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Sandia National Laboratories

Energy Resilience for the Americas

Frameworks, Tools, Applications, and Experiences in Reinforcing Energy Systems

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U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Outline

- Critical Infrastructure Resilience
  - Motivation and Definitions
- Framework and Tools
  - Early Sandia work in critical infrastructure resilience
  - Resilience Frameworks
  - Conceptual Design and Design Optimization
  - Conceptual Design Tools – MDT
- Application Examples
  - City-scale energy resilience – New Orleans, Louisiana
  - Rural community – Shungnak, Alaska
  - Transportation system – NJ TransitGrid (appendix)
- Summary

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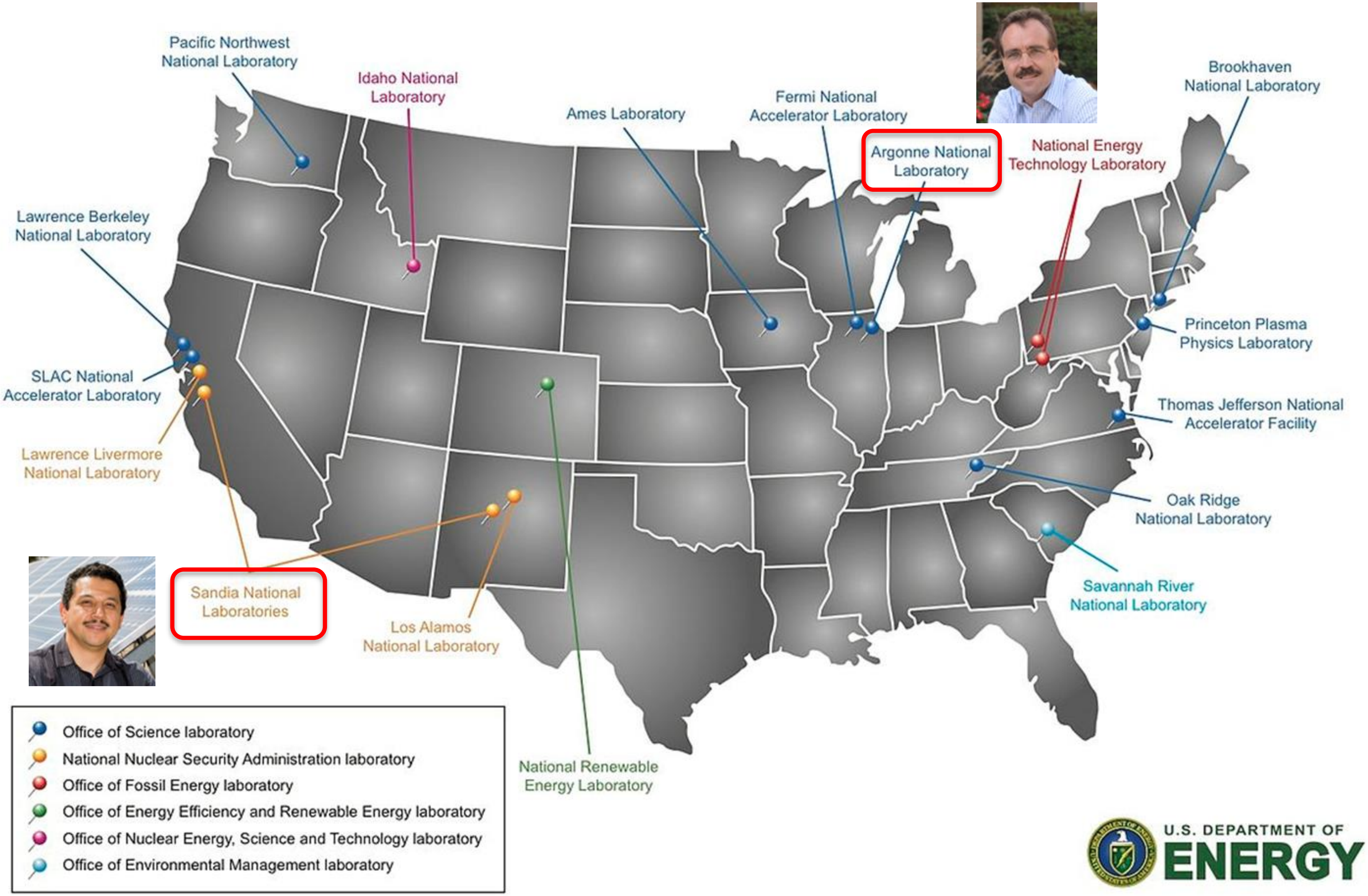
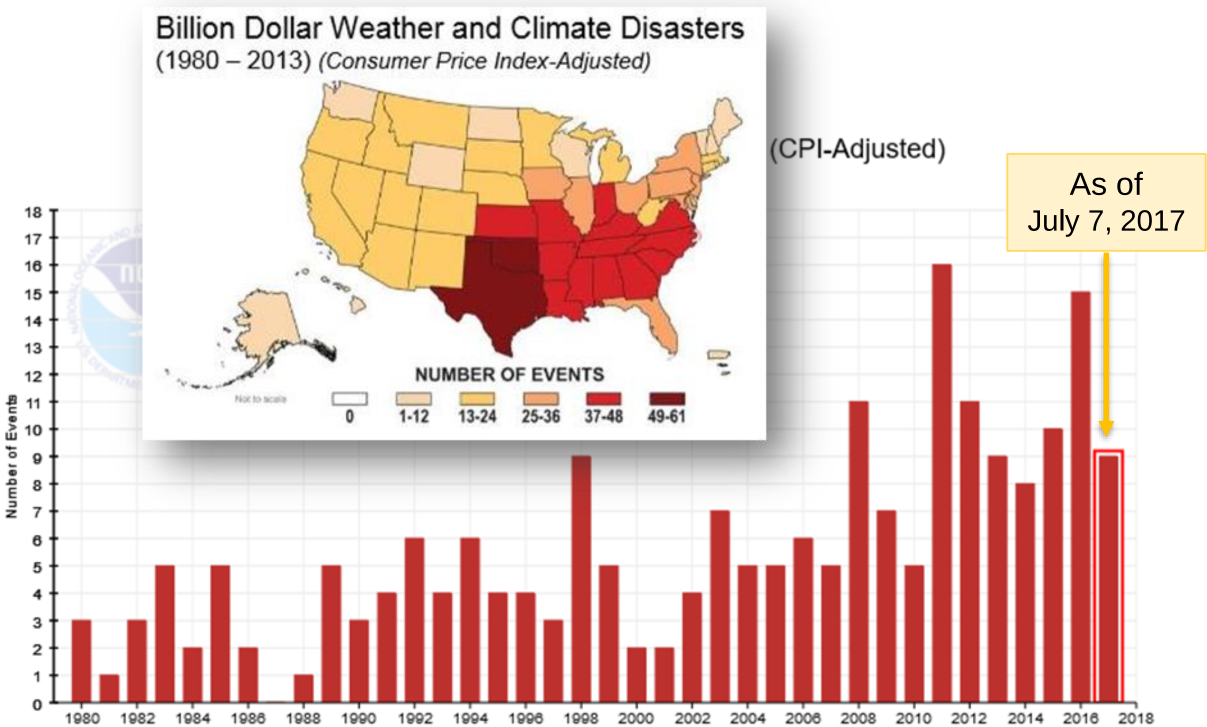
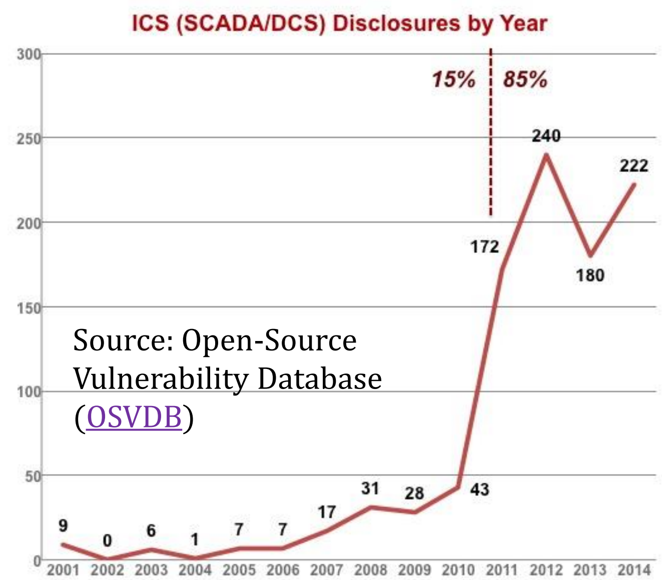


Critical Infrastructure Resilience

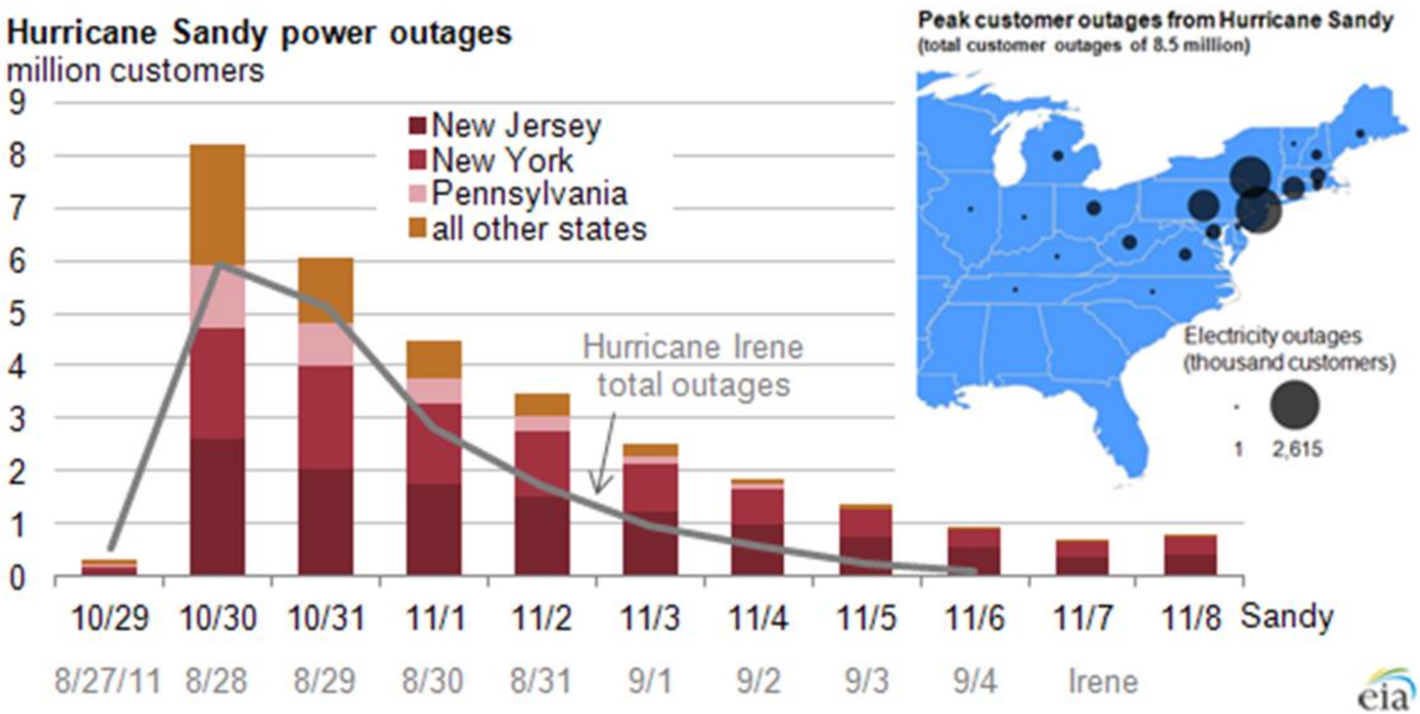
- U.S. critical infrastructure threats are becoming more frequent
- The electric grid is specially vulnerable
  - Weather-related power outages cause $25 to $70 billion of economic losses annually in the United States.





Superstorm Sandy, 2012

- Largest power system disruption in U.S. history
  - 110 deaths (U.S.), $63 billion in cost
  - Electricity outage affected 8.7 million customers
  - Took 2 weeks to restore service to 90% of customers affected



Critical Infrastructure Resilience Policy

- 2013 Presidential Policy Directive 21 (PPD21) – Critical Infrastructure Security and Resilience
  - *It is the policy of the United States to strengthen the **security and resilience** of its critical infrastructure… considering **all hazards** that could impact **national security, economic stability, public health and safety**…*
  - *…shall address the security and resilience… in an **integrated, holistic manner** to reflect this infrastructure's **interconnectedness and interdependency**. …identifies **energy and communications systems as uniquely critical** due to the enabling functions they provide across all critical infrastructure sectors.*

PPD-21 Resilience Definitions & Scope

- "Resilience"
  - *Ability to **prepare** for and **adapt** to changing conditions and **withstand** and **recover** rapidly from disruptions… includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents.*
- "All hazards" include **low probability, high consequence** events
  - *It includes **natural disasters, cyber incidents, industrial accidents, pandemics, acts of terrorism, sabotage, and destructive criminal activity** targeting critical infrastructure*.

Reliability and Resilience

Resilience

Resilience **encompasses** the concept of Reliability.

Focuses on ***low probability high consequence*** events.

Methods, metrics and tools are ***not well established or adopted.***

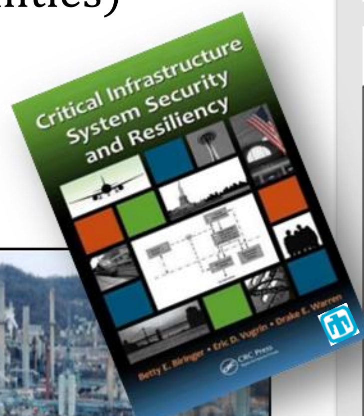
Reliability

Focuses on likely events such as failure or malfunction of system components, one at the time.

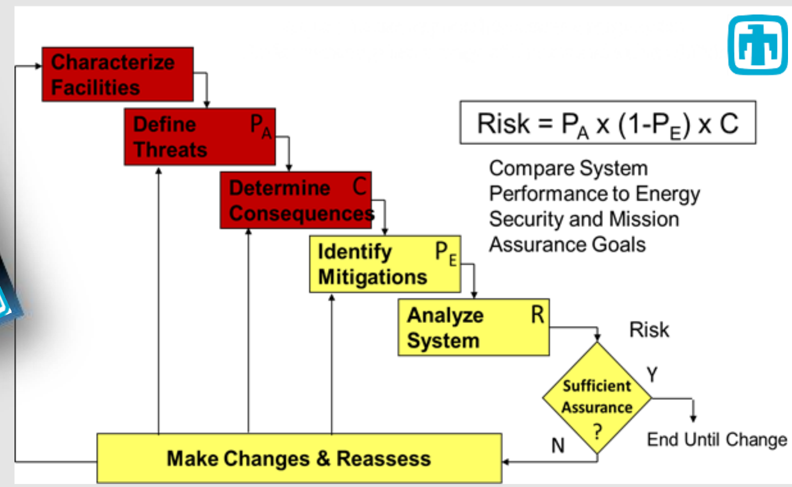
Methods, metrics and tools are well established and adopted.

Early Sandia Resilience R&D Work

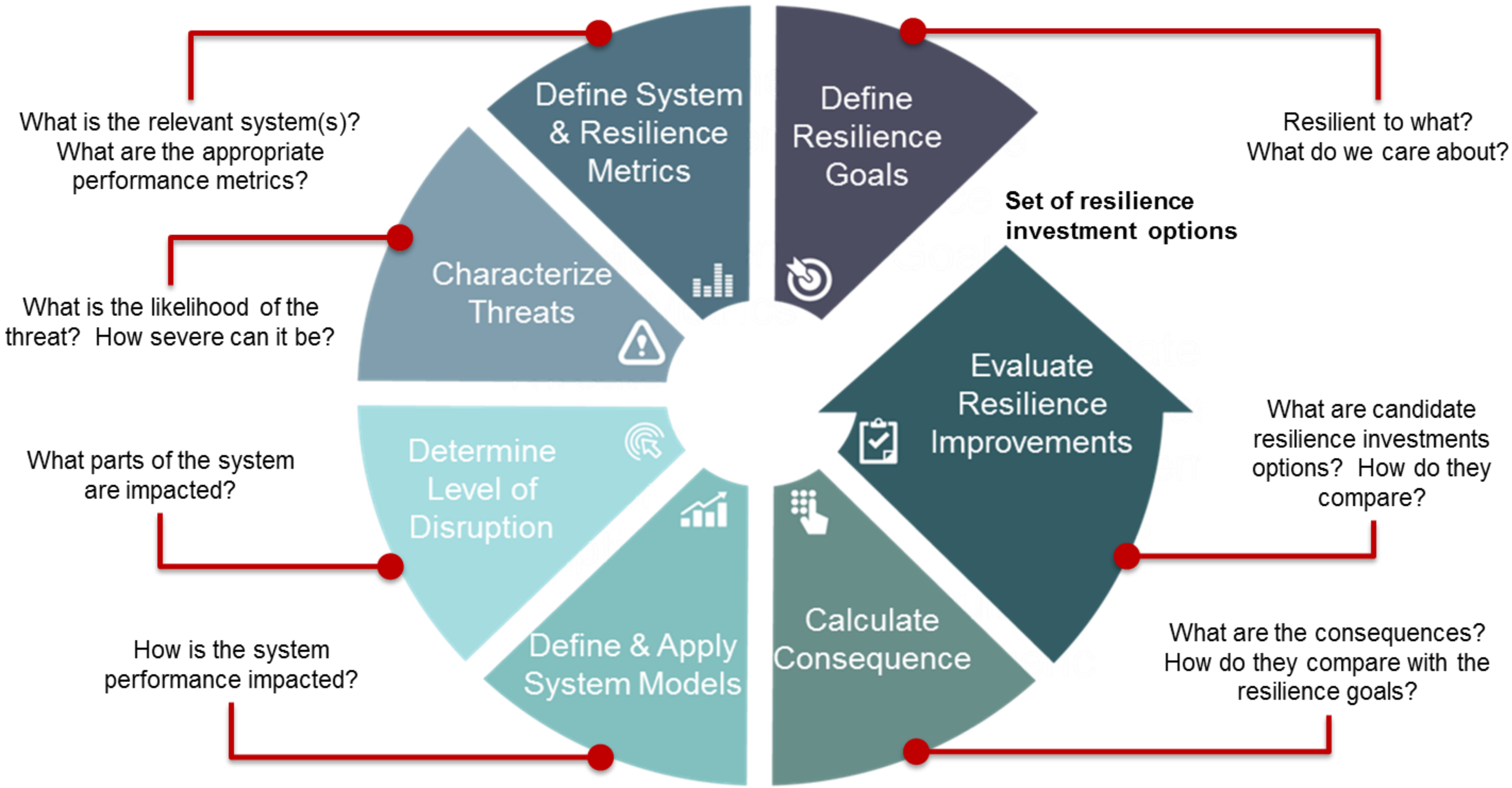
- Infrastructure Security Risk Assessment Methodology (RAM)
  - RAM-D (Dams)
  - RAM-T (Transmission)
  - RAM-W (Municipal Water)
  - RAM-C (Communities)
  - RAM-CF (Chemical Facilities)
  - RAM-E (Energy Systems)
  - RAM-FAA (Airspace facilities)
  - BioRAM (Bio hazards)
  - RAM-C (Communities)



Sandia RAM Framework & Software Tools

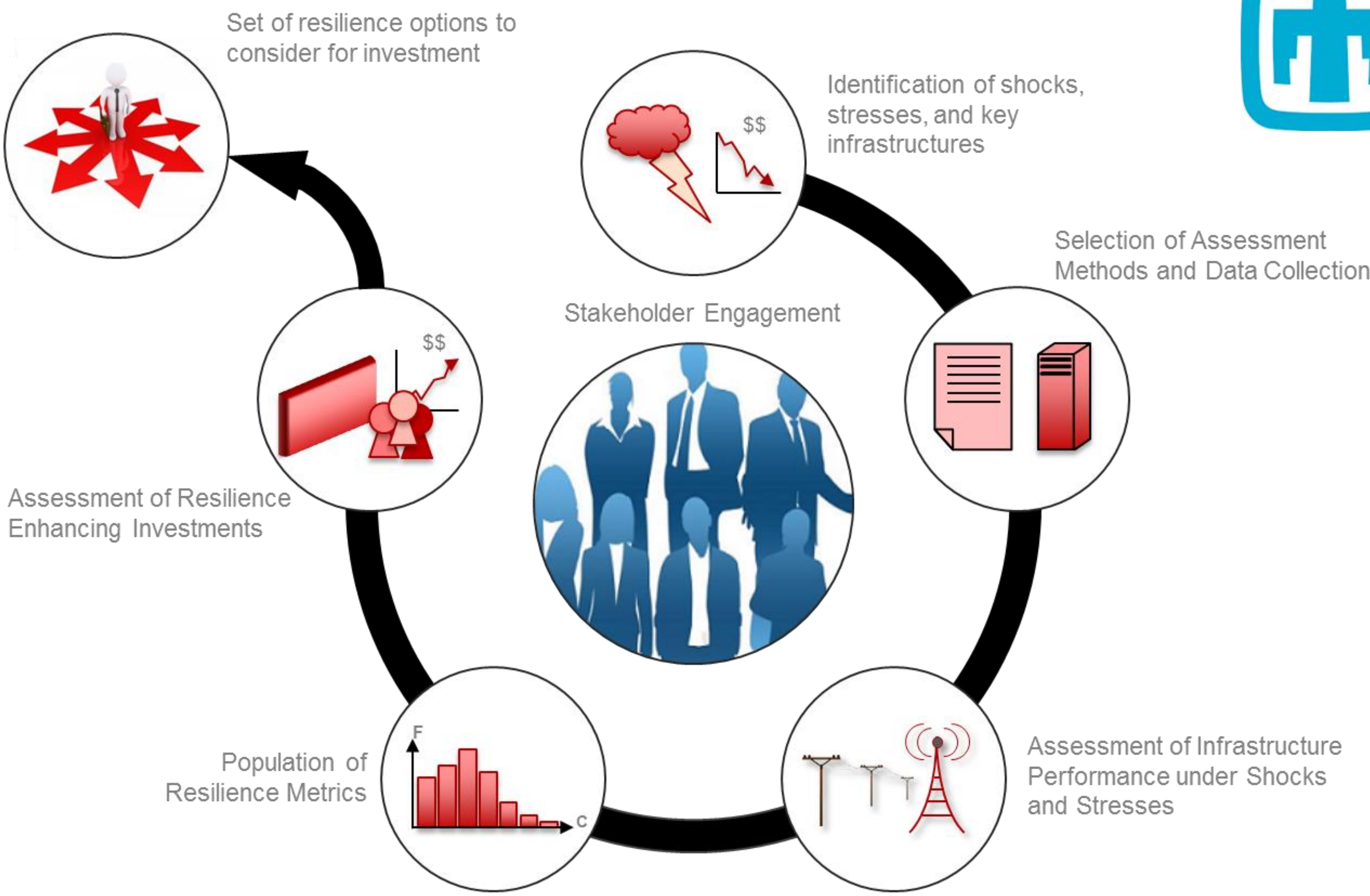


Sandia Resilience Analysis Framework



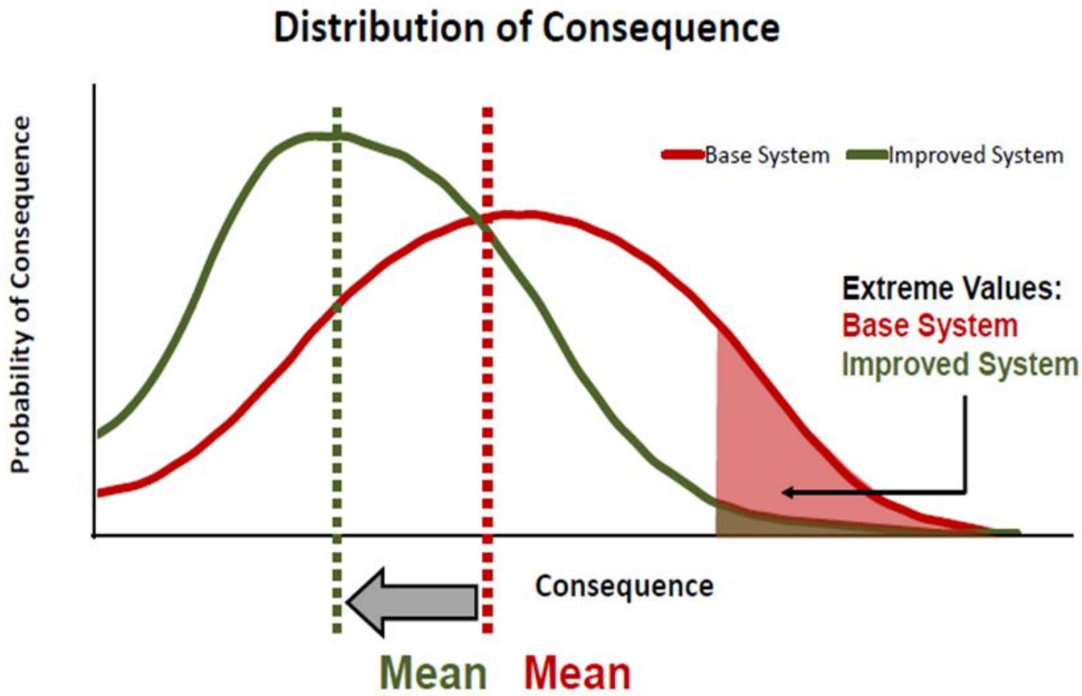
Source: SAND2014-18019—September 2014
A Resilience Framework published in the 2015 Quadrennial Energy Report (QER)

Urban Resilience Analysis Framework



Resilience Metrics – Desired Attributes

- Specific to the threat (*resilience to what?)*
- Performance-based (*how resilient is the system?)* or attribute-based (*what makes the system resilient?*)
- Expressed in terms of ***consequences***
- Risk-based (probabilistic)
- Consistent
- Scalable
- Practical



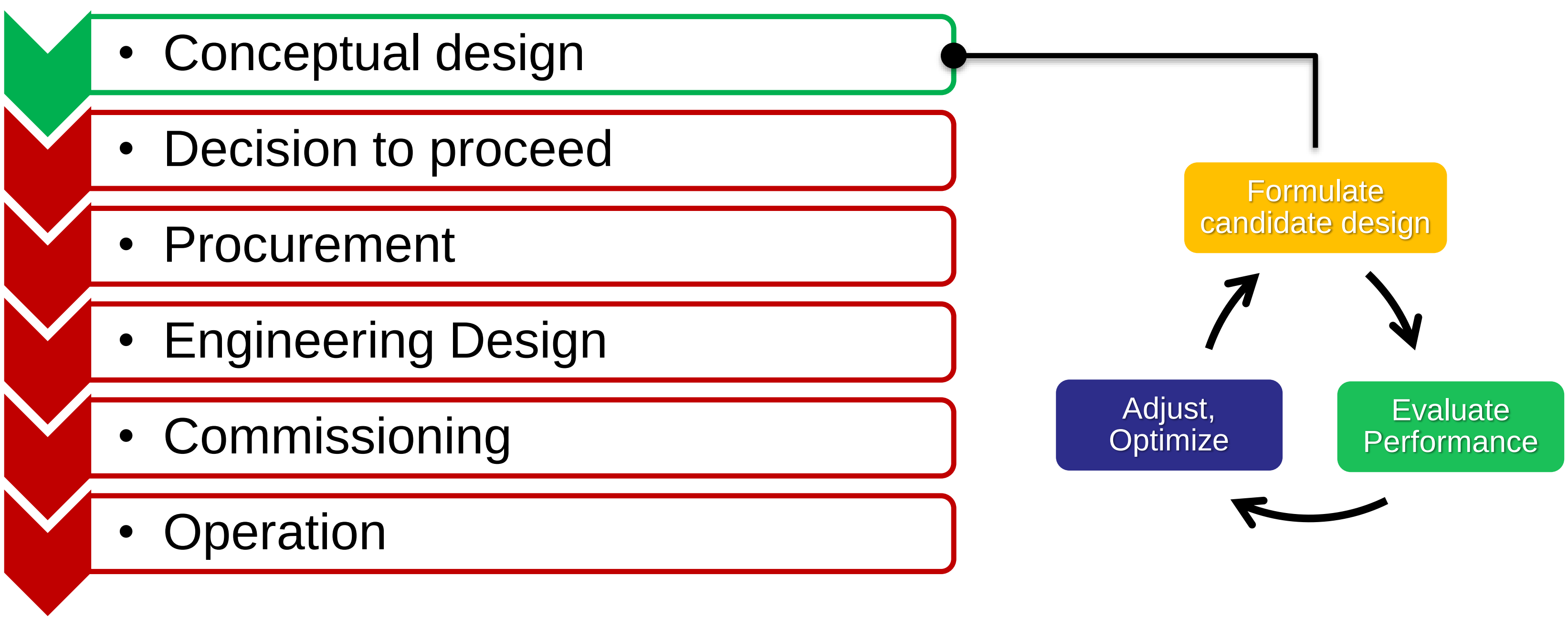
Resilience Metrics

- Typically, multiple resilience metrics are considered

Category	Resilience Metric
Electrical Service	• Cumulative customer-hours of outages • Cumulative customer energy demand not served • Number or % of customers experiencing an outage
Critical Electrical Service	• Cumulative critical customer-hours affected by outages • Critical customer energy demand not served • Number or % of critical loads that experience an outage • Critical services without power (hospitals, fire stations, etc.)
Social and Economic Impact	• Number of people without access to critical services • Cost of recovery effort • Loss of revenue or economic activity • Cost to repair/replace damaged equipment (transformers, etc.)

Investment Options: Conceptual Design

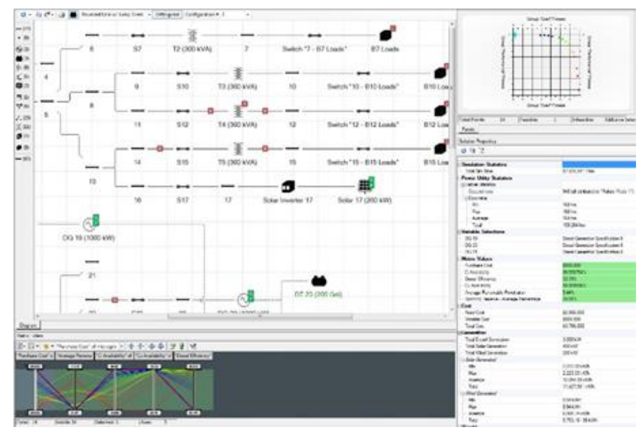
- A resilience framework compares conceptual designs options
  - Technical description of candidate resilience improvements and their respective cost estimates
  - Could involve optimization and analysis of trade-offs among options
- Useful engage stakeholders and drive decision-making



Design Optimization Tools

Sandia Microgrid Design Toolkit (MDT)

- A decision support tool for early-stage resilience design involving microgrids.
- Has functions to identify and compare microgrid design options in terms of user defined objectives such as cost, performance, and reliability.
- Provides many views and features to help explore that trade space and extract information.
- Publically available
  - http://www.energy.gov/oe/services/technology-development/smart-grid/role-microgrids-helping-advance-nation-s-energy-syst-0



Microgrid Design Toolkit (MDT)

Mission Requirements and Baseline Models

- **Equipment deployed creates demand**
- **Or demand (load) models**
- **Or custom load models**

Equipment Data Base

- **Energy demand/production**
- **Usage specification**
- **Reliability information**

Technology Options and User Inputs

- **Identify energy producers and technology options**
- **Select location & season (solar and/or wind profile)**
- **Reliability and maintenance cost data**
- **Select user mode**
  - Performance analysis
  - Parametric study
  - Optimization

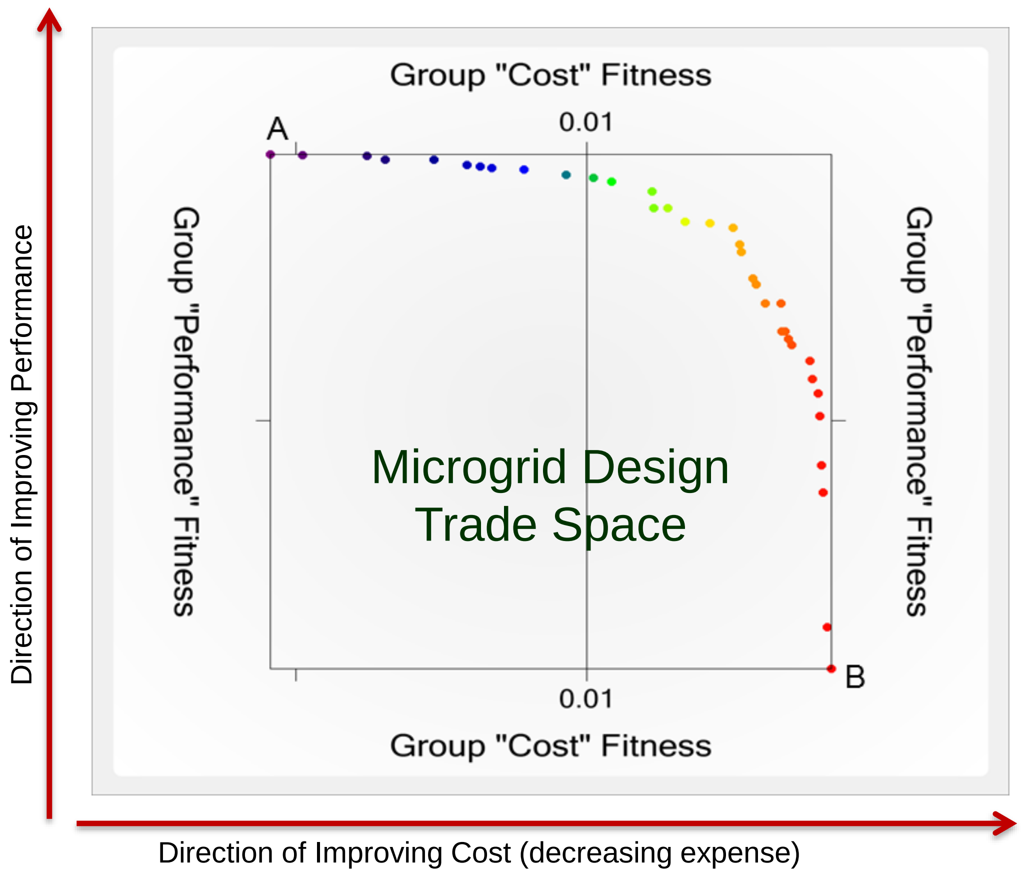
MDT Results

- **Energy performance**
  - Energy availability, cost, fuel used, volume, silent watch, gen utilization
- **Parametric sweep results**
- **Optimal & feasible solutions**
  - Generator types/counts
  - PV type/amount
  - Battery type/quantity

ITERATIONS to Refine Results

Microgrid Design Toolkit (MDT)

- MDT calculates a Pareto Frontier, a set of solutions that represent efficient trade-offs among the design objectives.



Each point represents a complete, unique microgrid design.

Point “A” is the highest cost, highest performing solution. Point “B” is the lowest cost, lowest performing solution. There are many options in between representing different trade offs.

Given any point on the chart, no improvement in cost can be made without corresponding decrease in performance and visa versa.

This chart shows 2 objective dimensions, cost and performance. The MDT supports up to 5 dimensions

Application Examples

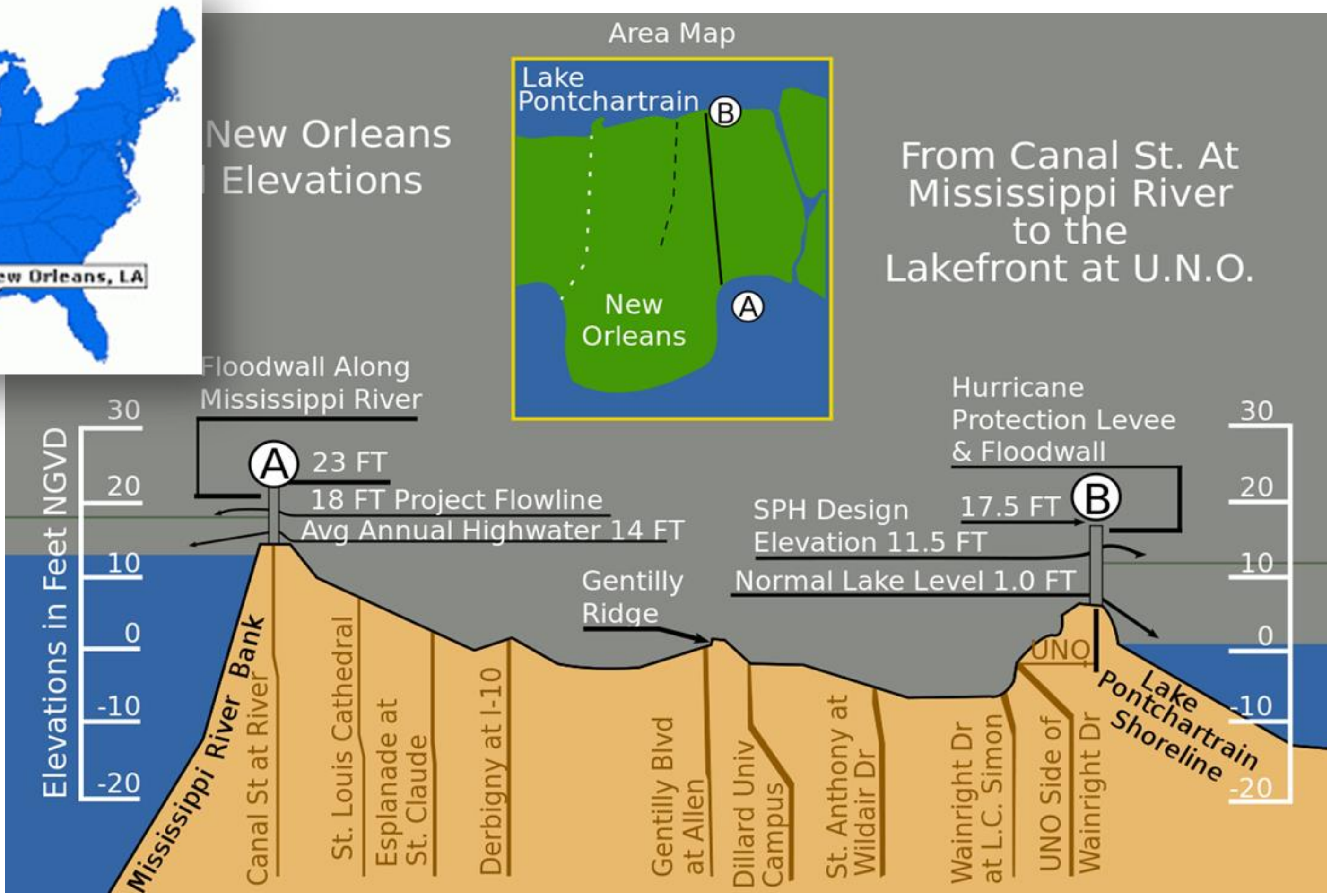
- Urban Resilience
  - City of New Orleans, Louisiana
  - Major flood scenario
- Remote Community Resilience
  - Village of Shungnak, Alaska
  - Diesel fuel supply risk
- Transportation Resilience (appendix)
  - New Jersey / NJ TransitGrid
  - Major storm and grid outage scenario

Urban Resilient Application

New Orleans, Louisiana

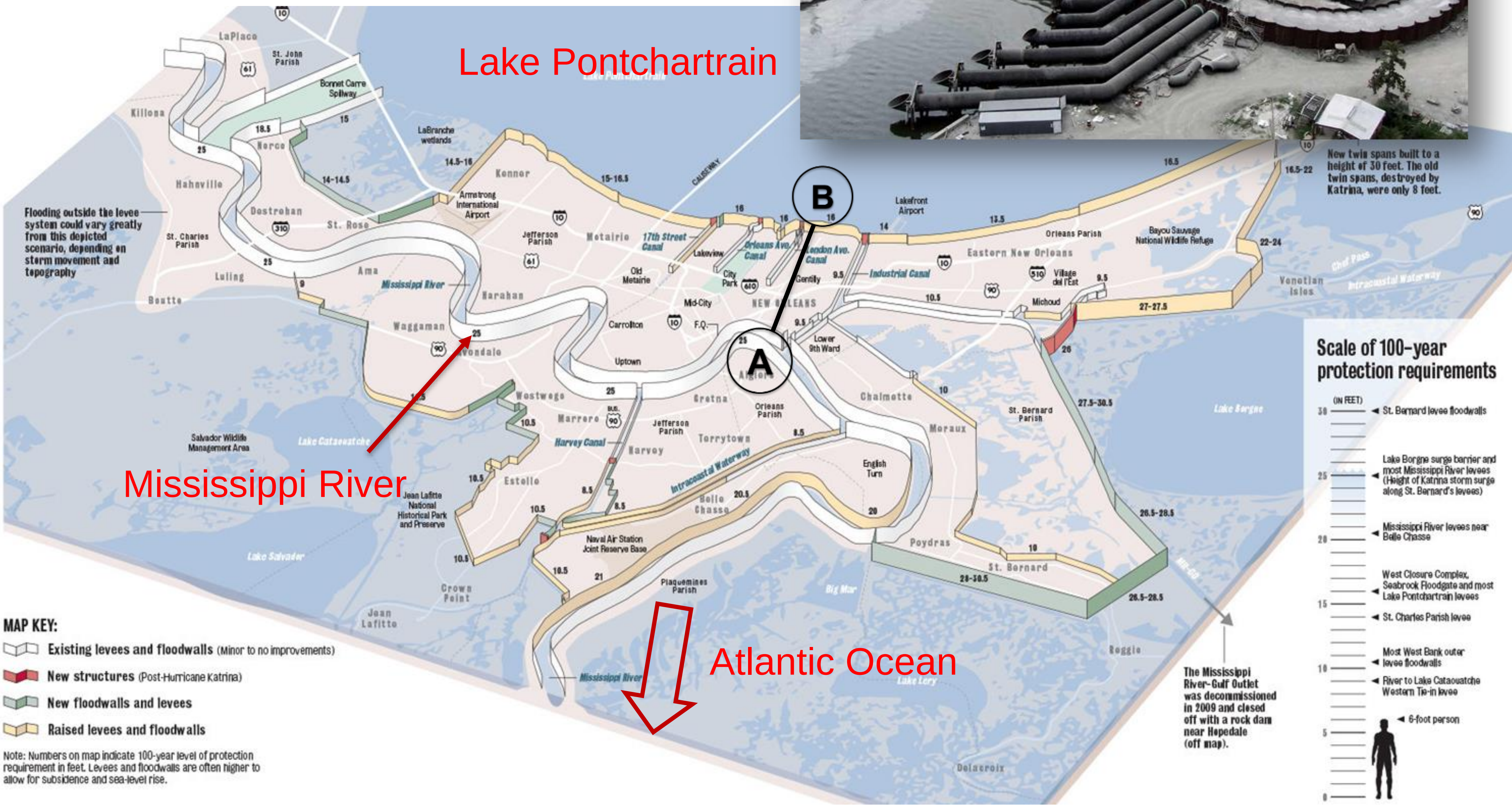
New Orleans, Louisiana (NOLA)

- High risk of flooding due to topology and location



Flood Protection

- Levies and Pumps



Infrastructure Resilience Effort

- Catastrophic flooding during Hurricane Katrina (2005)

- Sandia is providing technical assistance to NOLA to identify optimal energy resilience options
  - What are the most cost-effective grid enhancements?
  - Can rigorous decision-making be done under uncertainty?
  - Can the benefits be demonstrated to stakeholders?

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Los Alamos NATIONAL LABORATORY EST. 1943

100 RESILIENT CITIES

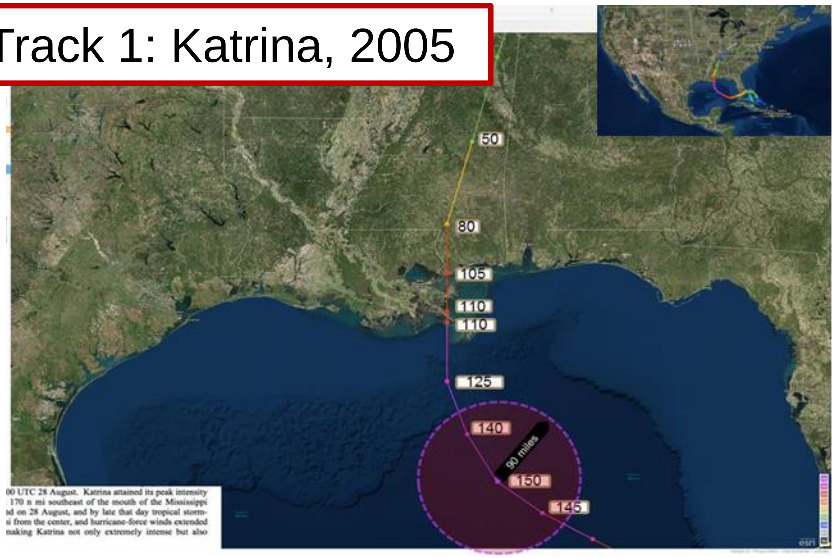
Entergy

US Army Corps of Engineers

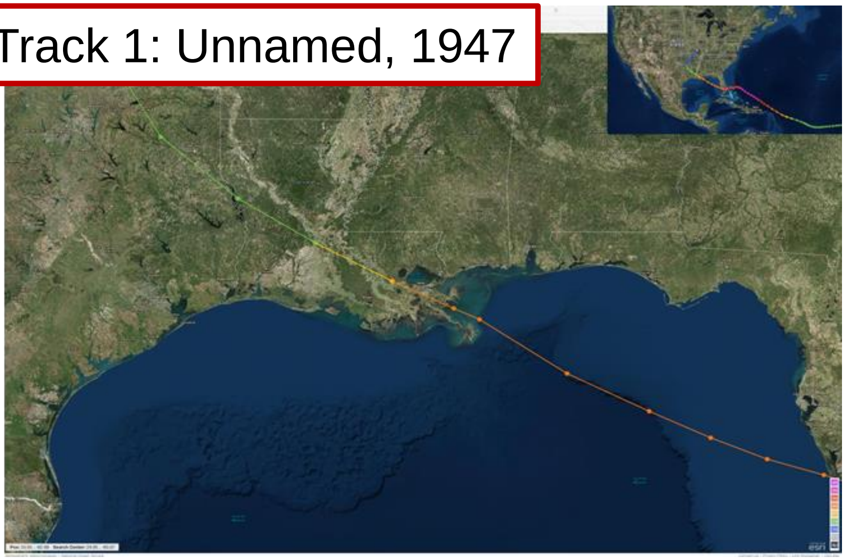
Definition of Threat Scenario

- High Cat 2 or low Cat 3 storm with surge < 24 ft
- Stalls and drops >20”of rain in 24 hrs
- Track1: Katrina 2005; Track 2: 1947 storm
- City does not issue a mandatory evacuation
- Pumps performing at 50% capacity

Track 1: Katrina, 2005



Track 1: Unnamed, 1947



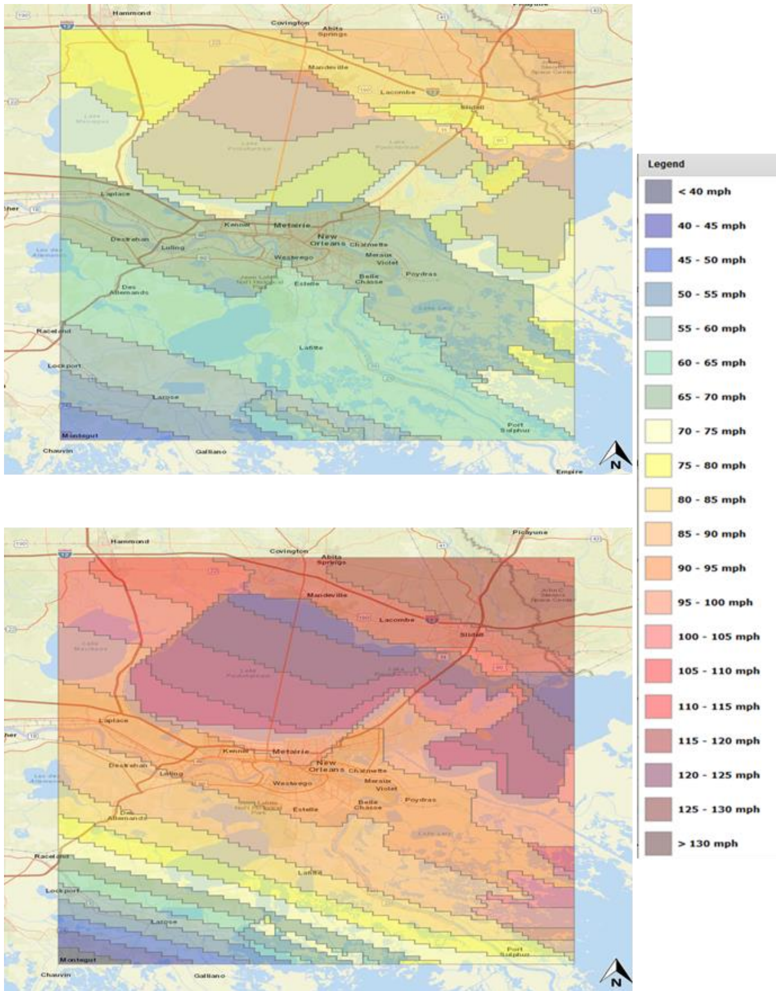
Characterization of the Threat

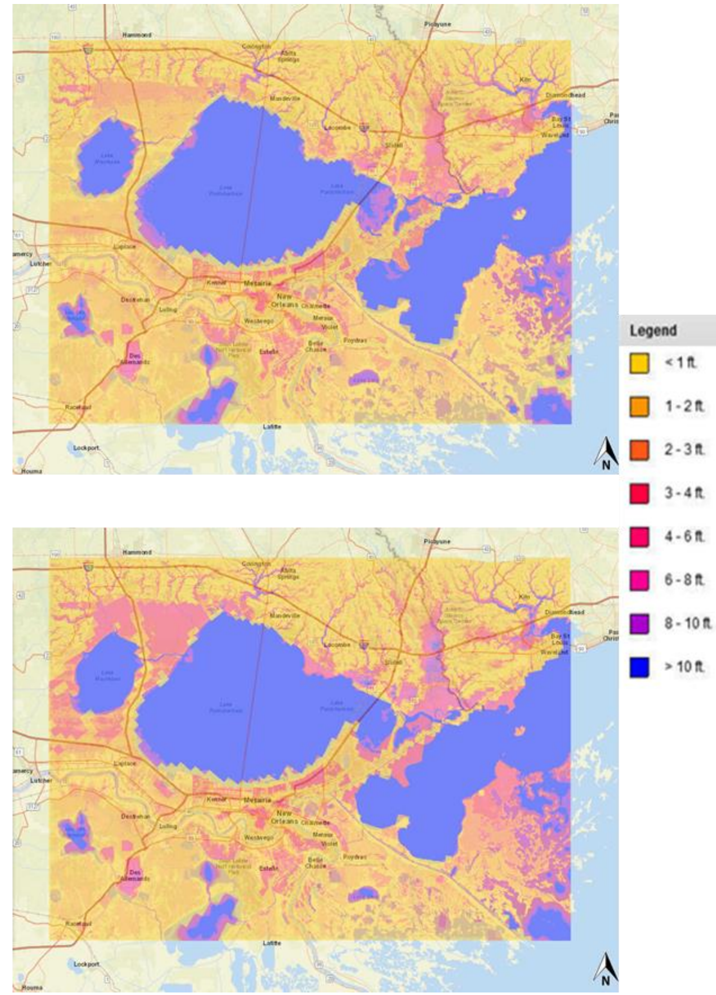
Max Wind – 1947 Track

Flooding – 1947 Track

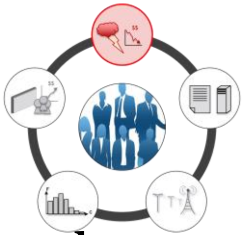
Cat 2 Storm

Cat 4 Storm





Stakeholder Engagement



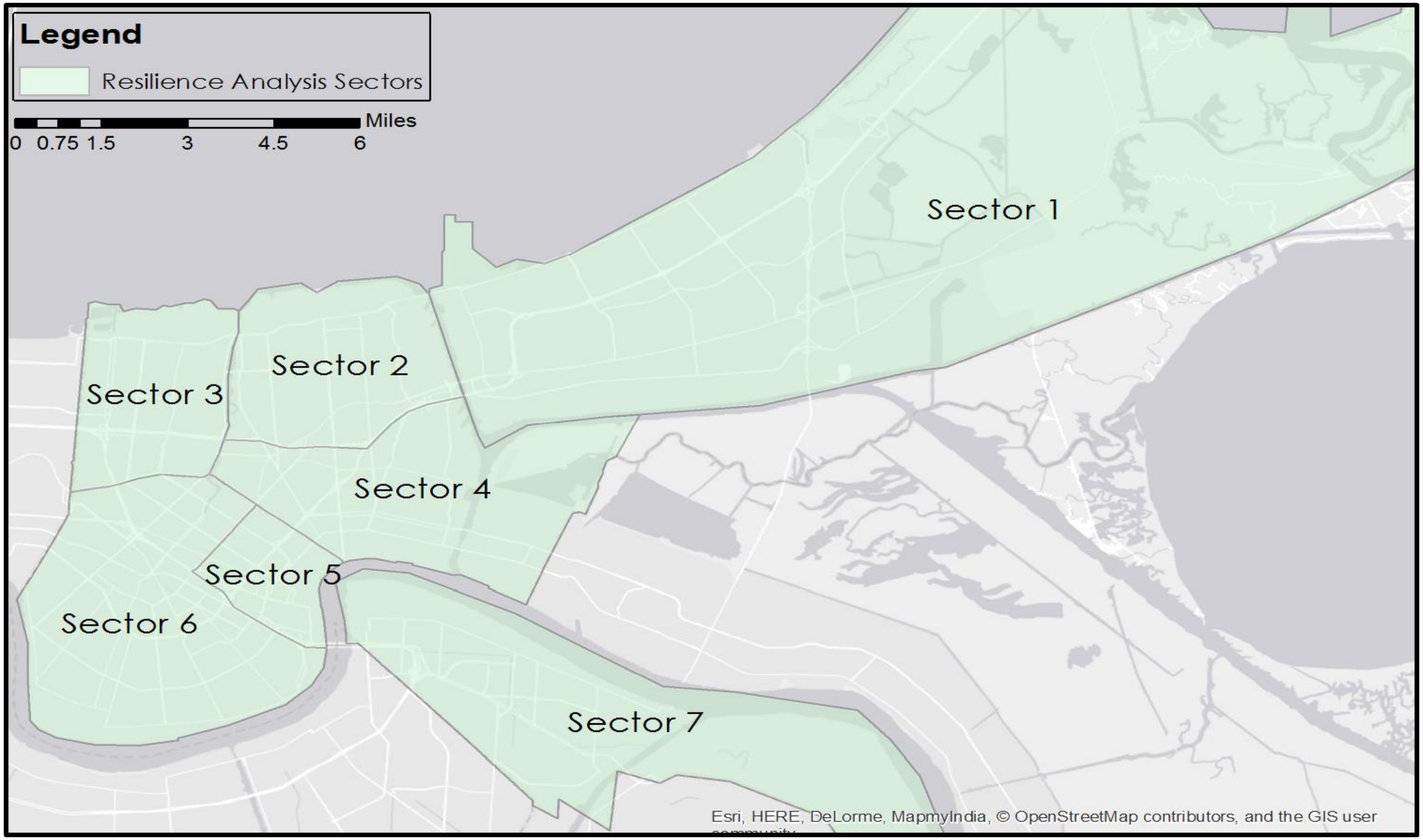
- Multiple community stakeholders need to be involved in the process to identify options.

"Lifeline" infrastructure services and Providers

Electric Power	Entergy, SWBNO
Drinking water	City/SWBNO, PODs
Dewatering	City/SWBNO
Sewerage	City/SWBNO
Medical Services	Hospitals, Pharmacies
Shelter	City shelters, Schools
Food	Commercial, PODs
Emergency Resp.	Police, Fire, 911
Communications	Voice, data, broadcast
Finances	Banks, ATMs
Transportation	Fuels, Road clearing

Technical Approach

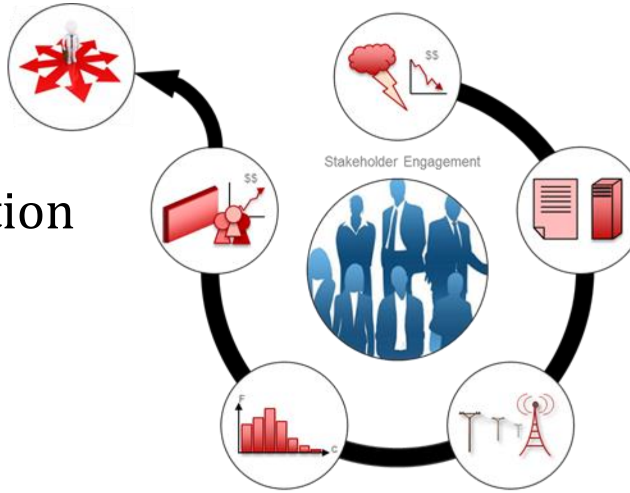
- NOLA stakeholders selected a Quadrant Resilience approach
  - Note that the technical approach can drive the analysis results…



Community Resilience Goals

- Provide energy resilience to support critical services to NOLA citizens in each one of the Resilient Quadrants, as well as major critical infrastructure that serve NOLA as a whole.

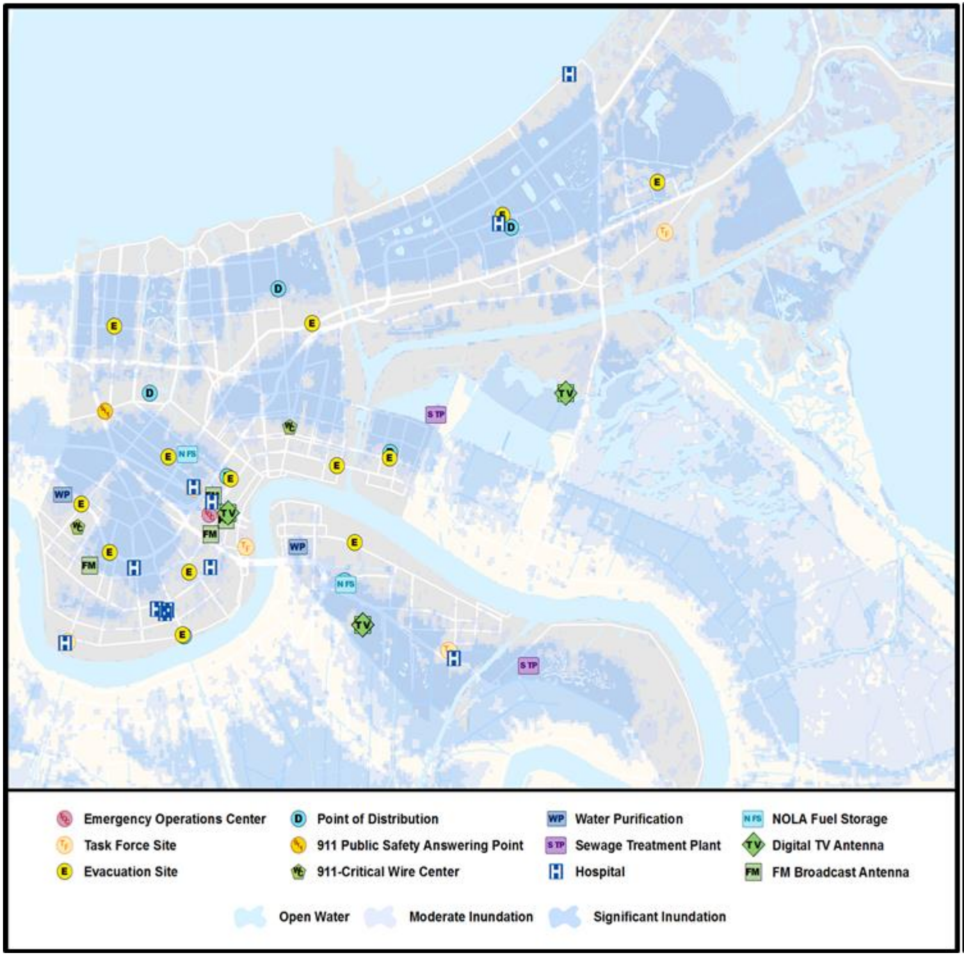
- Consider a variety of technical and social factors:
  - **Location of critical infrastructure** (centralized & decentralized)
  - **Impact of flooding** on ability to provide services
  - Likelihood of suffering a **power outage**
  - Expected **population movement** to dry areas
  - **Population characteristics**: age, income, education
  - **Cost** of resilience investment

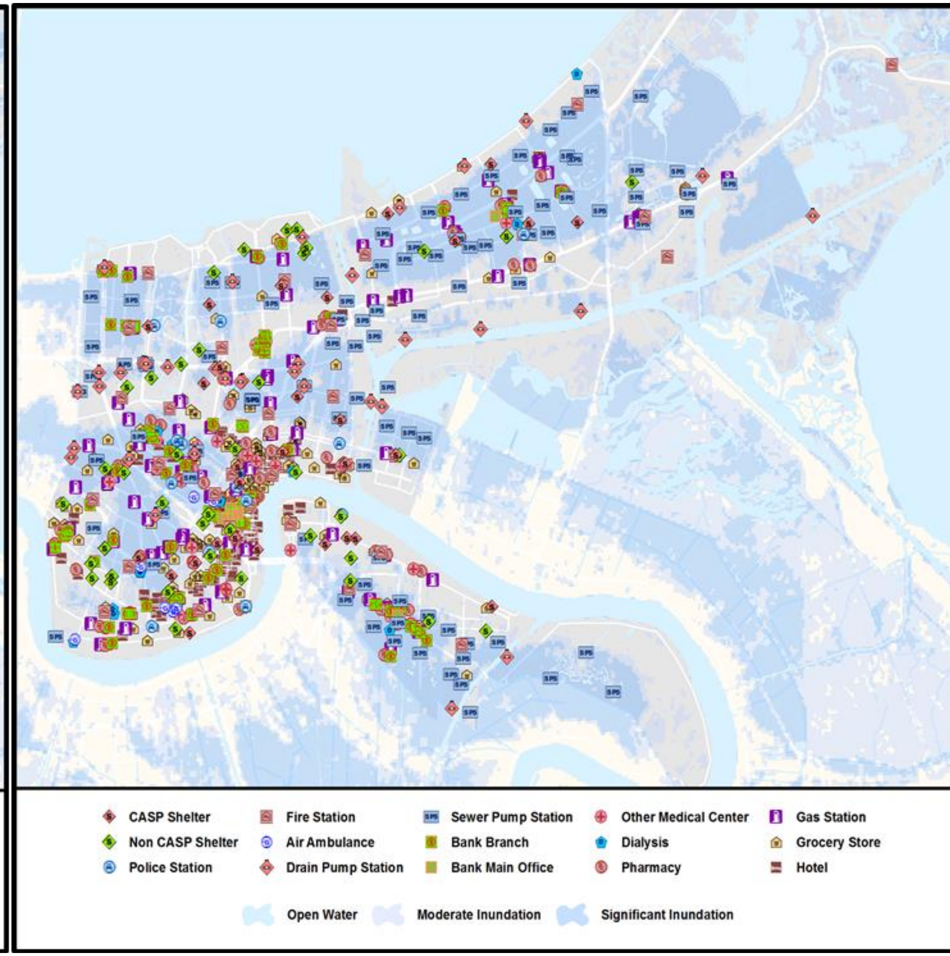


Analysis of Consequences

Centralized: Hospitals, Water purification, Emergency Operations Centers, etc.

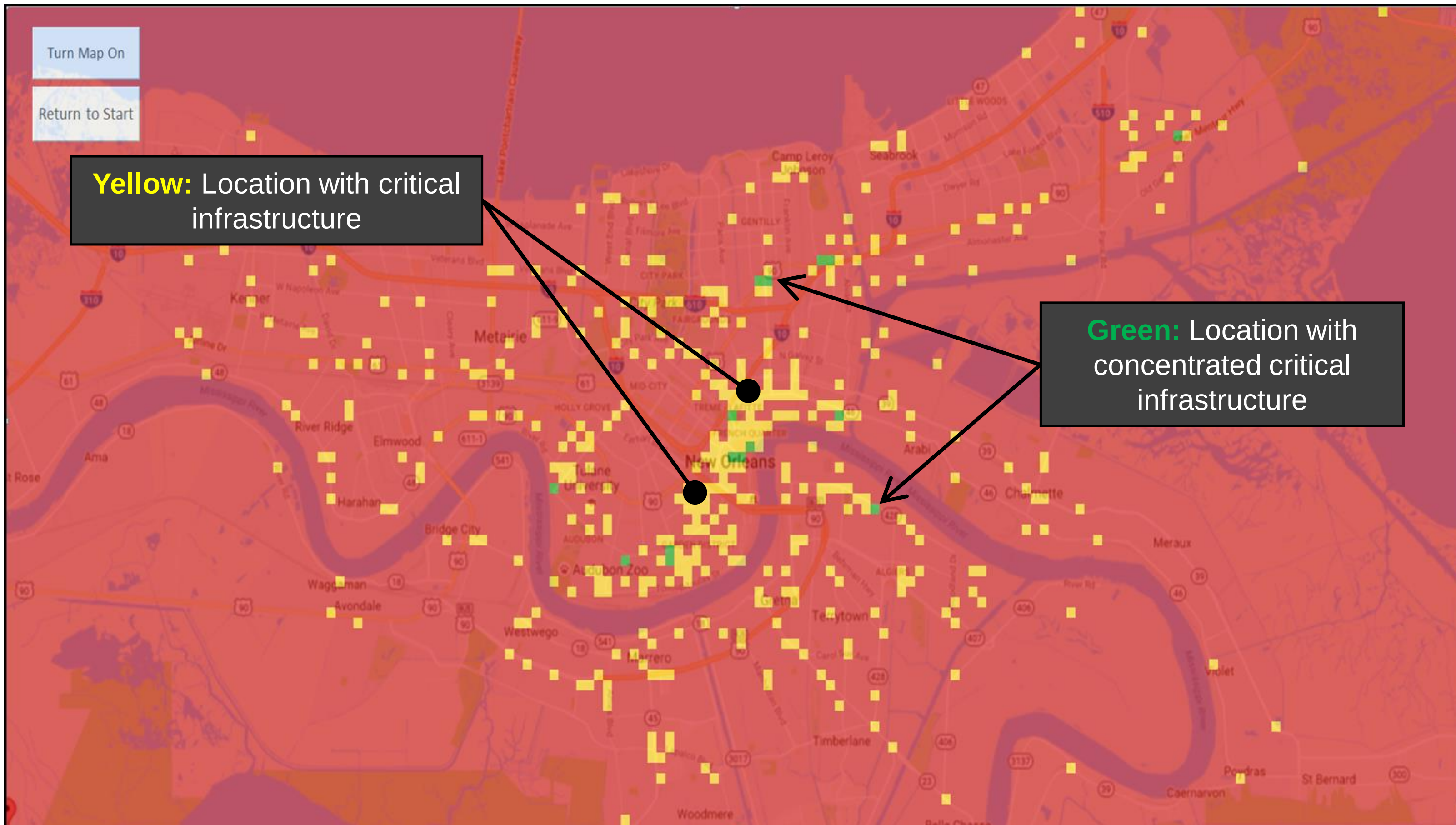
Decentralized: Shelters, Police and Fire stations, drain pumps, Gas stations, etc.





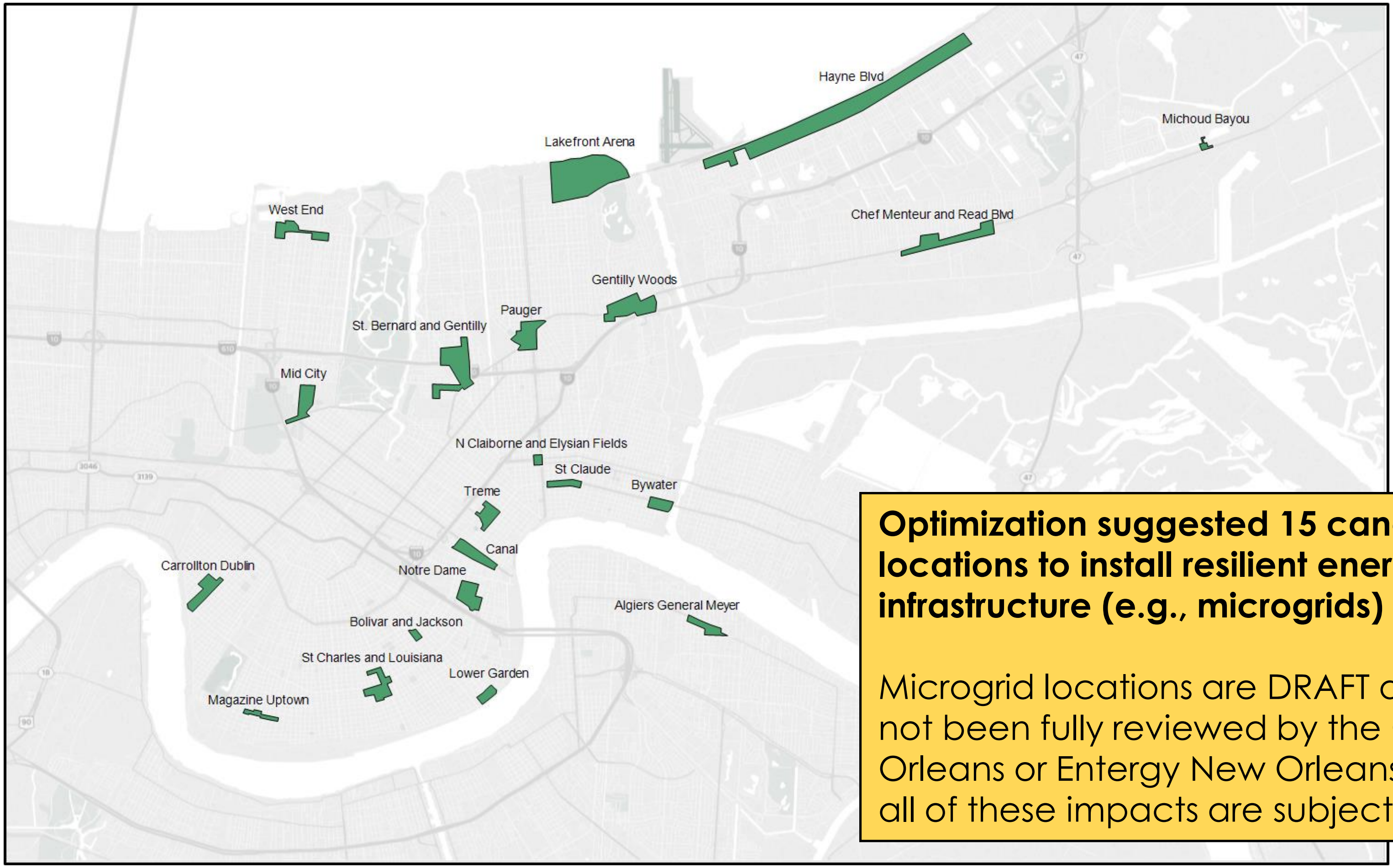
GIS Analysis as a Tool

- Due to the nature of the resilience goals and threats, GIS analysis was used to identify areas of interest.



NOLA Energy Resilience Nodes

- Further analysis identified candidate Resilience Nodes considering all technical and social factors.



Optimization suggested 15 candidate locations to install resilient energy infrastructure (e.g., microgrids)

Microgrid locations are DRAFT and have not been fully reviewed by the City of New Orleans or Entergy New Orleans. Therefore, all of these impacts are subject to change.

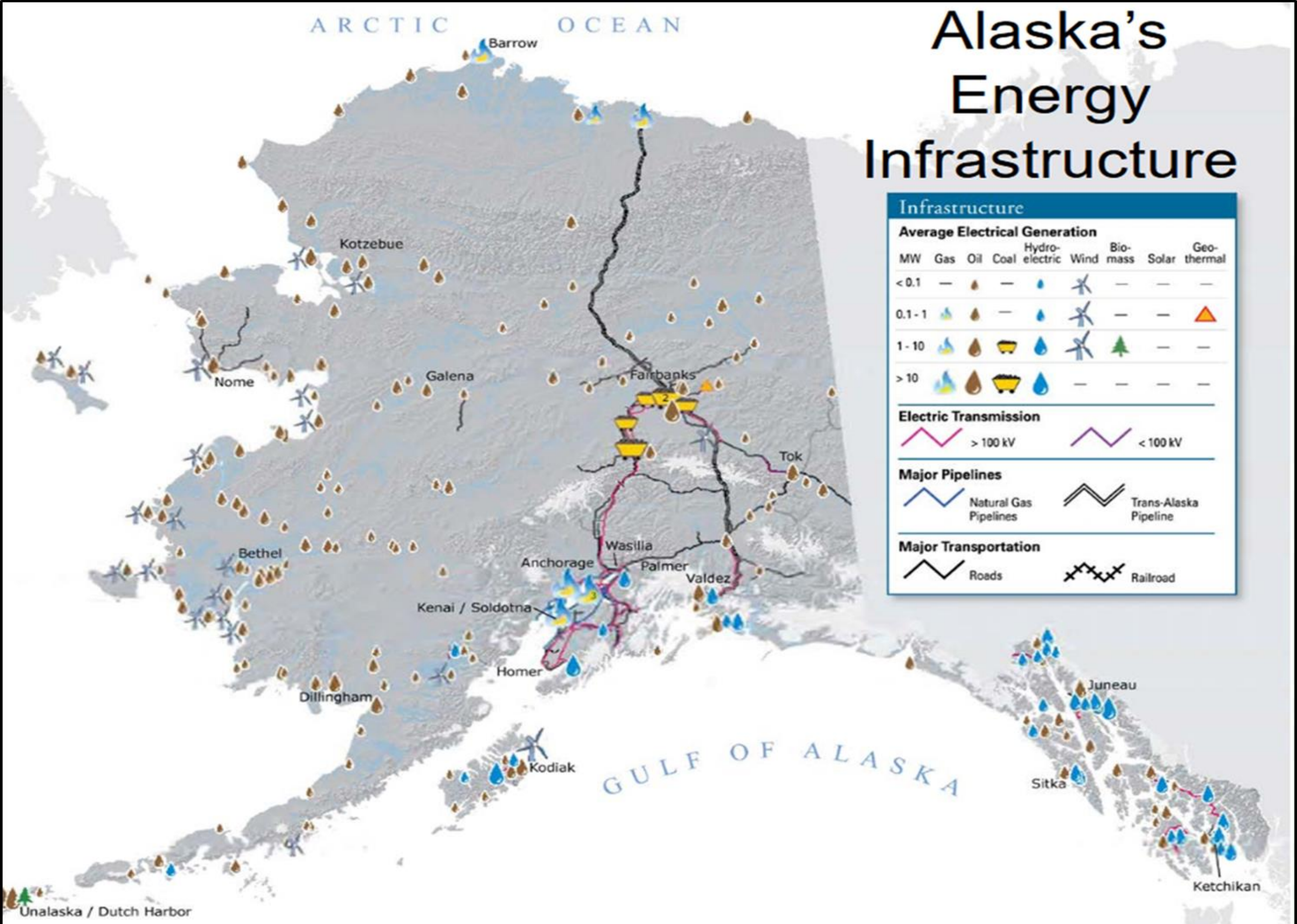
Rural Community Application

Shungnak, Alaska

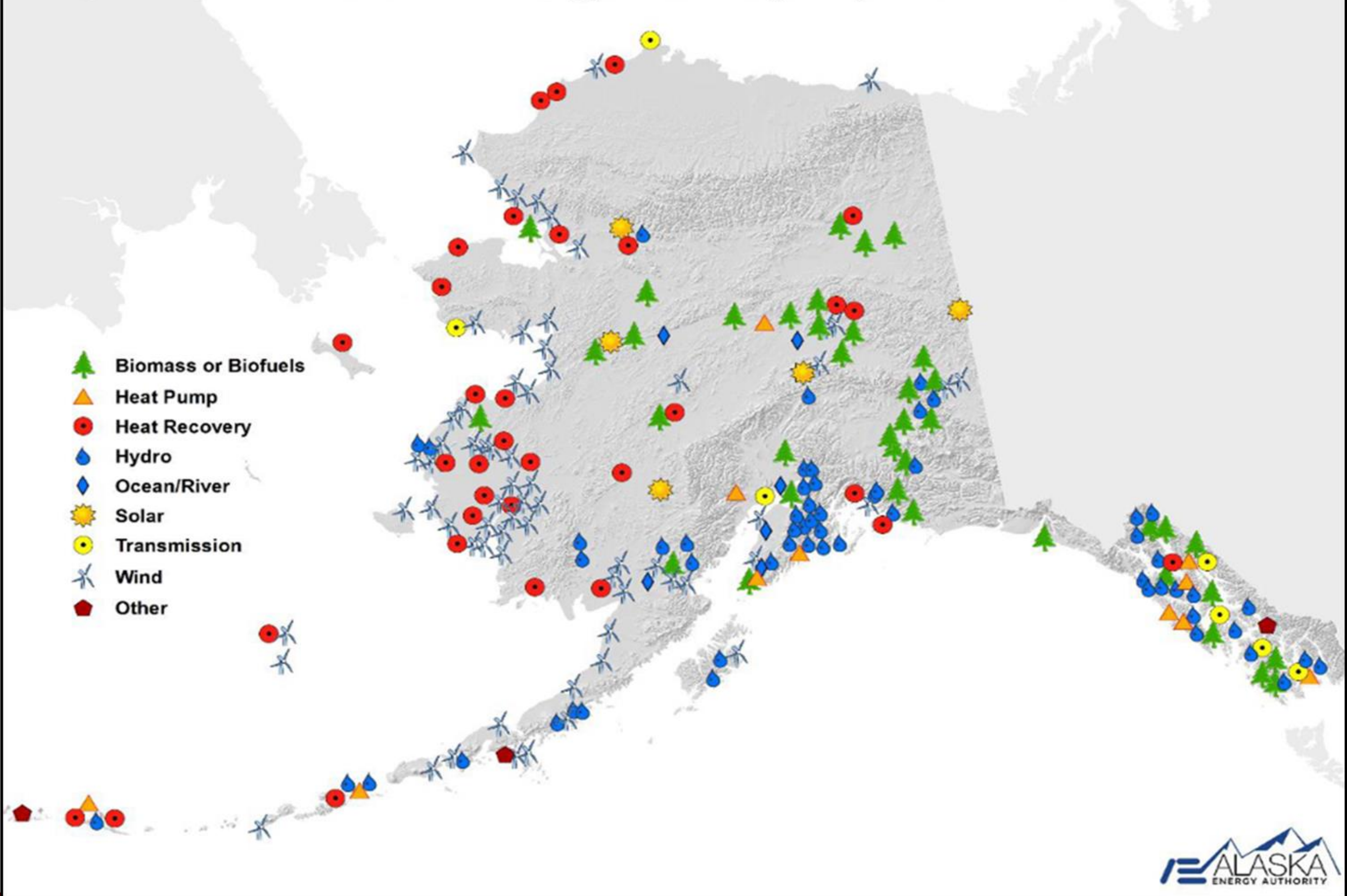
Alaska Energy Challenges

- Alaska has over 250 communities with remote power systems
  - ~1/3 are hybrid (use renewable energy and/or energy storage in combination with diesel)
- Challenges conditions
  - **High Cost:** 5 X to 10 X the U.S. national average, low income levels
  - **Environmental Sustainability:** Diesel storage and emissions
  - **Institutional Factors:** Local technical capacity, difficult logistics
- Resilience considerations
  - Extreme climate conditions
  - Long supply lines
  - Climate change

Alaska's Energy Infrastructure



Renewable Energy Fund Projects, 2008 - 2015



Energy Resilience for Shungnak, AK

- All the electricity is generated with diesel fuel
- Many buildings and homes use heating oil to keep warm
- Extremely cold winters make resilient access to energy a critical health and safety issue.
- Fuel delivery cost and supply risks are high

NREL NATIONAL RENEWABLE ENERGY LABORATORY

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BERKELEY LAB

ACEP Alaska Center for Energy and Power

REAP Renewable Energy Alaska Project

Project Goals and Design Options

Demonstrate a combination of investments that achieves a 50% reduction in imported fuel with a positive return on investment for Shungnak

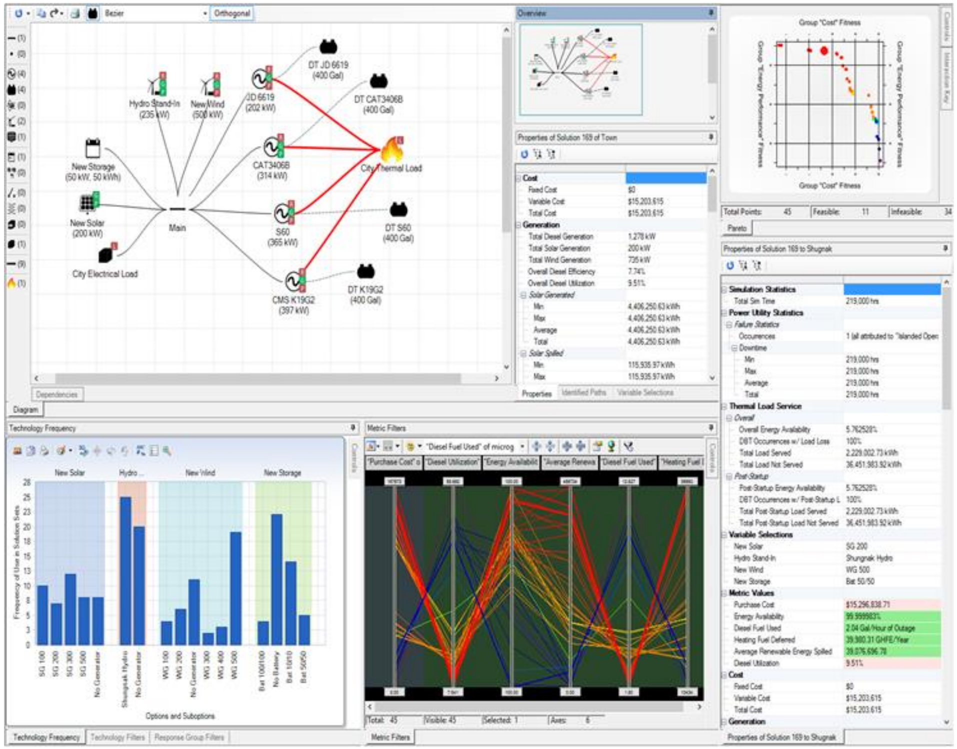
Design options include:

- Load reduction through efficiency
- Heat recovery
- Use of hydro-power on Kobuk river
- Addition of solar PV
- Addition of wind turbines
- Battery energy storage
- Thermal stove energy storage

*Reduction in fuel requirements and use of local energy resources improves **resilience***

Shungnak MDT Analysis Results

- Sandia performed analysis demonstrating trade-offs between investment levels and fuel savings
- The results show that several grid design options can reduce fuel and heating oil requirements by 50% of current usage levels.
- Some designs provide positive NPV for both utility and customers and positive ROI percentages.

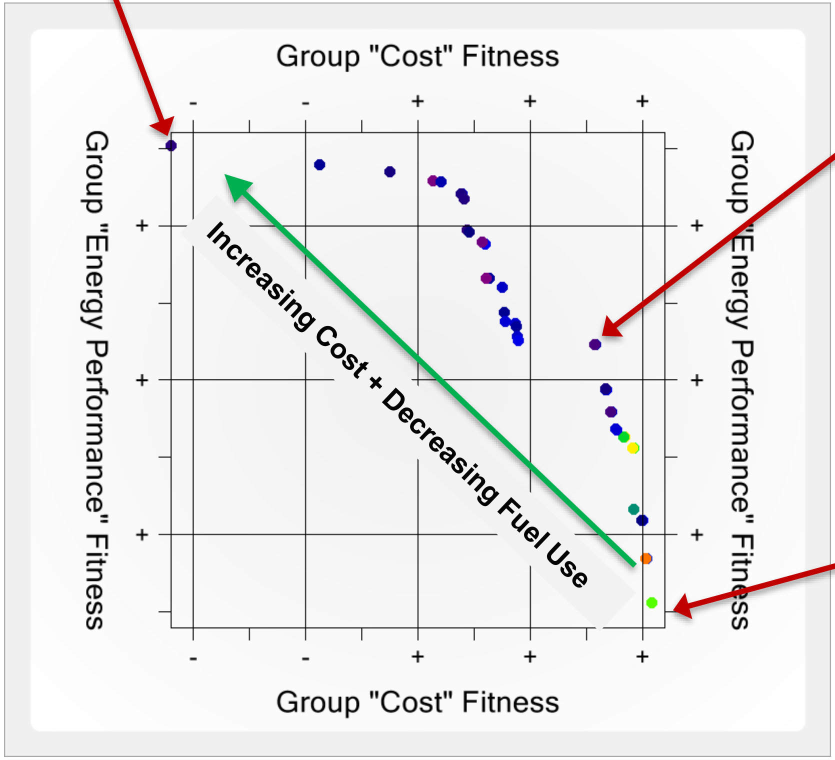


Analysis of Shungnak Alternatives

Variable Selections	
New Solar	SG 500
Hydro Stand-In	Shungnak Hydro
New Wind	WG 500
New Storage	No
Metric Values	
Purchase Cost	**$16.7M**
Energy Availability	100.00%
Diesel Fuel Used	**1.85 Gal / Hour**
Heating Fuel Deferred	39,980 GHFE/Year
Average Renewable Energy Spilled	45.1 MW-hr
Diesel Utilization	8.30%

Add Hydro

Variable Selections	
New Solar	SG 500
Hydro Stand-In	No
New Wind	WG 500
New Storage	No
Metric Values	
Purchase Cost	**$6.4M**
Energy Availability	100.00%
Diesel Fuel Used	**3.28 Gal / Hour**
Heating Fuel Deferred	21,864 GHFE/Year
Average Renewable Energy Spilled	17.6 MW-hr
Diesel Utilization	13.0%



Add wind and solar

Variable Selections	
New Solar	No
Hydro Stand-In	No
New Wind	No
New Storage	No
Metric Values	
New investment Cost	**$0**
Energy Availability	100%
Diesel Fuel Used	**12.63 Gal / Hour**
Heating Fuel Deferred	11,860 GHFE/Year
Average Renewable Energy Spilled	0
Diesel Utilization	58.5%

Diesel-only case

Summary

- Critical infrastructure resilience is a topic of high interest, increasingly codified in policy and investment decisions.
  - Energy infrastructure resilience is essential—it supports other critical infrastructure.
- Resilience problems tend to be difficult
  - Technically complex
  - Subject to high uncertainty and value by diverse stakeholders
- There are useful frameworks, metrics and tools out there…
  - Application examples show that resilience can be approached in a rigorous manner
- …but more work needs to be done to ensure full and widespread adoption of resilient design principles

Questions? Comments?

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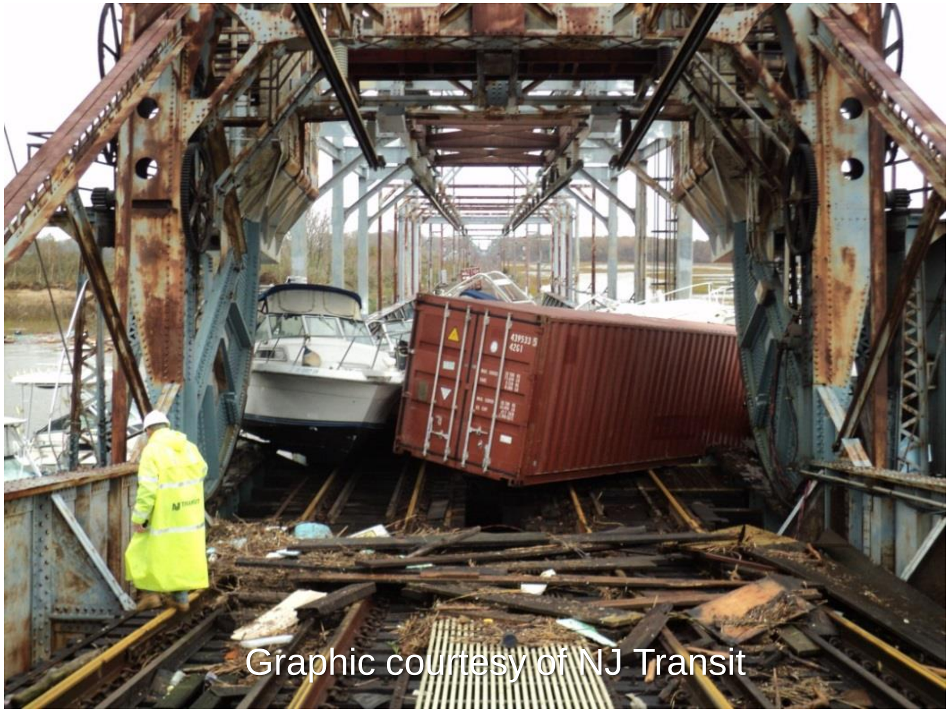
Transportation Resilience Example

New York/New Jersey

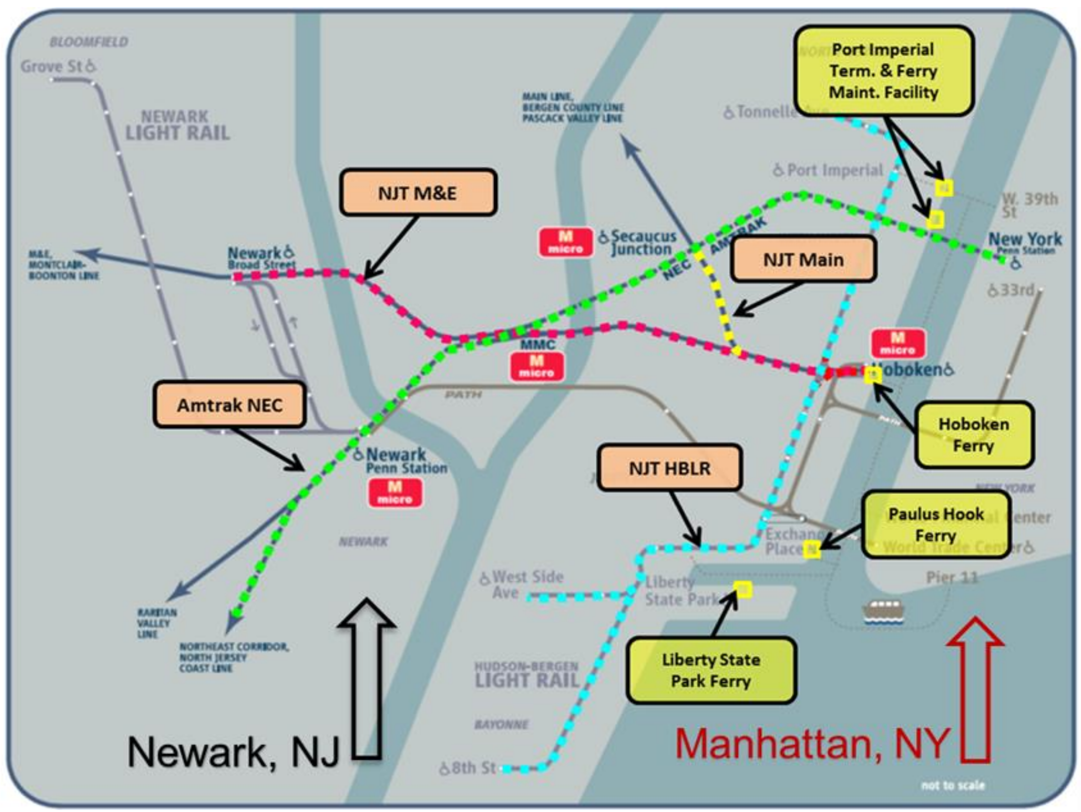
Transportation Resilience - NJTransit

- Superstorm Sandy caused major human and economic losses
  - The transportation system linking NJ/NY was severely disrupted for weeks, hampering evacuation and recovery efforts
  - Re-built infrastructure required to be resilient to future events


Graphic courtesy of NJ Transit

Project Scope and Stakeholders

- Sandia provided technical assistance to the NJ Transit Authority to define transportation energy resilience options
  - Region of interest is the Northeast Corridor, one of the world's busiest



Goals and Performance Objectives

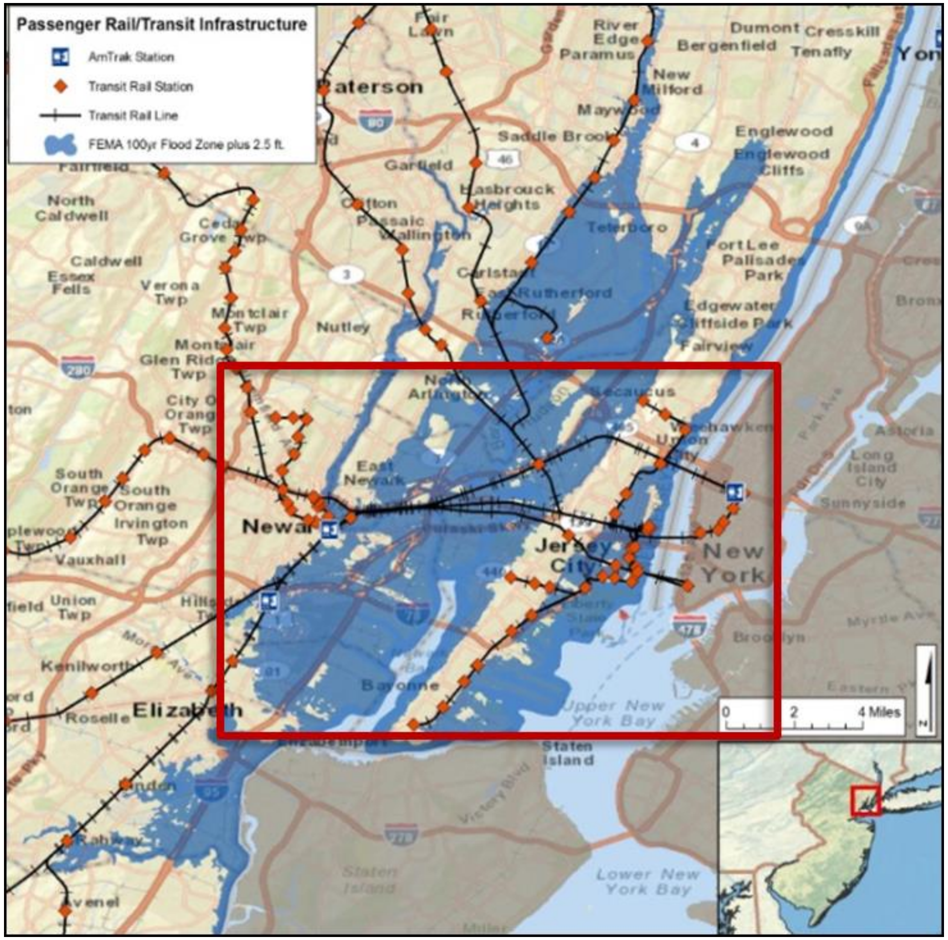
- **Improve resilience of the transportation system** for the following scenarios:
  1. A **major flood event** 2.5 ft. above the FEMA 100 Year flood level
  2. An extended **regional grid outage** that affects the region of a part of it

- System Definition:
  - Focus on Train, Buses and Ferry services linking NY and NJ

- Performance Objectives
  1. During the **DBT scenario**, **enable rail, bus and ferry transportation for up to 7 days** to support evacuation & recovery efforts.
  2. During **blue-sky** conditions, **support grid reliability**, **increase transit capacity**; **generate revenue** through participation in energy, capacity and ancillary markets; **generate renewable energy credits**.

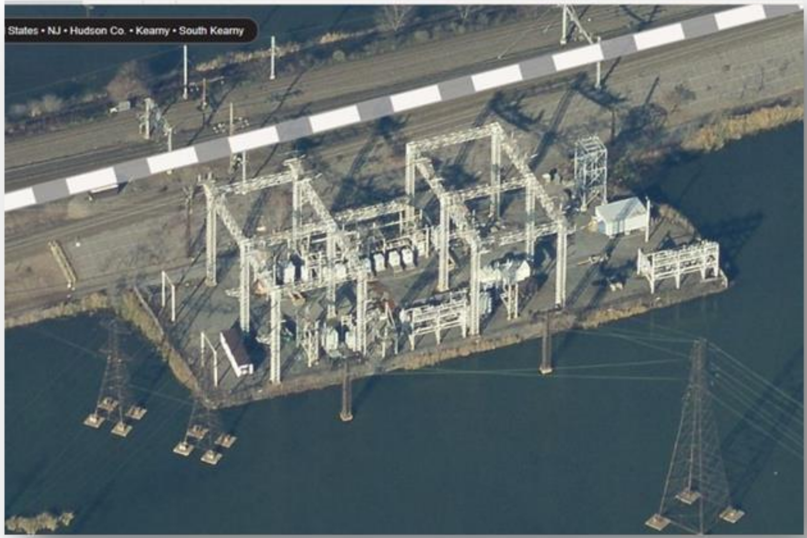
Characterizing the Threat

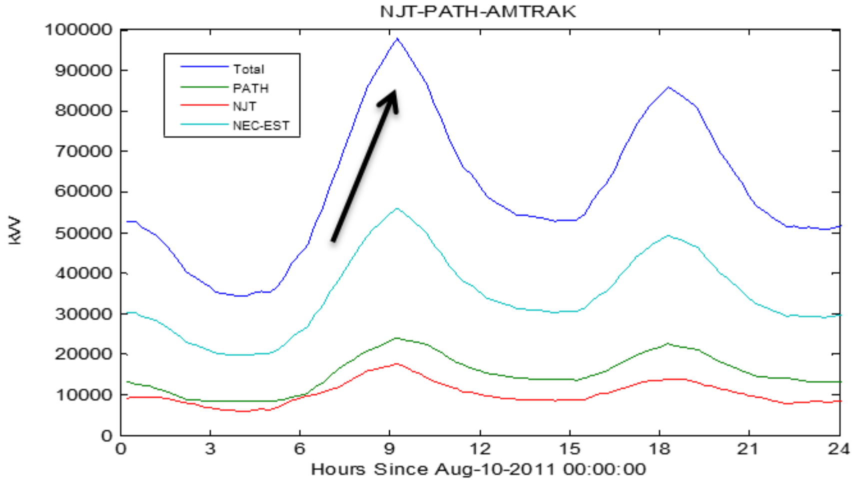
- Analysis helped identify critical infrastructure needs and technical challenges:
  - Rail/port passenger stations; critical operations facilities
  - Rail lines, tunnels, roadways
  - Critical transmission and distribution substations and other, electric facilities.
  - Fuel pumping stations for ferries and buses
- Analysis also quantified the economic benefits and social of resilience enhancements



Modeling Performance & Consequences

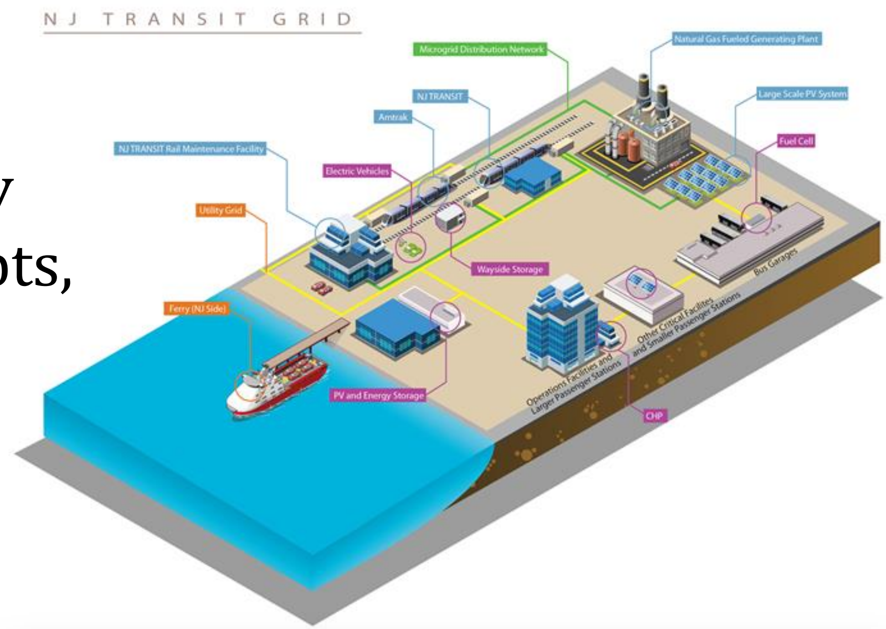
- Many challenges identified
  - Critical facilities in flood zones
  - Limited Right-of-Way for deployment of new infrastructure
  - Challenging demand profile
  - Integration with utility systems
  - Regulatory/policy gaps

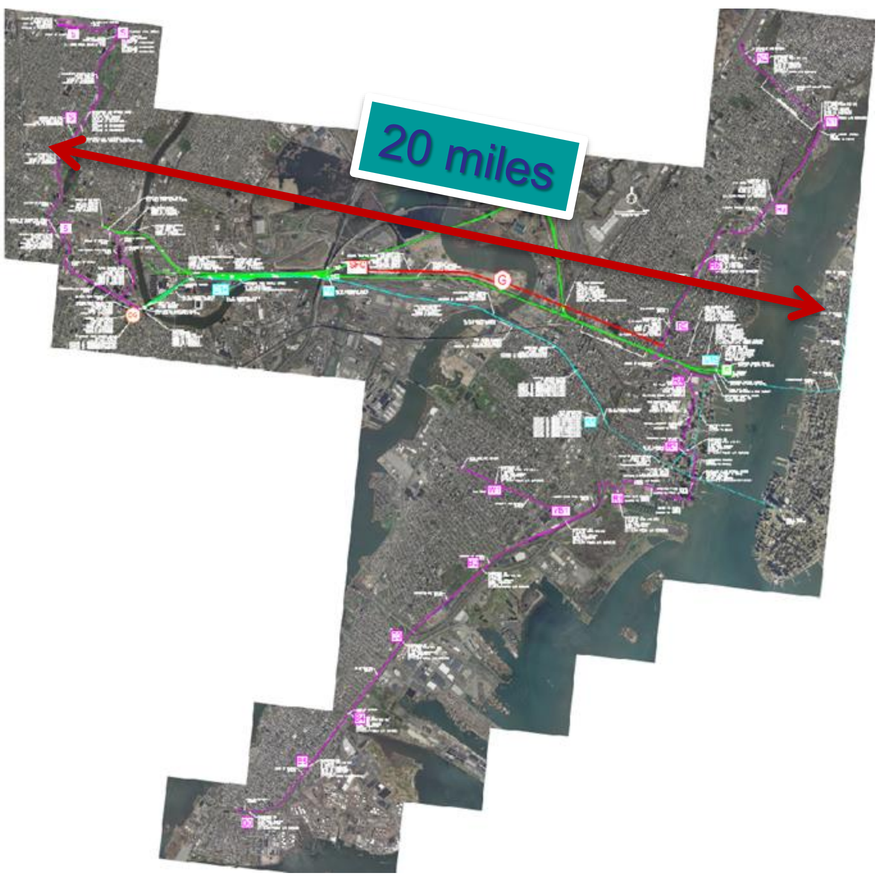


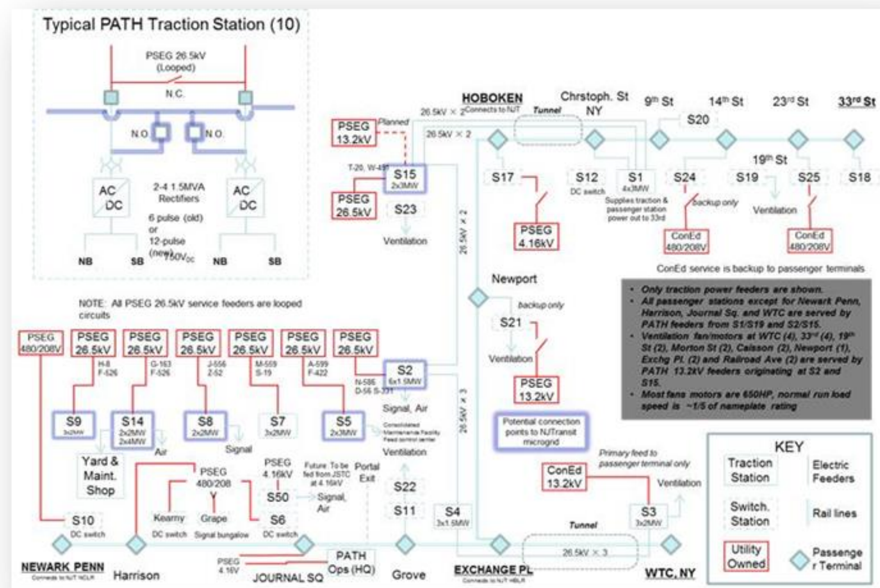


Conceptual Design

- Several iterations progressively more detailed resilience concepts, with stakeholder feedback

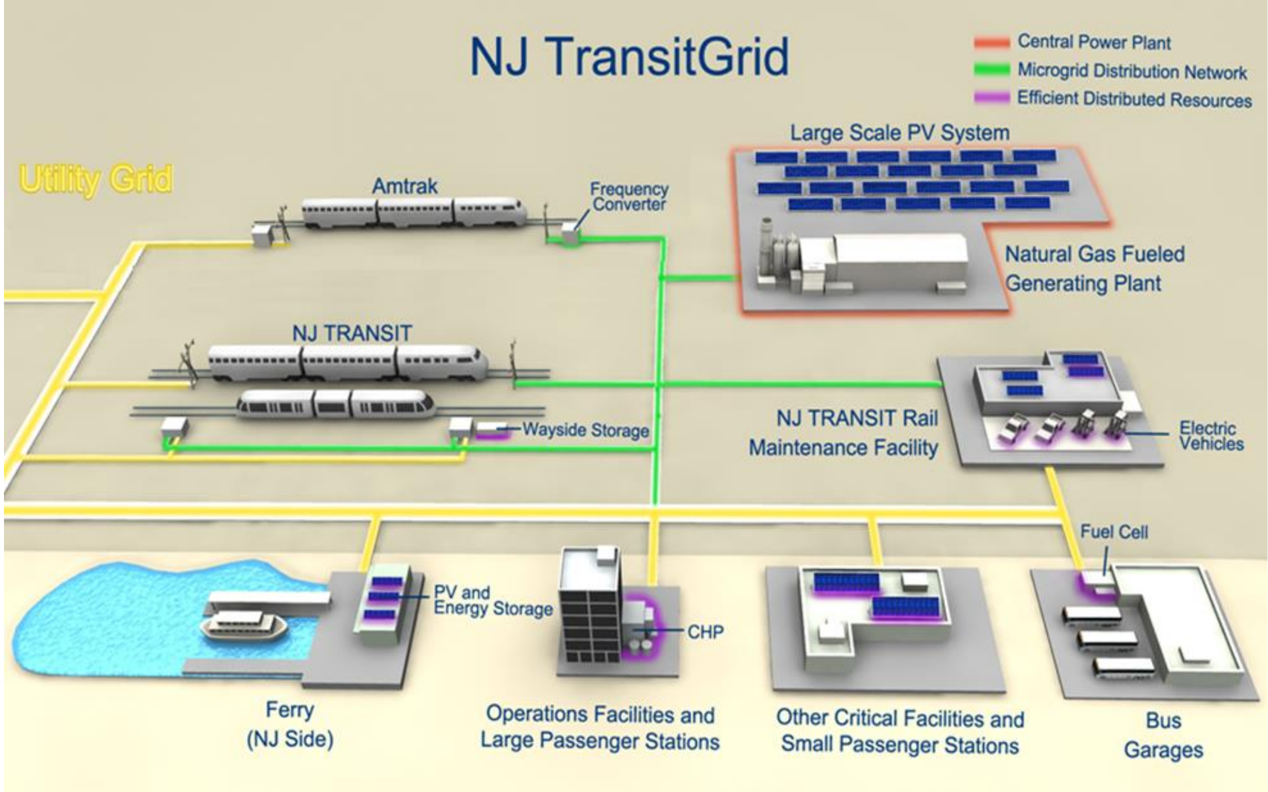






NJ TransitGrid Project Implementation

- Resilience analysis and design provided indication of technical viability, estimated cost, and estimated resilience benefits.
  - Project is currently under development



Major Project Components

- 100 MW gas-fired plant
- 50 MW frequency converter
- 6 MW of PV
- 6 MW of CHP
- Wayside energy storage (regenerative braking)
- PV+storage facilities
- Electric vehicles
- New distribution lines and switches
- Flood protection