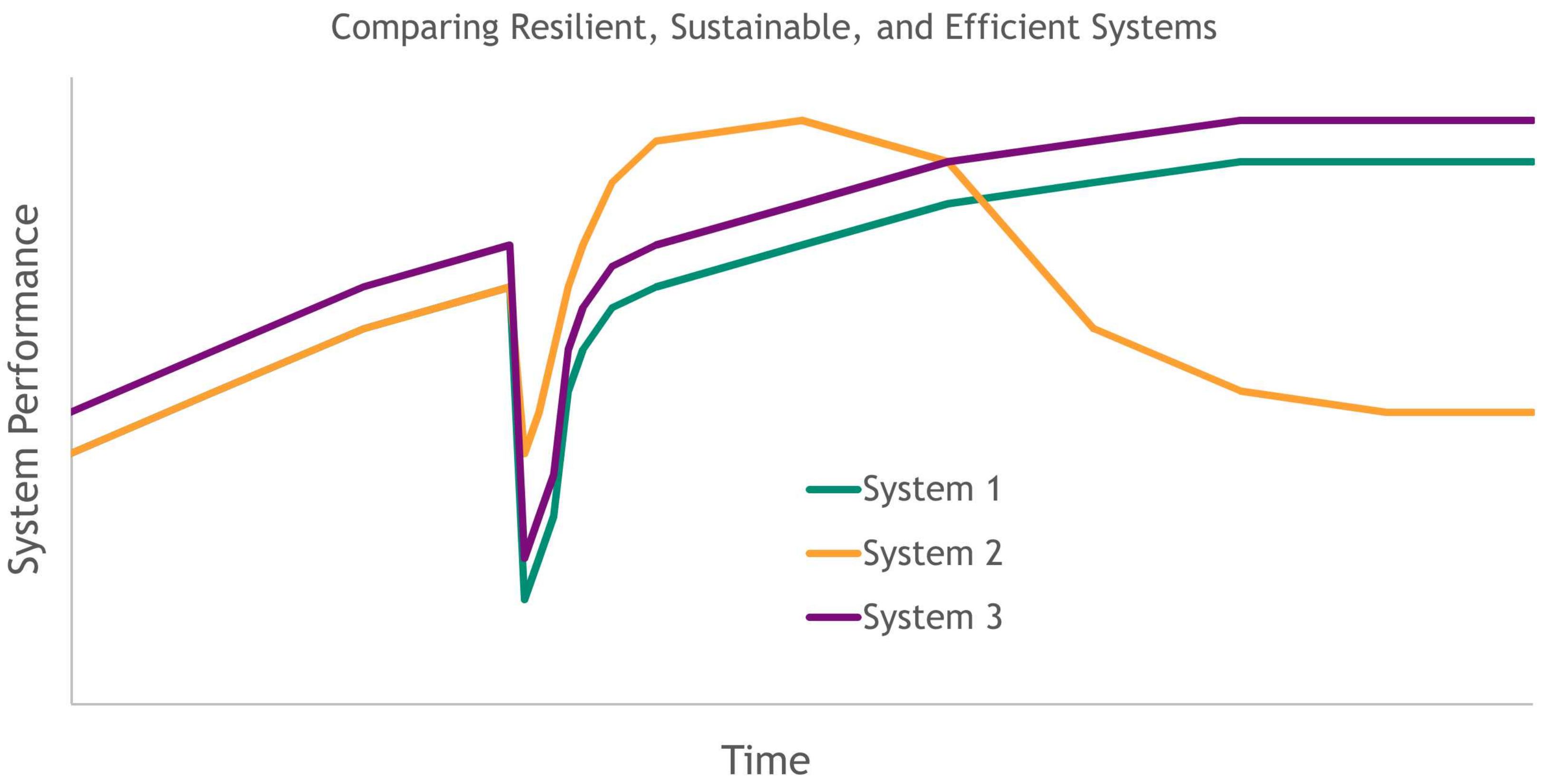
Comparing Efficiency, Sustainability, and Resilience

To avoid "double-counting," we have separated Energy Master Planning goals into three dimensions:

Efficiency: A system that improves performance day to day

Sustainability: A system that avoids long-term (~50+ years) collapse in performance

Resilience: A system that improves performance subject to acute shocks



How Do We Measure Resilience?

More equations will be introduced in individual steps, but overall we can look at the system impact.

$$SI = \int_{t_0}^{t_f} [TSP(t) - SP(t)]dt$$

System Impact

Targeted System Performance (nominal performance w/o disruption)

System Performance subject to disruption

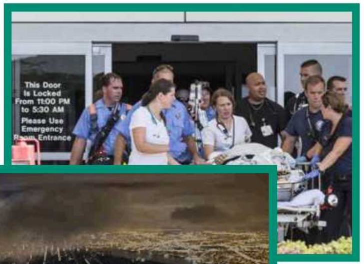
Our goal through the EMP process is to minimize SI for as little cost as possible. We balance this with other goals such as efficiency and sustainability.

How are Resilience and Reliability Related?

Resilience

Includes ***low probability, high consequence*** events.

Not widely adopted. Still working on ***methods, metrics, and tools***

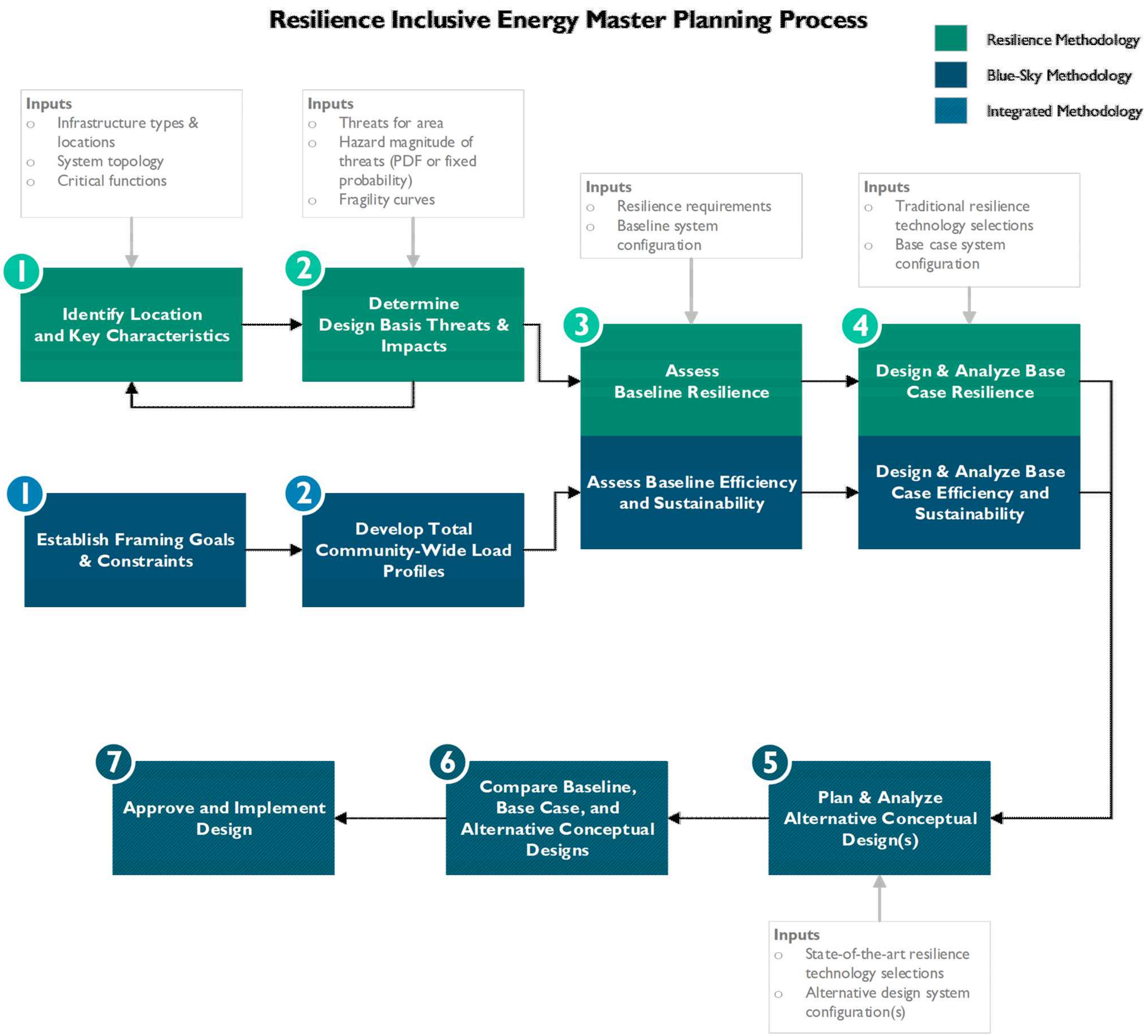


Reliability

Focuses on system performance with respect to **commonly expected events** (component failure, etc.)

Widely adopted for infrastructure investment decision-making

A Resilience-Inclusive Planning Process



Who is This Process For?

- The resilience process is meant to be integrated into the EMP process
- Currently focusing on a framework that can be used for mid-size areas with simplified owner and funding situations such as:

Military Installations

Hospitals

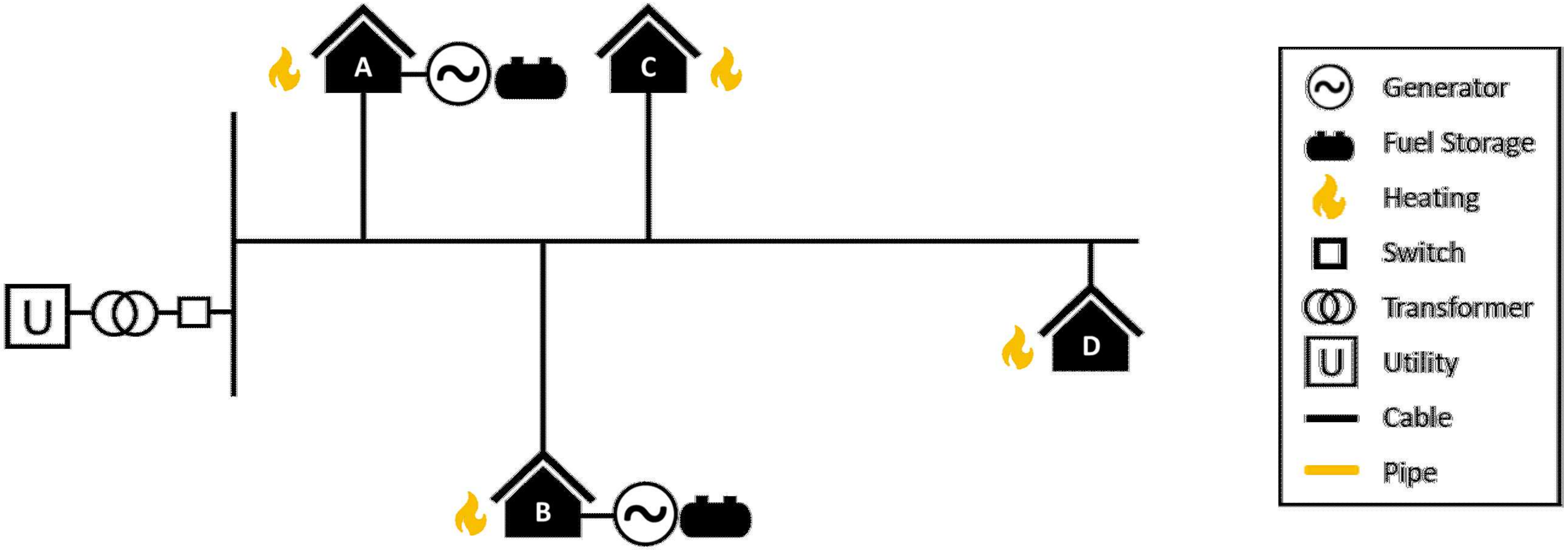
Campuses

Public Housing

- Some methods and processes require systems modeling and/or optimization capabilities
  - Guide describes compromises for these steps if planners don't have these capabilities

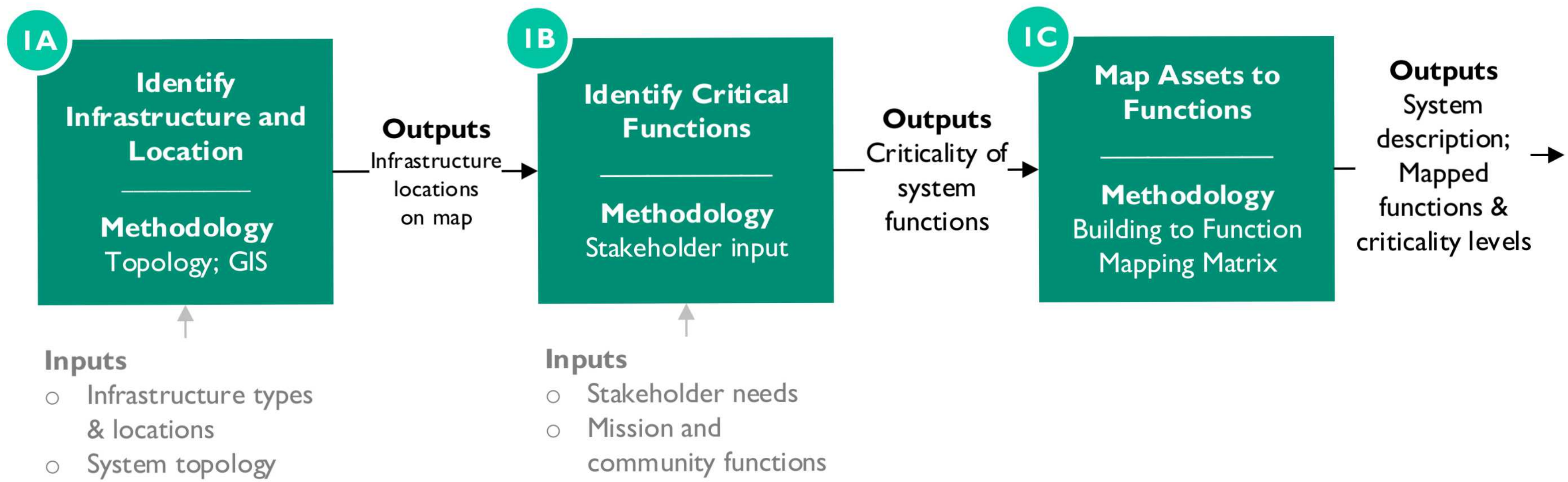
Example Energy System

To illustrate the steps of the resilience planning process, we use a notional energy system.



- Simple radial distribution electrical system design with four buildings
- Electrical bus representing substation on left with facility transformer and breaker switch to the electric utility
- Buildings A & B have backup generators and fuel storage
- All buildings have their own boiler for heat fueled by natural gas

Step 1 Identify Location and Key Characteristics

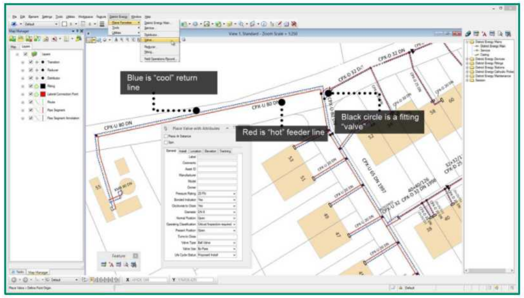


Step 1A: Identify Infrastructure and Location

- Select location to be analyzed (the area of interest, or AOI)
- Identify all buildings and other assets with electrical or thermal loads and record their location
- Map the energy supply system including thermal and electrical assets (transformers, switchgear, conductor, piping, boilers, etc.)
- Include any expected upgrades to infrastructure within planning horizon
- Use GIS to incorporate the multiple data sets

Area of Interest

Building and Asset Locations



Energy Supply System

High-Level Prioritization Risk Equation

- If needed, we can use the following equation to rank the highest priority threats
- All of the metrics for the equation will be calculated by the end of step 2

$$R_t = p_t \sum_f v_{t,f} \, c_f$$

- R_t: Risk index for threat t
- p_t: Likelihood of threat t occurring in a given year
- $v_{t,f}$: Vulnerability of critical function f to threat t
- c_f: Criticality of function f

Step 1B: Identify Critical Functions

- Critical functions enable the area to serve its purpose and can be separated into life-sustaining functions and mission functions
- Focus on providing resilience to functions builds flexibility
  - Many functions can be provided by multiple buildings/assets or only require part of a building
- Identify critical functions and their criticality rating, c_f
  - Criticality rating of 1.0 would be the largest, whereas a rating of 0.0 would indicate purely non-critical

Example Life-Sustaining Functions
Communications
Emergency Logistics
Evacuation
Finance
Food
Fuel
Medical Services
Medications
Restoration
Safety
Security
Shelter
Transportation
Waste Management
Water

Example Mission Functions
Communications
Cybersecurity
Data Management and Storage
Force Mobilization and Deployment
Intelligence
Logistics
Manufacturing and Maintenance
Operational Support
Research and Development
Secure Storage
Security and Force Protection
Strategic Command
Surveillance and Reconnaissance
Training

Critical functions should be assessed in partnership with community planners and/or mission owners

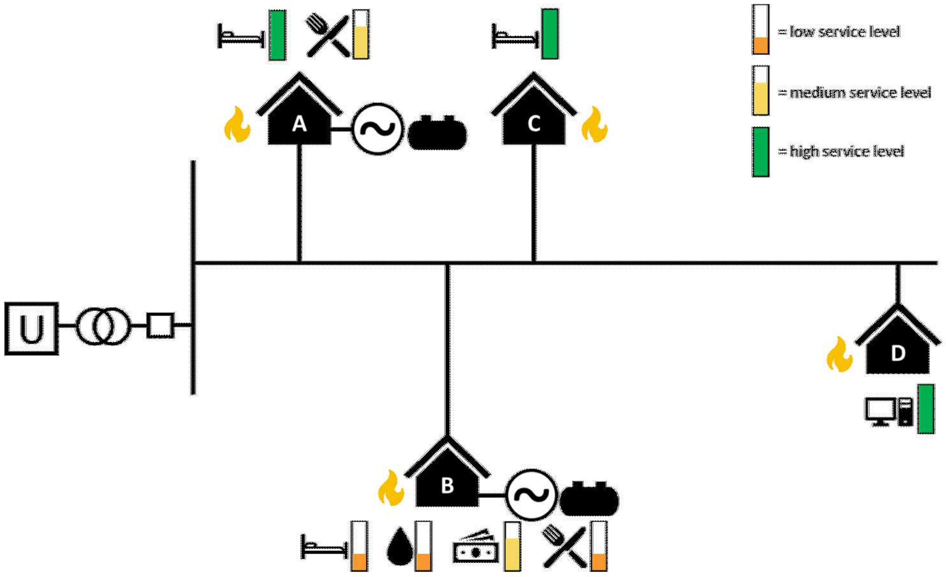
Step 1C: Map Assets to Functions

- In steps 1A and 1B we identified the critical assets and the critical functions. In this step we map the assets to the functions and indicate the ability of that asset to provide or enable the critical function
  - Score of 1.0 would indicate the asset can provide 100% of that function to the AOI
  - Score of 0.5 would indicate ability to provide 50% of that function to the AOI
  - Etc.
- Emergency plans and stakeholder input is needed to understand how assets will operate in emergency situations as opposed to day-to-day scenarios

	Assets and Buildings			
Critical Function	Asset 1	Asset 2	Asset 3	…
Function A				
Function B				
Function C				

Step I Example

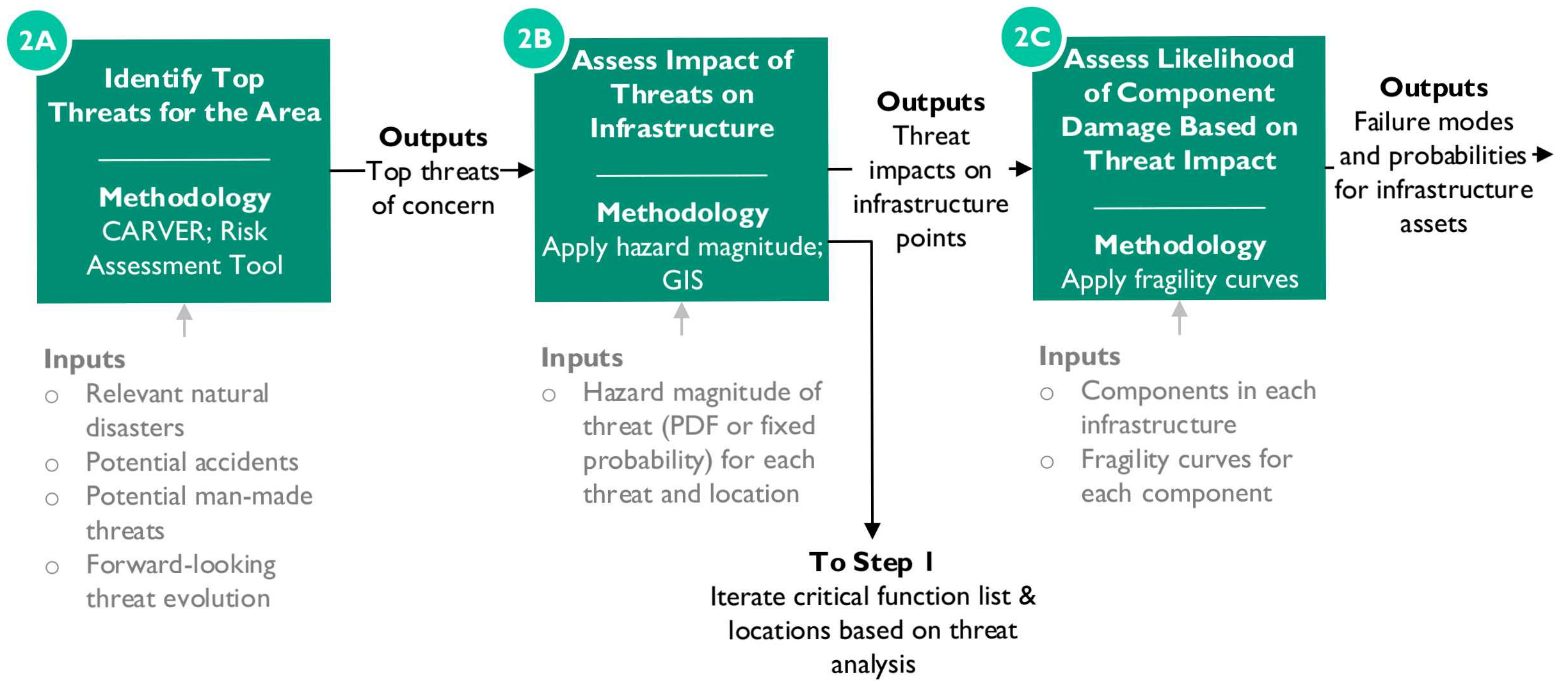
- In the notional example, buildings A, B, C, and D are deemed critical
- For the area (a university campus), the critical functions are shelter, food, finance, water, and IT & data
- Each building and critical function is shown in the matrix, along with what percentage of the function each building provides



Critical Function	Building A	Building B	Building C	Building D
Shelter	1.0	0.5	1.0	
Food	0.75	0.25		
Finance		0.5		
Water		0.25		
IT and Data				1.0

Step 2 Overview

Step 2 Determine Design Basis Threats & Impacts



Step 2A: Identify Top Threats for the Area

- Threats may be man-made, accidents, or natural disasters
- For a given location, planners must down-select to a list of design basis threats (DBTs) that are specific to their area
  - The guide discussions various methods of ranking threats such as THIRA, CARVER, RAT, and the risk management process by ARNORTH

Natural Disasters
Avalanches
Blizzards
Droughts
Earthquakes
Extreme Heat
Floods
Geomagnetic Disturbances (GMD)
Hurricanes/Cyclones/Typhoons
Ice Storms
Landslides
Lightning
Tornadoes
Volcanic Eruptions
Wildfires
Wind

Accidents
Transportation Accidents that Damage Infrastructure
Animals that Cause Power Outages
Untrimmed Vegetation
Equipment Reliability Failures
Infrastructure Damaged by Construction
Infrastructure Failures/Collapses

Man-made Threats
Cyberattacks (insider and outsider)
Electromagnetic Pulses (EMPs)
Physical Attacks on Infrastructure
Riots/Wars
Terrorist Attacks

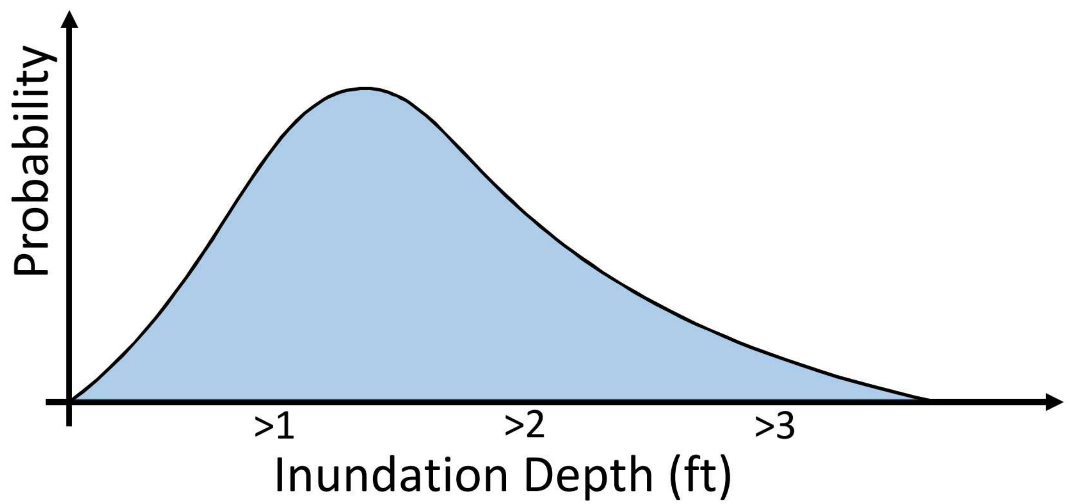
Top threats for the area will be used in the resilience planning process

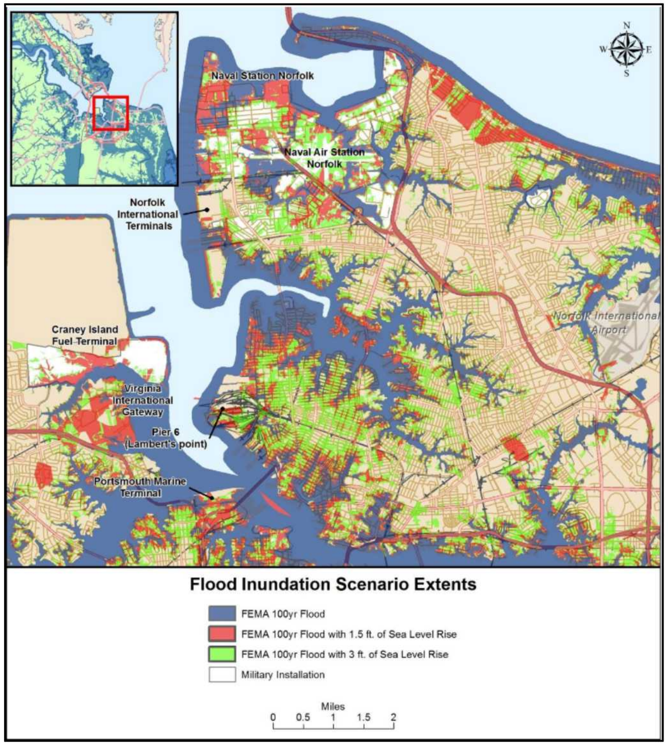
Step 2B: Assess Impact of Threats on Infrastructure

- Apply hazard magnitude (PDF or fixed probability) for each threat at location
- Probabilities may change over the planning horizon
- Want to be forward-looking so may need to use data with simulation model and project out to future years

Sources of Threat Data

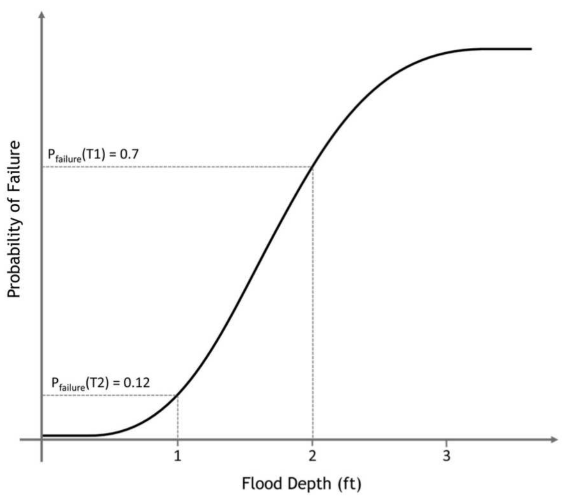
- FEMA: inundation, wind, earthquakes, wildfires
- USGS: landslides
- NOAA: extreme heat, extreme cold, drought
- Sensor/record data

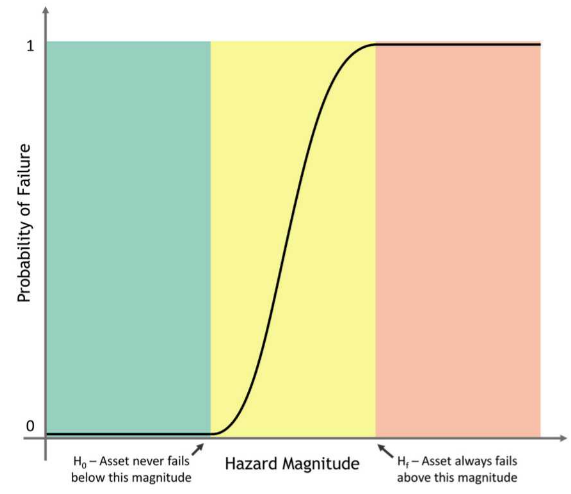




Threat distributions are needed for each threat type/combo and can be obtained from various sources

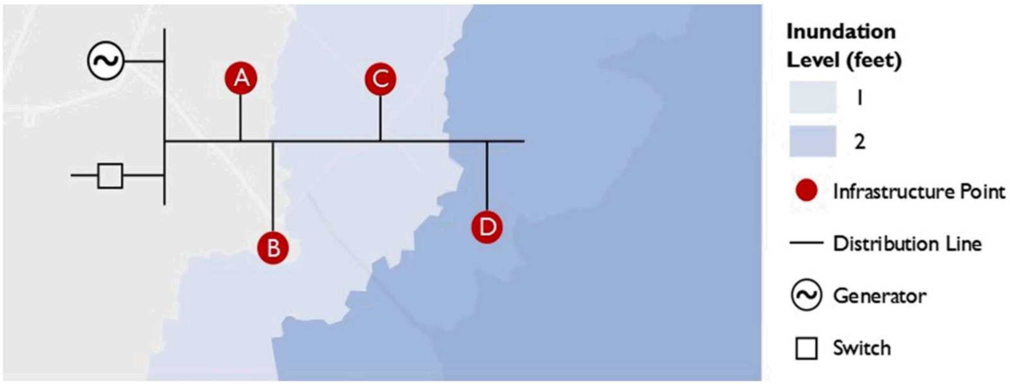
Step 2C: Assess Likelihood of Asset Damage Based on Threat Impact

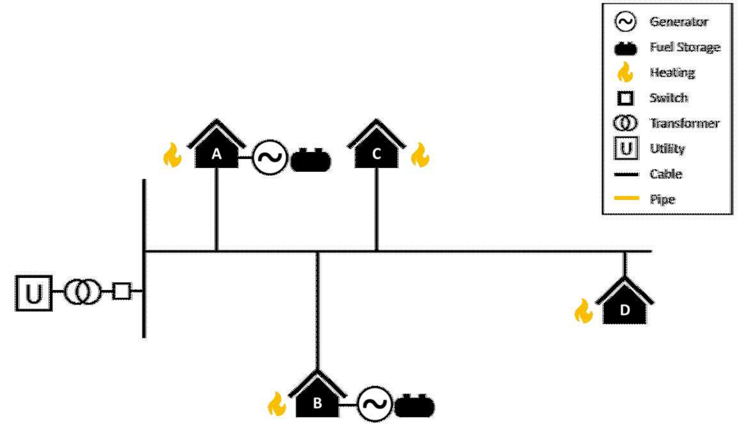




- Once the hazard magnitude for each threat/combination of threats is known for each asset, assess the probability of asset damage using fragility curves
  - Fragility curves are generated by component manufactures and available in literature. There are also fragility curves for different classes of construction for buildings
  - If no fragility curve is available, planner can work with SME to create a fragility curve based on a lower and upper cutoff value (right figure)
- Calculate the vulnerability of each mission function to each DBT
  - Probability that each asset is unable to serve its intended purpose
- Use risk equation on slide 11 to rank risks if needed

Step 2 Example





Critical Function	Building A vulnerability	Building B vulnerability	Building C vulnerability	Building D vulnerability	Water Network vulnerability
Shelter	0	0	0.1		
Food	0	0			
Finance		0			
Water		0			0.5
IT and Data				0.7	

- Buildings A & B have robust backup generation; vulnerability=0
- Based on fragility of transformer serving Building D, the probability of failure to serve energy is estimated at 0.7. Building D is completely dependent on power to serve its function, so vulnerability=0.7
- Building C can provide some service without power. Failure probability for the transformer serving building C is 0.25, but function vulnerability=0.1.

Step 2 Function Vulnerability

By the end of Step 2, we will have all the information necessary to calculate function vulnerability. This equation uses information for Steps 1 and 2.

$$v_f = 1 - \sum_b f_{b,f}(1 - v_b)$$

Function vulnerability

Function contribution of building b to function f (slide 14)

Vulnerability of building b (slide 19)

Function vulnerability cannot be negative, so if equation result in negative value, the vulnerability should be estimated as zero

Step 3 Overview

Step 3 Assess Baseline Resilience

3A Determine Baseline Resilience Requirements

Methodology
Stakeholder input

Inputs
- Required energy availability and maximum allowable outage duration for each function

Outputs
Defined resilience metrics and requirements

3B Assess Current Resilience Levels

Methodology
System performance model of baseline system

Inputs
- System operations and maintenance cost

Outputs
Current energy availability and maximum allowable outage duration by function

3C Evaluate Difference Between Required and Current Resilience Levels

Methodology
Gap analysis

Outputs
Baseline resilience metrics and cost

Step 3A: Determine Baseline Resilience Requirements

- Requirements for energy resilience should be specified for each critical function
- For each function, stakeholders need to determine the required energy availability and the maximum allowable outage duration
- Certain industries (data centers, healthcare facilities, food storage) have already established energy resilience requirements
- In absence of other requirements, the following sets are suggested:
  - Energy Availability: {99.995%, 99%, 95%, 80%, 50%}
  - Maximum Outage Duration: {1, 30, 60, 120, 480} minutes

$$Energy\ Availability = Uptime/(Uptime + Downtime)$$

Critical Function	Required	
	Energy Availability	Max Allowable Outage Duration
Function A		
Function B		
Function C		

Step 3B: Assess Current Resilience Levels

- Once requirements are set, planners will need to evaluate the current system (the baseline) to measure resilience metrics without any investments or enhancements
- If areas have not experienced extreme disruptions and do not have this data, systems modeling should be used to generate the baseline resilience performance
  - Model can describe the energy system when disrupted for resilience and can also look at the system under blue-sky conditions

	Baseline	
Critical Function	**Energy Availability**	**Max Allowable Outage Duration**
Function A		
Function B		
Function C		

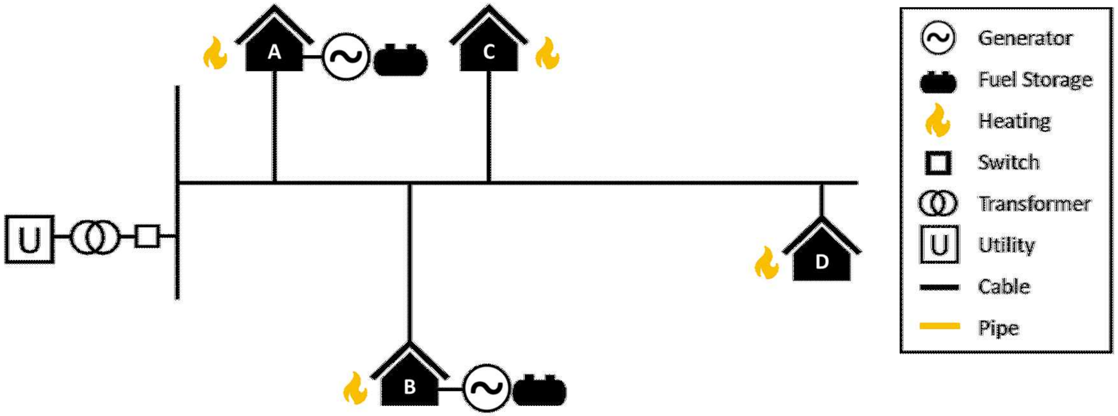
Step 3C: Evaluate Difference Between Required and Current Resilience Levels

- The final step is to evaluate the differences in resilience metrics between the baseline and the requirements for each function
- If areas have not experienced extreme disruptions and do not have this data, systems modeling should be used to generate the baseline resilience performance
  - Model can describe the energy system when disrupted for resilience and can also look at the system under blue-sky conditions
- Power quality is not a resilience metric but rather a constraint when optimizing a system for both resilience and blue-sky performance, and should be considered during the planning process as a metric of underlying component systems

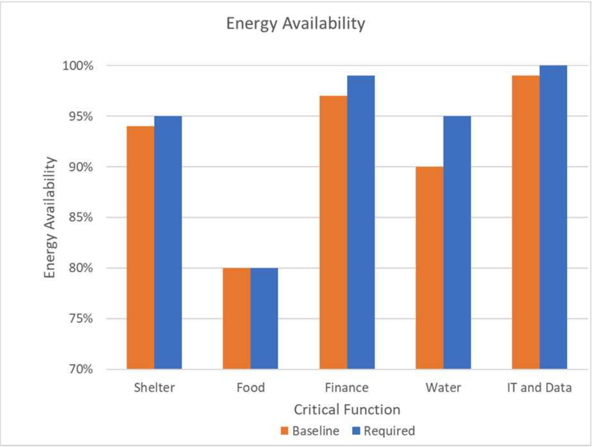
	Required		Baseline	
Critical Function	**Energy Availability**	**Max Allowable Outage Duration**	**Energy Availability**	**Max Observed Outage Duration**
Function A				
Function B				
Function C				

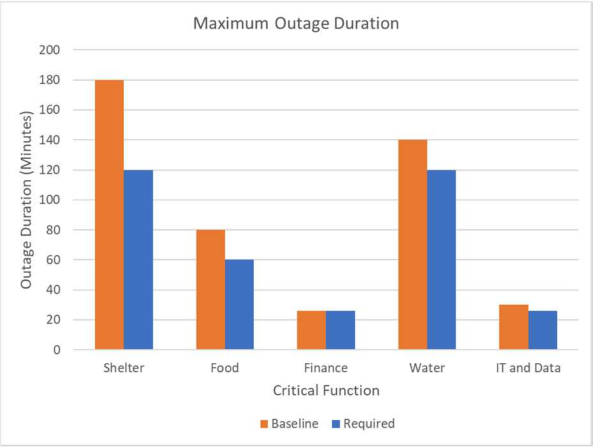
Gaps between baseline metrics and requirements must be addressed in base case and alternative designs

Step 3 Example



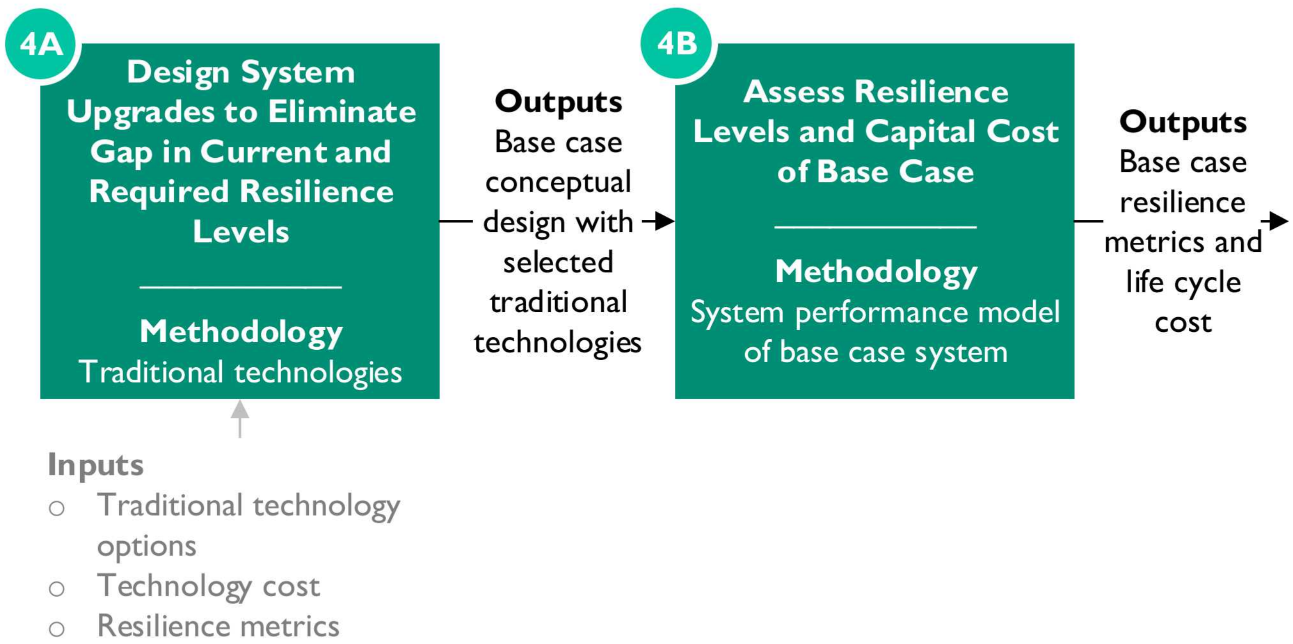
	Required		Baseline	
Critical Function	Energy Availability	Max Allowable Outage Duration (minutes)	Energy Availability	Max Observed Outage Duration (minutes)
Shelter	95.0%	120	94.0%	180
Food	80.0%	60	80.0%	80
Finance	99.0%	26	98.0%	26
Water	95.0%	120	90.0%	140
IT and Data	99.995%	26	99.0%	30





Step 4 Overview

Step 4 Design and Analyze Base Case Resilience



Step 4A: Design System Upgrades to Eliminate Gap in Current and Required Resilience Levels

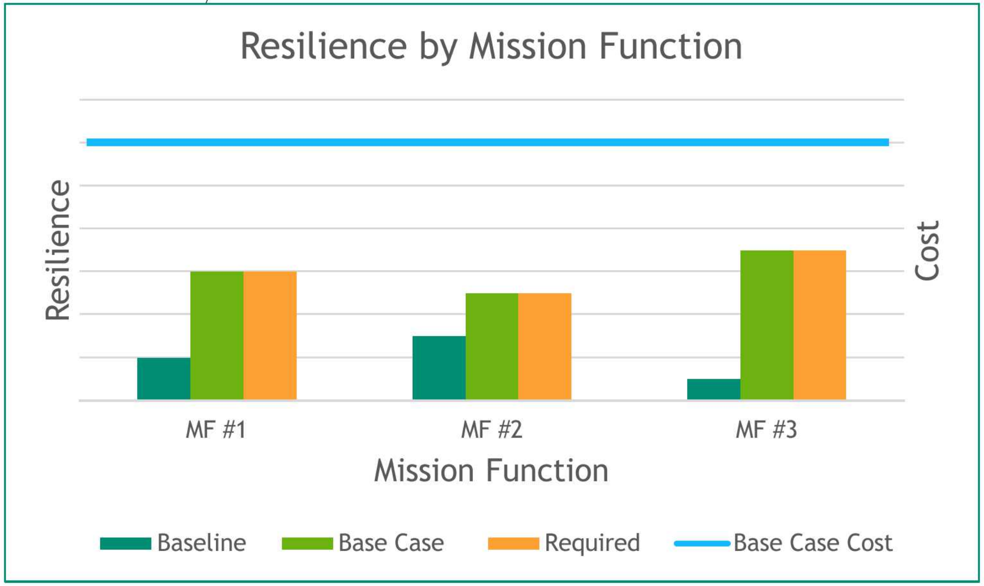
- The base case will be the first conceptual design made to improve resilience
- Solutions will include traditional technologies
- The base case conceptual design must enable the system to meet resilience requirements
- Planners should also explore the possibility of relocating functions when possible
- Cost of the base case conceptual design should also be tracked

Traditional Technology Options

- Local backup boilers
- Local backup diesel generators
- UPS
- Fuel storage
- Strengthen overhead lines
- Replace overhead lines with underground lines
- Physical protection for existing assets
- Add extra systems to ensure n+1 local redundancy

Step 4B: Assess Resilience Levels and Capital Cost of Base Case

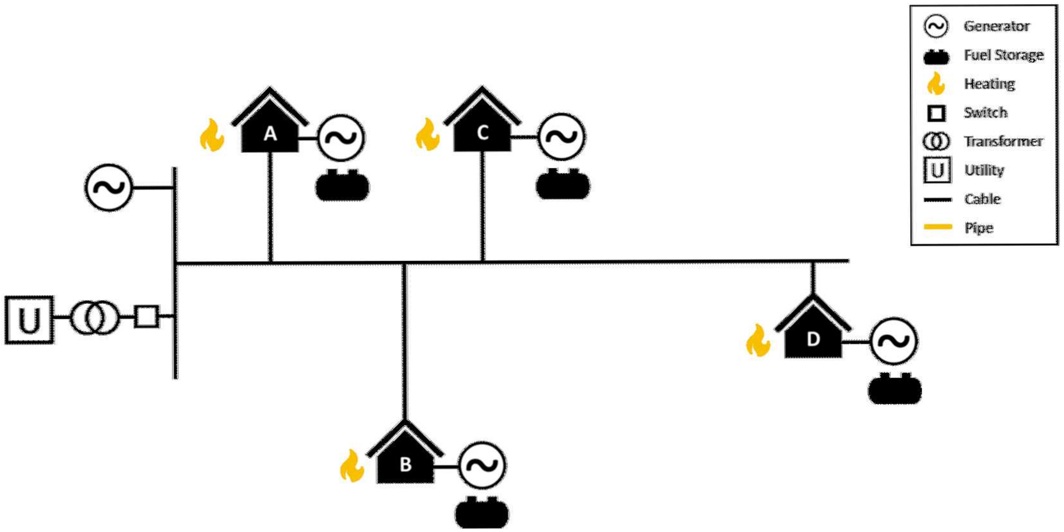
- Once the base case conceptual design is complete, planners should use a systems model to compute resilience metrics
  - This may be an iterative process to ensure the system is not under- or over-built
- Planners should record the metrics and cost of the conceptual design
- Base case must meet resilience requirements
  - Meeting requirements may lead to high costs when using off-the-shelf technology options, particularly if including n+1 redundancy

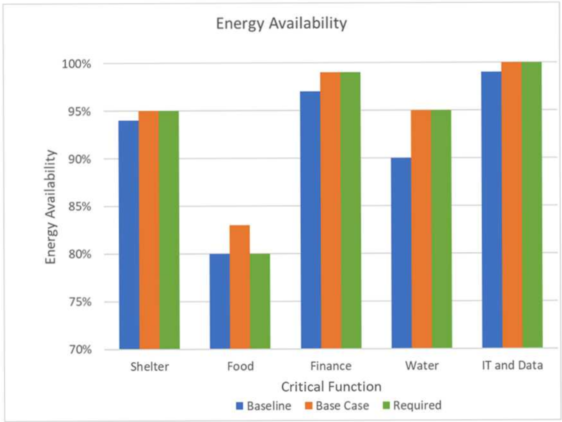


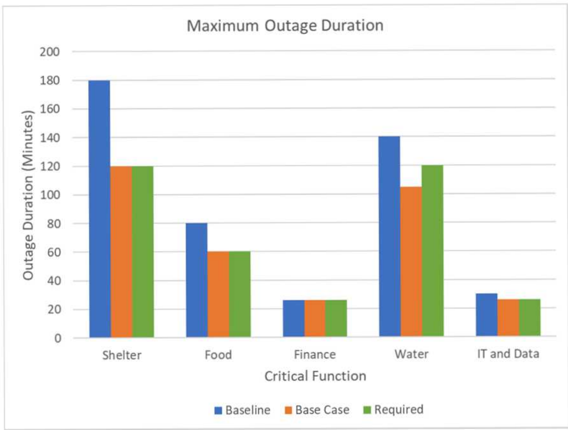
Base case design meets resilience requirements but may have high costs

Step 4 Example

For the notional system, the most straightforward way to increase resilience is to add backup generators to buildings C and D which would normally experience an outage if the utility and/or distribution conductor goes down.



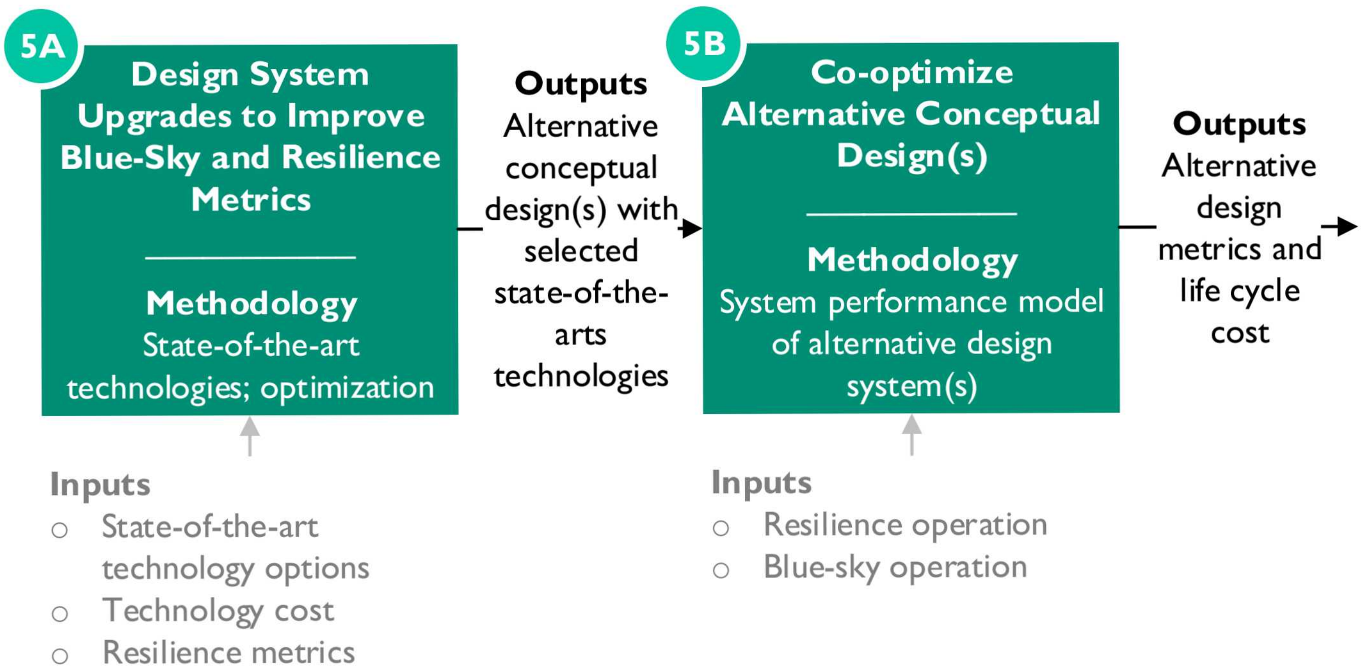




	Required		Base Case Design	
Critical Function	**Energy Availability**	**Max Allowable Outage Duration (minutes)**	**Energy Availability**	**Max Observed Outage Duration (minutes)**
Shelter	95.0%	120	95.0%	120
Food	80.0%	60	83.0%	60
Finance	99.0%	26	99.0%	26
Water	95.0%	120	95.0%	105
IT and Data	99.995%	26	99.995%	26

Step 5 Overview

Step 5 Plan and Analyze Alternative Conceptual Design(s)



Step 5A: Design System Upgrades to Increase Resilience and Lower Cost

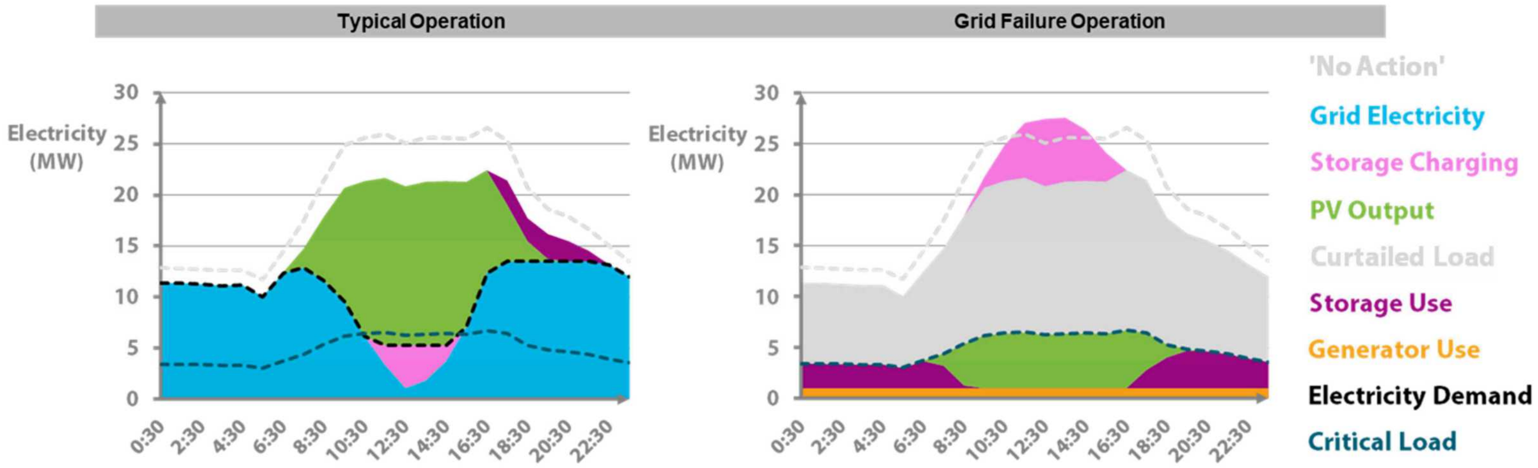
- Alternative designs will be developed to further improve resilience and/or decrease the capital cost as compared to the baseline and base case designs
- Solutions may include state-of-the-art technologies, system mitigation, and optimal technology selection and placement within the system
- Technologies must be feasible for an area both in footprint and in function

Example State-of-the-Art Technology Options

- Low and medium temperature district heating networks
- High temperature district cooling networks
- Efficient electric heat pumps
- Combined cooling, heat, and power (CCHP) with ad-/absorption cooling systems
- Power-to-heat systems
- Large scale electrical storage systems
- Short term and seasonal thermal systems
- Microgrids
- Alternative electrical distribution topologies
- Distributed and district solar PV and hot water systems
- Centralized flexible power generation
- Distribution system automation
- Waste heat
- Regenerative technologies

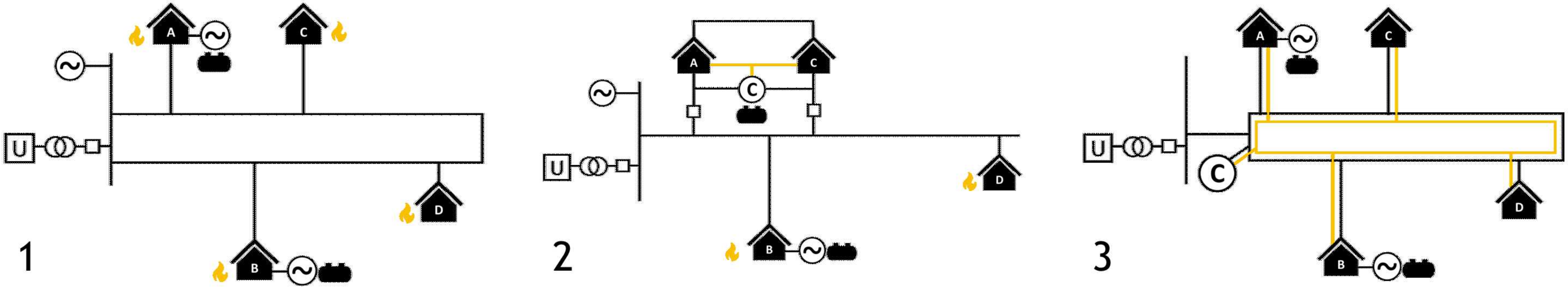
Step 5B: Co-optimize Alternative Conceptual Design(s)

- Once the alternative conceptual design(s) is complete, planners should use a systems model to compute resilience metrics
- Planners should record the metrics and cost of each of the alternative conceptual designs
- Planners should consider co-designing systems accounting for both blue- and black-sky operations for maximized performance since systems may exhibit additional financial justification through operation during normal blue-sky conditions



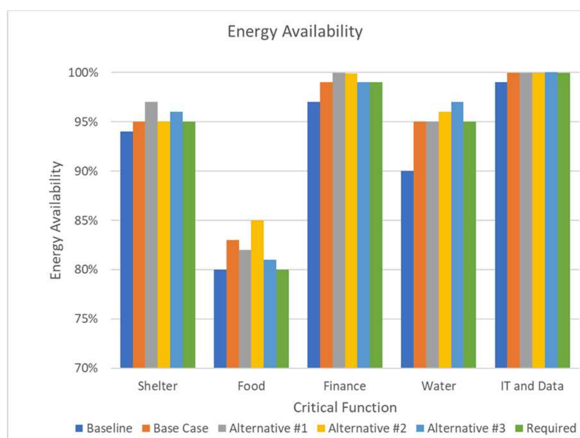
Alternative designs use new technologies and/or optimization to meet or exceed resilience requirements while minimizing cost

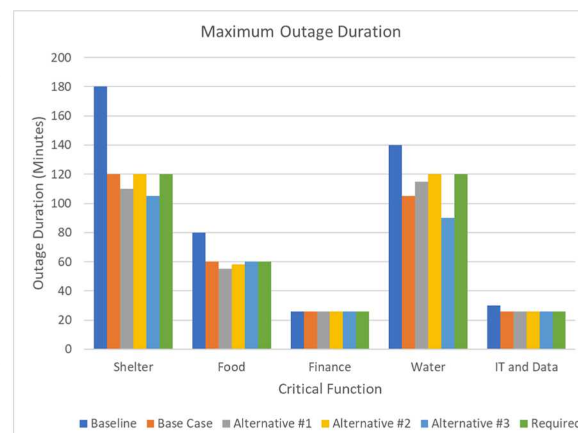
Step 5 Example



	Required		Alternative Conceptual Design #1		Alternative Conceptual Design #2		Alternative Conceptual Design #3	
Critical Function	Energy Availability	Max Allowable Outage Duration (minutes)	Energy Availability	Max Observed Outage Duration (minutes)	Energy Availability	Max Observed Outage Duration (minutes)	Energy Availability	Max Observed Outage Duration (minutes)
Shelter	95.0%	120	97.0%	110	95.0%	120	96.0%	105
Food	80.0%	60	82.0%	55	85.0%	58	81.0%	60
Finance	99.0%	26	99.99%	26	99.99%	26	99.0%	26
Water	95.0%	120	95.0%	115	95.0%	120	97.0%	90
IT and Data	99.995%	26	99.995%	26	99.995%	26	99.999%	26

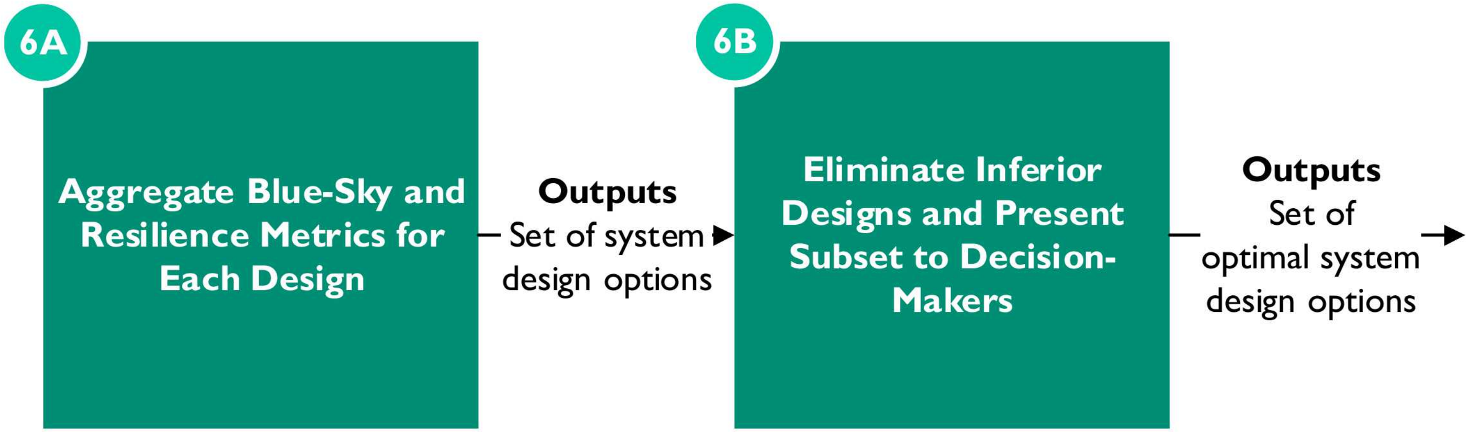
- Design 1: Change from radial network to loop system
- Design 2: Network buildings A & C into small microgrid and provide heat and power through CCHP system
- Design 3: Expand microgrid and CCHP to all four buildings





Step 6 Overview

Step 6 Compare Baseline, Base Case, and Alternative Conceptual Designs



Step 6A: Aggregate Blue-Sky and Resilience Metrics for Each Design

- For each design, planners will need to calculate the following metrics:
  - Blue Sky Performance (measured in U.S. Dollars)
  - Resilience Performance (unitless, value of 1.0 indicates all requirements met exactly)

$$BlueSkyPerformance$$
$$= EndOfLifeValue - CapEx$$
$$+NPV(-ElectricityPurchases$$
$$-GasPurchases - O\&M - EmissionsCost)$$

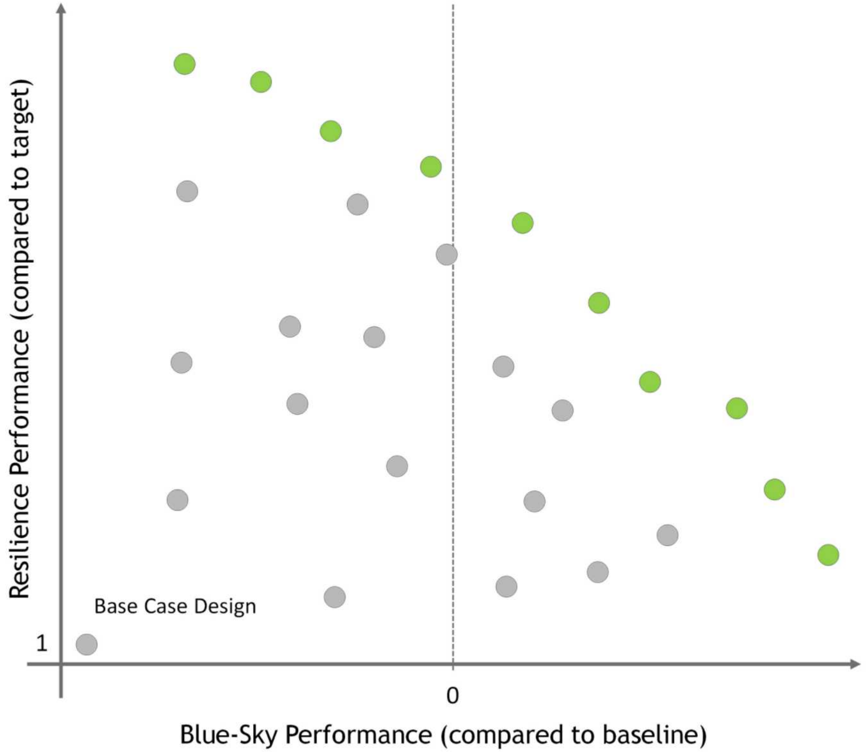
$$Resilience\ Performance = \frac{\sum_{i=1}^{n}\left[FC * 0.5 * [Achievement(EA) + Achievement(MD)]\right]_i}{\sum_{i=1}^{n} FC_i}$$

$$Achievement = \begin{cases} 0, metric < target \\ 1 + a * (metric - target), metric \geq target \end{cases}$$

Alternative designs must attempt to improve both blue-sky and resilience performance compared to the baseline

Step 6B: Eliminate Inferior Designs and Present Subset to Decision-Makers

- Designs can be compared in two dimensions—resilience performance and blue-sky performance
- Green dots show designs that are Pareto-efficient—designs can't be improved in one dimension without decreasing performance in the other dimension
- Gray dots show designs that are sub-optimal—there is another design that is better in at least one dimension
- Base case design has no blue-sky gains so some designs have higher life-cycle cost than the baseline and show negative blue-sky performance
- Designs represented by green dots should be presented to decision-makers for consideration



Step 7 Overview

Step 7 Approve and Implement Design

After the baseline, base case, and all alternative options have been designed and evaluated, the planner should select the desired design based on comparison of metrics. The selected design becomes the guideline for an A&E firm.

Conclusions

- This process focuses on quantifying resilience for communities and installations. Resilience has been largely overlooked in past energy planning processes.

- This resilience inclusive process is designed to integrate into the current EMP process and work together with the blue-sky analysis

- More work still needs to be done on tools that can be used for resilience in EMP, but this group is making progress and we're happy to help!