SAND2020-4115C

Energy Storage and Resilience, and the Resilience of Energy Storage

Maryland Public Service Commission

April 15, 2020, WebEx Presentation

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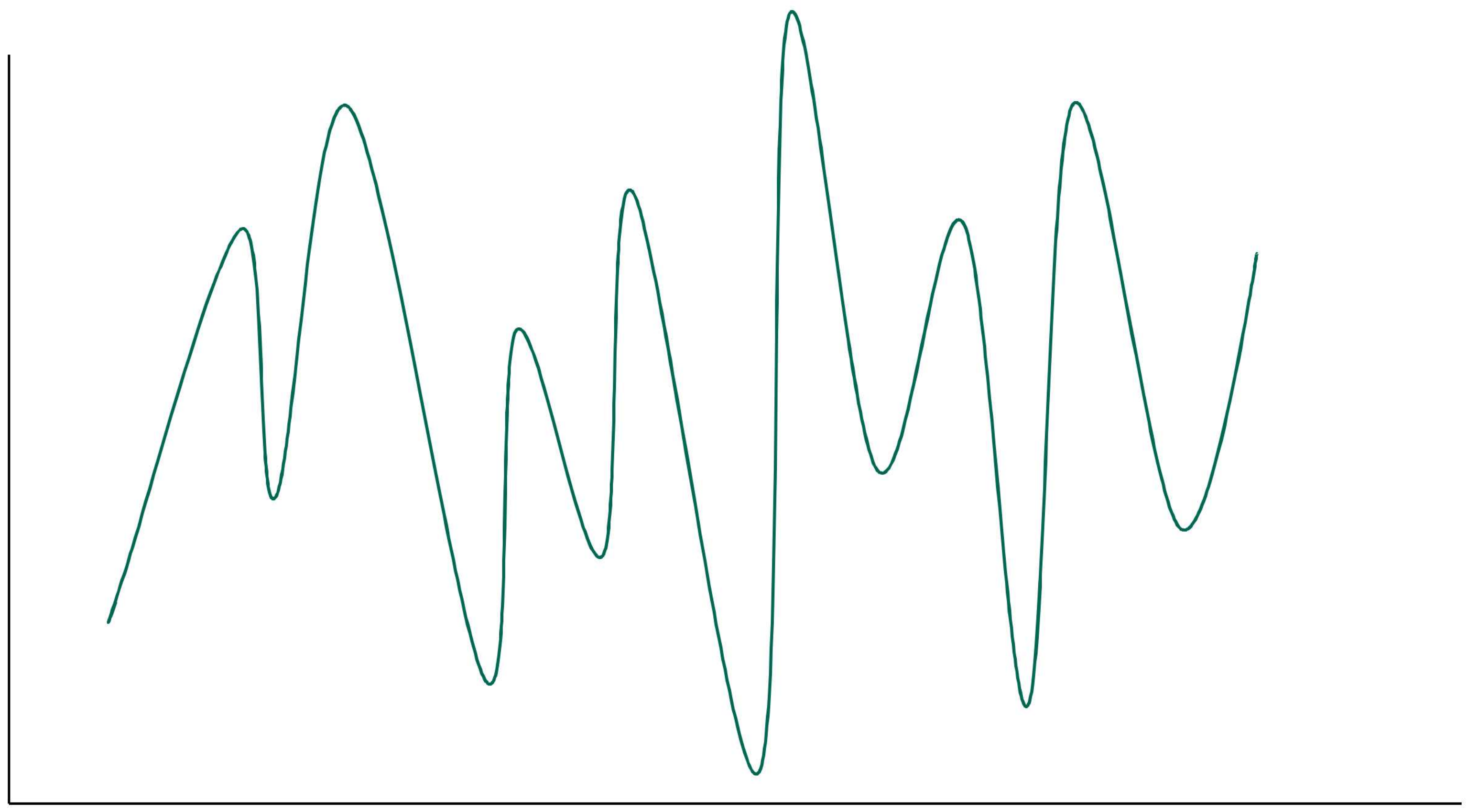
SAND2020-???

Resilience

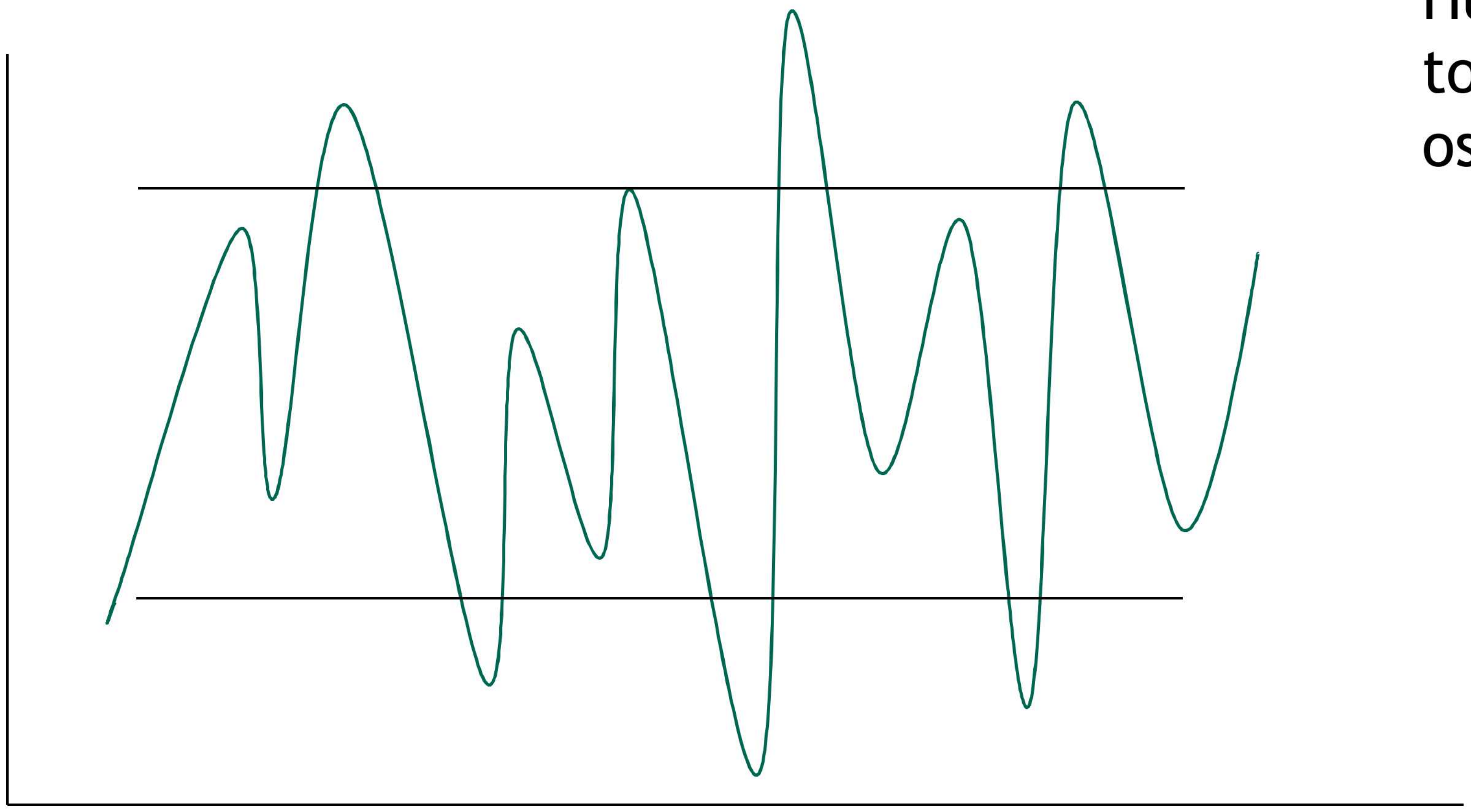
Complex adaptive systems oscillate



Resource systems, economic systems, social systems, the grid . . .

Resilience confers sustainability

Complex systems oscillate (experience disruptions)

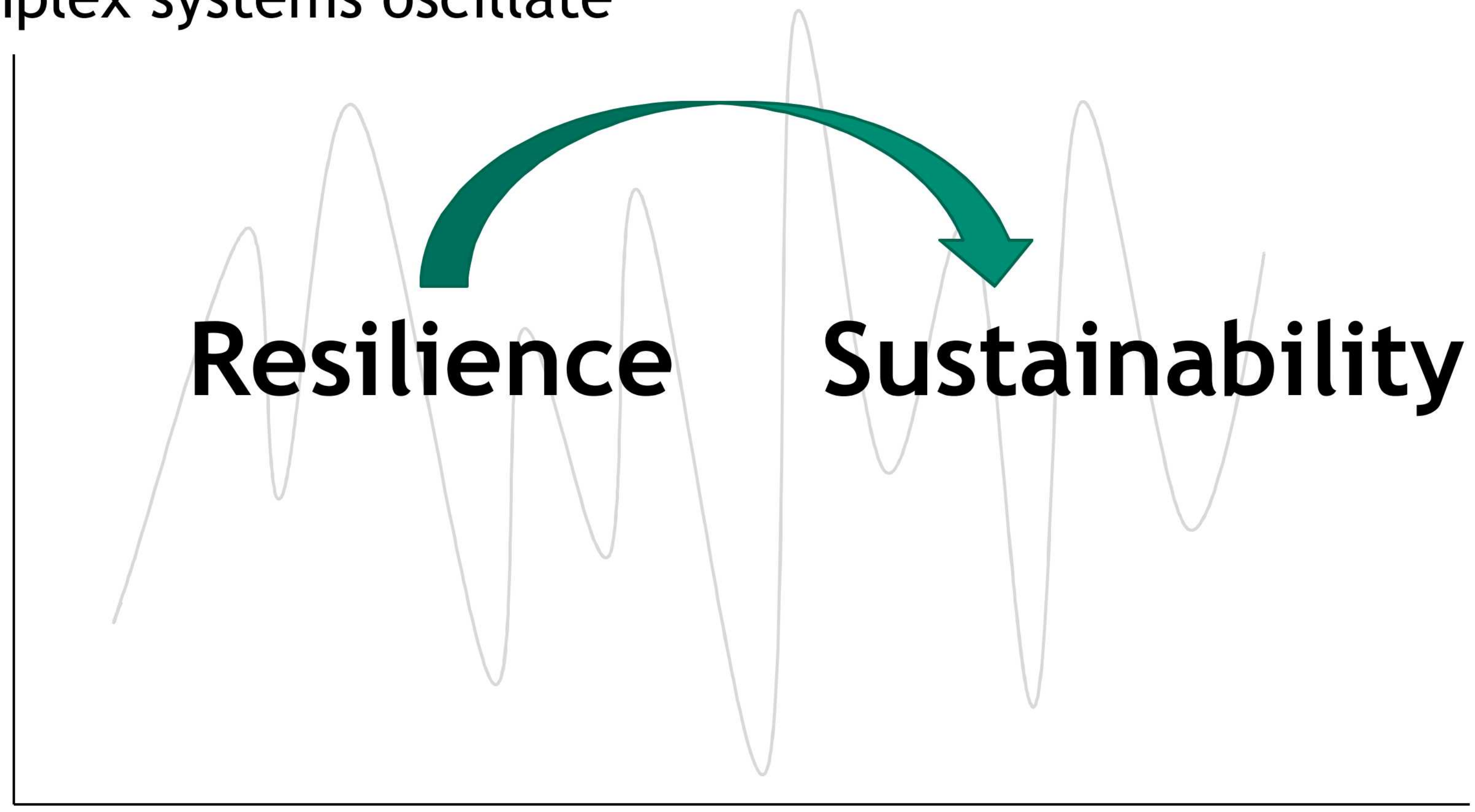


Humans want to dampen the oscillations

Resource systems, economic systems, social systems, the grid . . .

Resilience confers sustainability

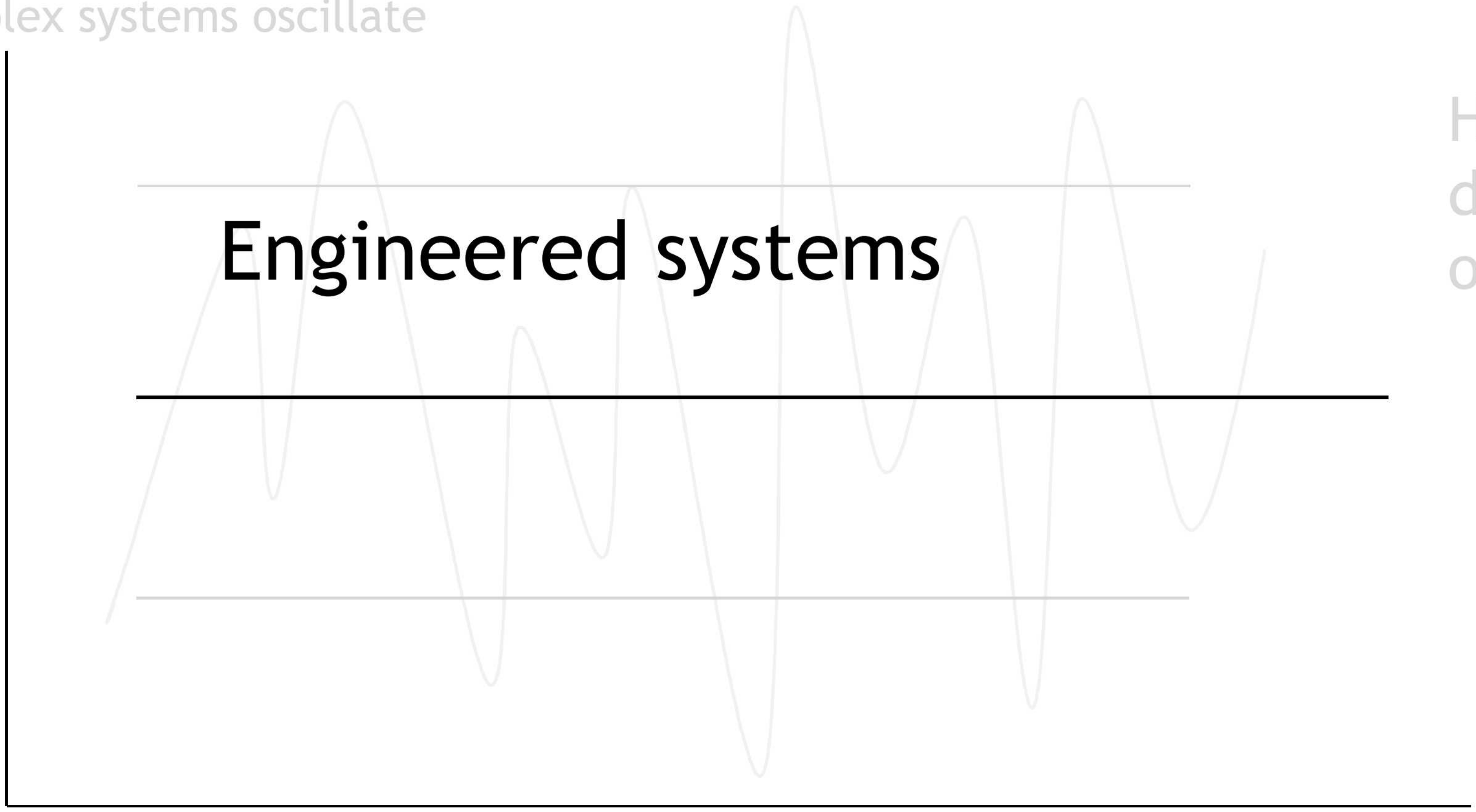
Complex systems oscillate



Resource systems, economic systems, social systems . . .

Resilience confers sustainability

Complex systems oscillate



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Resource systems, economic systems, social systems . . .

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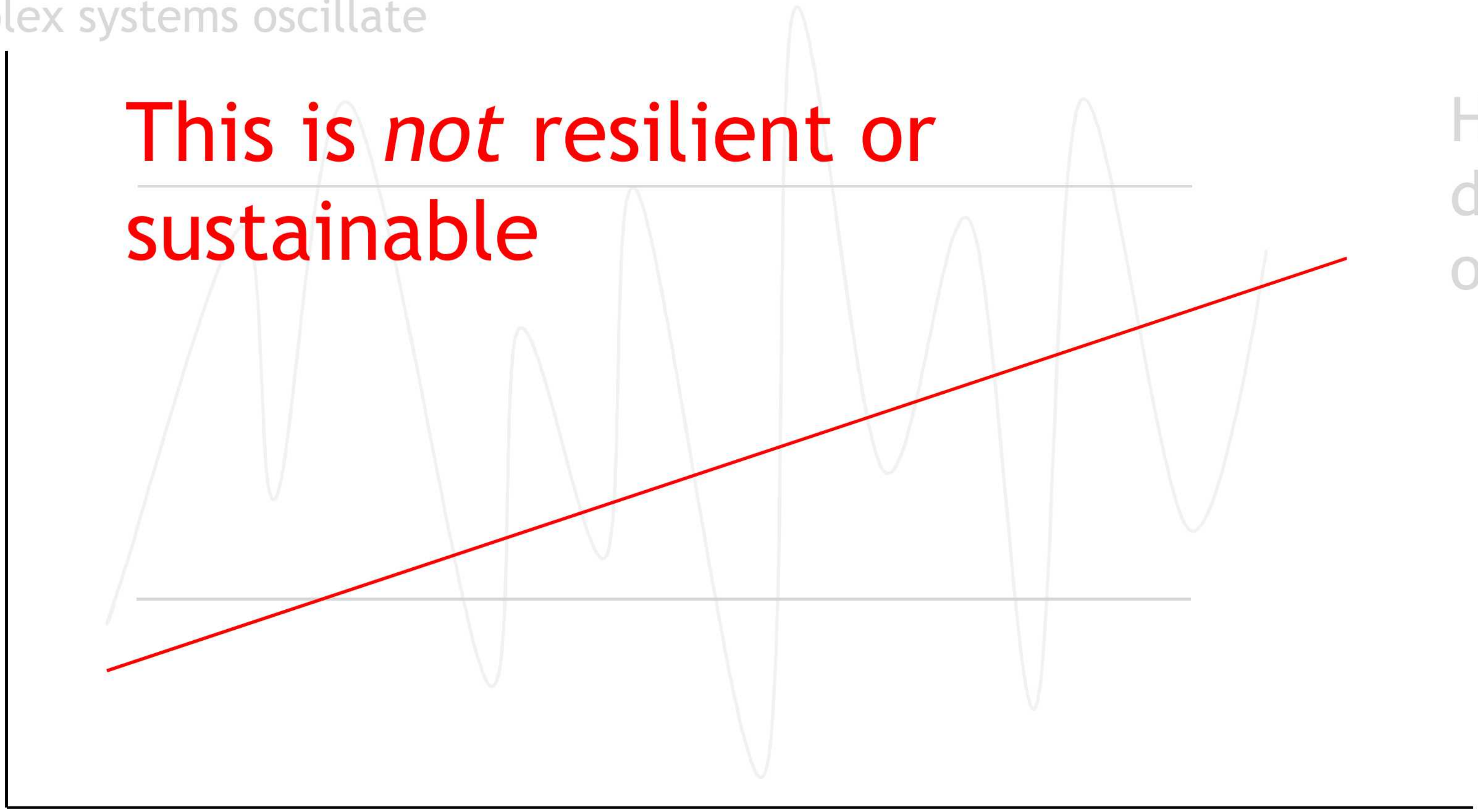
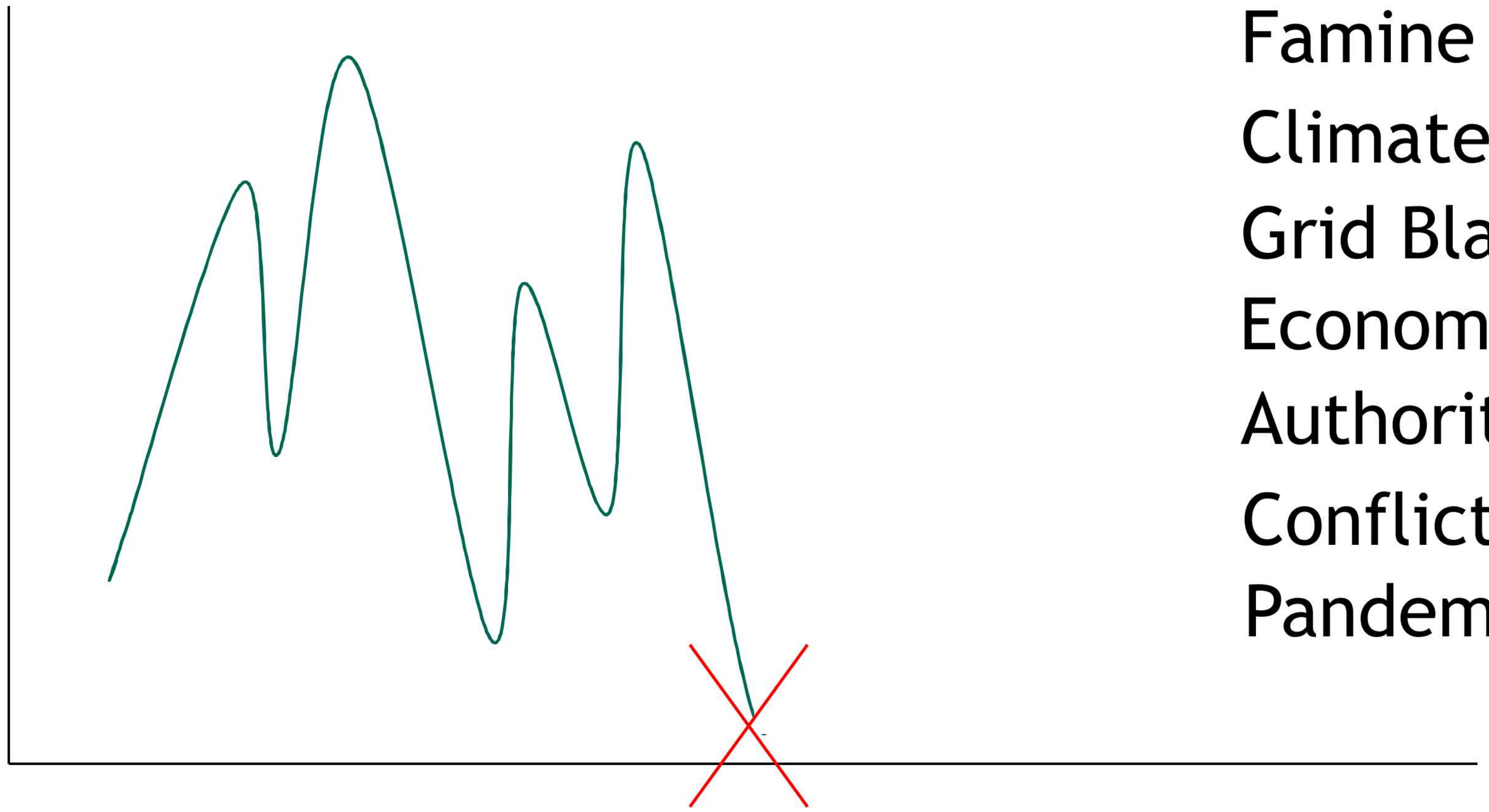


Humans want to dampen the oscillations

Resource systems, economic systems, social systems . . .

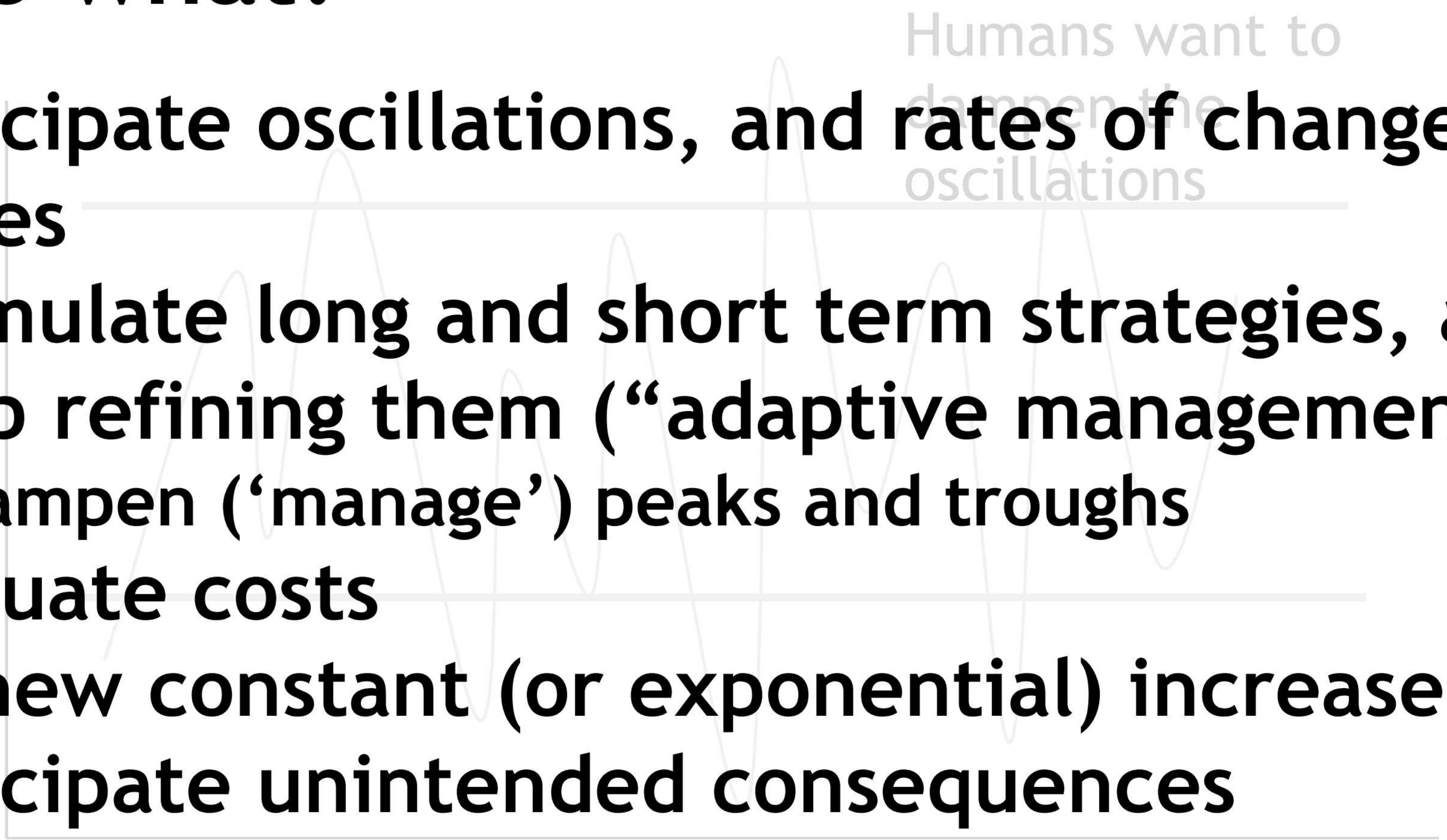
Resilience confers sustainability



Species extinction
Water scarcity
Famine
Climate crisis
Grid Blackouts
Economic collapse
Authoritarianism
Conflict
Pandemics

Resource systems, economic systems, social systems . . .

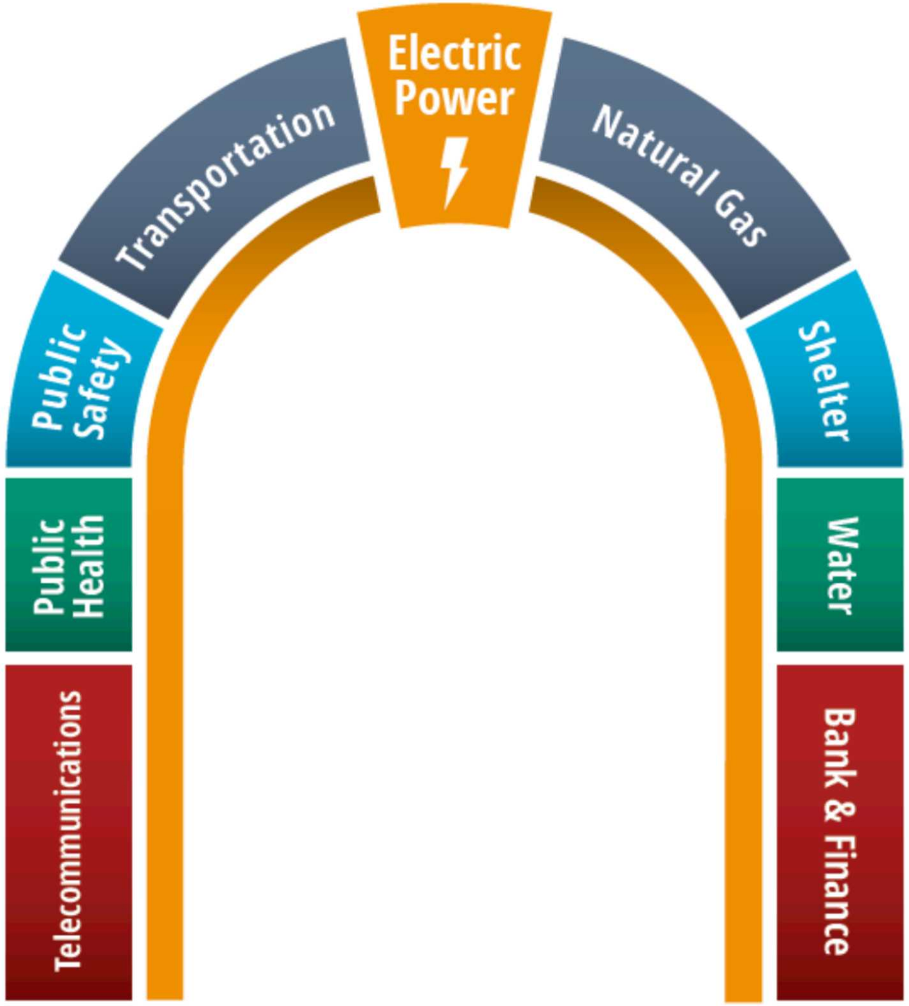
So what?



- Anticipate oscillations, and rates of change, at all scales
- Formulate long and short term strategies, and keep refining them (“adaptive management”)
  --Dampen (‘manage’) peaks and troughs
- Evaluate costs
- Eschew constant (or exponential) increase
- Anticipate unintended consequences

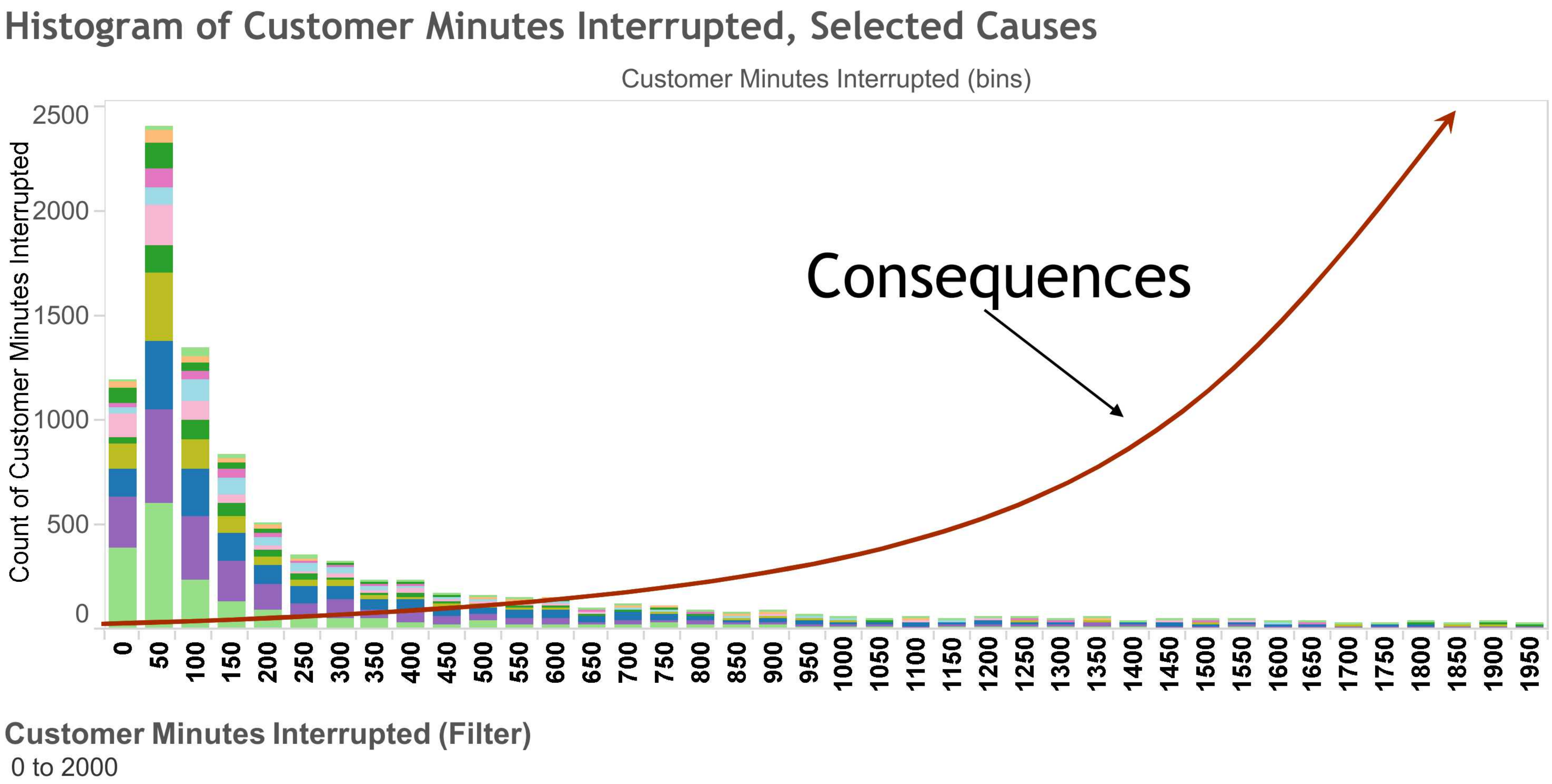
Resource systems, economic systems, social systems . . .

ENERGY RESILIENCE and COMMUNITY RESILIENCE



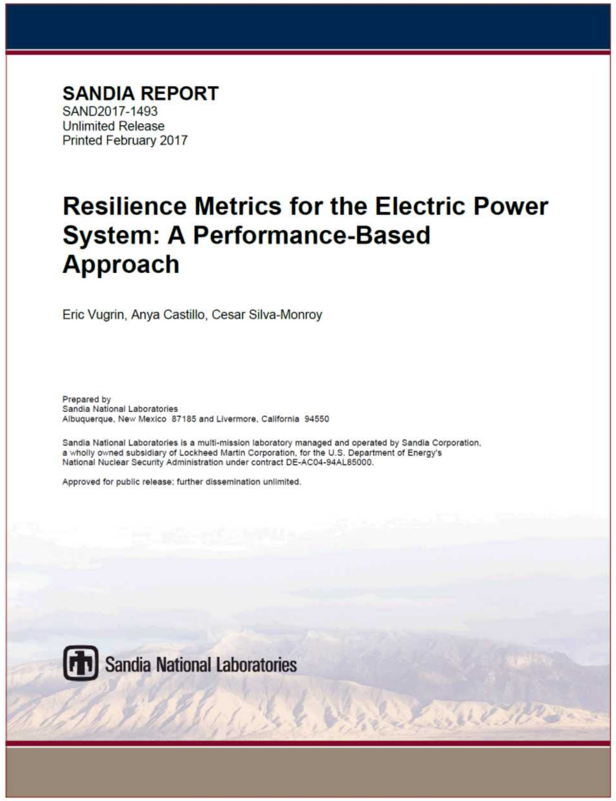
The grid is the keystone infrastructure – central to the web of interconnected systems that support life as we know it

RESILIENCE for GRID PLANNERS



Power system planners currently use reliability metrics and criteria to ensure a reliable grid. There is no standardized or accepted practice for resilience.

RELEVANT WORK FROM SANDIA


SANDIA REPORT
SAND2017-1493
Unlimited Release
Printed February 2017

Resilience Metrics for the Electric Power System: A Performance-Based Approach

Eric Vugrin, Anya Castillo, Cesar Silva-Monroy

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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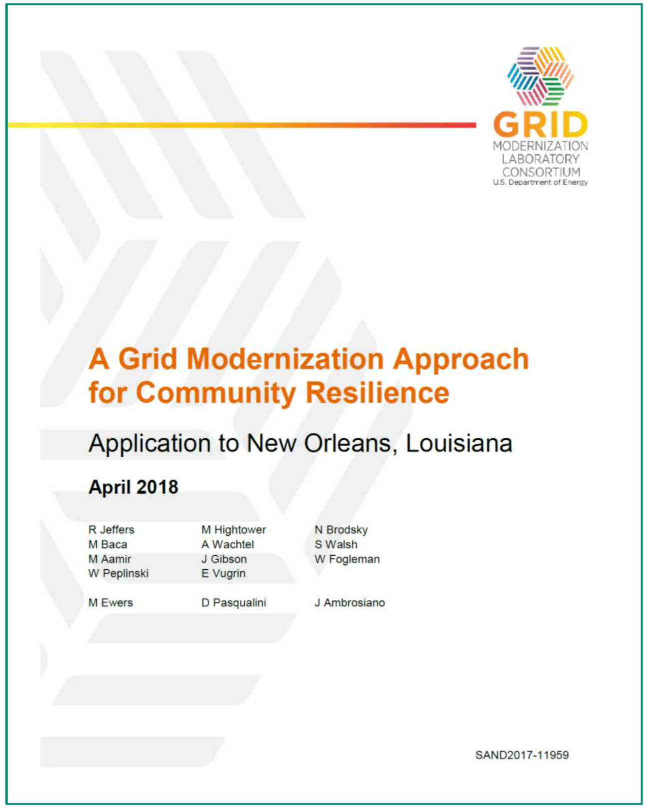
Approved for public release; further dissemination unlimited.

Sandia National Laboratories

Vugrin et al. 2017


GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

A Grid Modernization Approach for Community Resilience

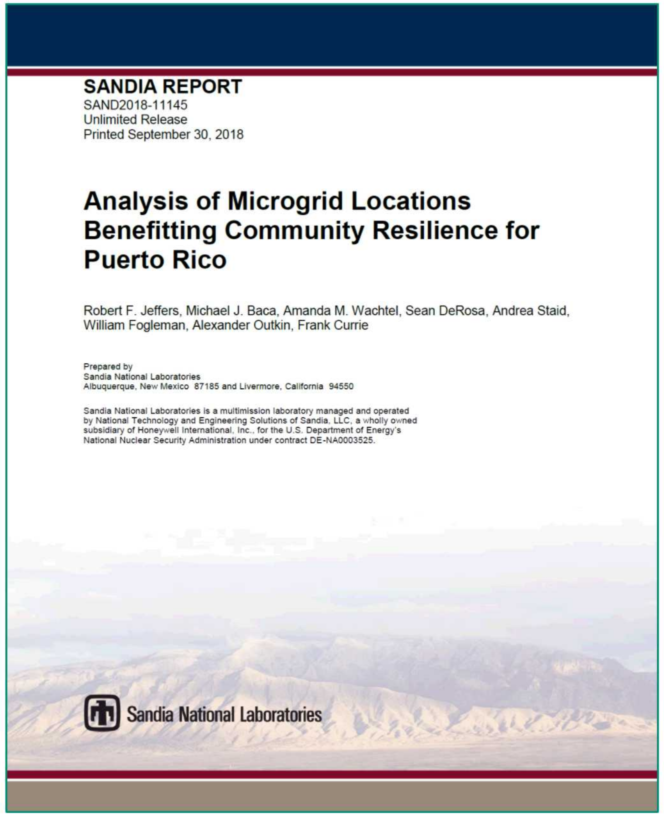
Application to New Orleans, Louisiana

April 2018

R Jeffers	M Hightower	N Brodsky
M Baca	A Wachtel	S Walsh
M Aamir	J Gibson	W Fogleman
W Peplinski	E Vugrin	
M Ewers	D Pasqualini	J Ambrosiano

SAND2017-11959

Jeffers et al. 2018a


SANDIA REPORT
SAND2018-11145
Unlimited Release
Printed September 30, 2018

Analysis of Microgrid Locations Benefitting Community Resilience for Puerto Rico

Robert F. Jeffers, Michael J. Baca, Amanda M. Wachtel, Sean DeRosa, Andrea Staid, William Fogleman, Alexander Outkin, Frank Currie

Prepared by
Sandia National Laboratories
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Sandia National Laboratories

Jeffers et al. 2018b

ATTRIBUTE-BASED VS PERFORMANCE BASED RESILIENCE

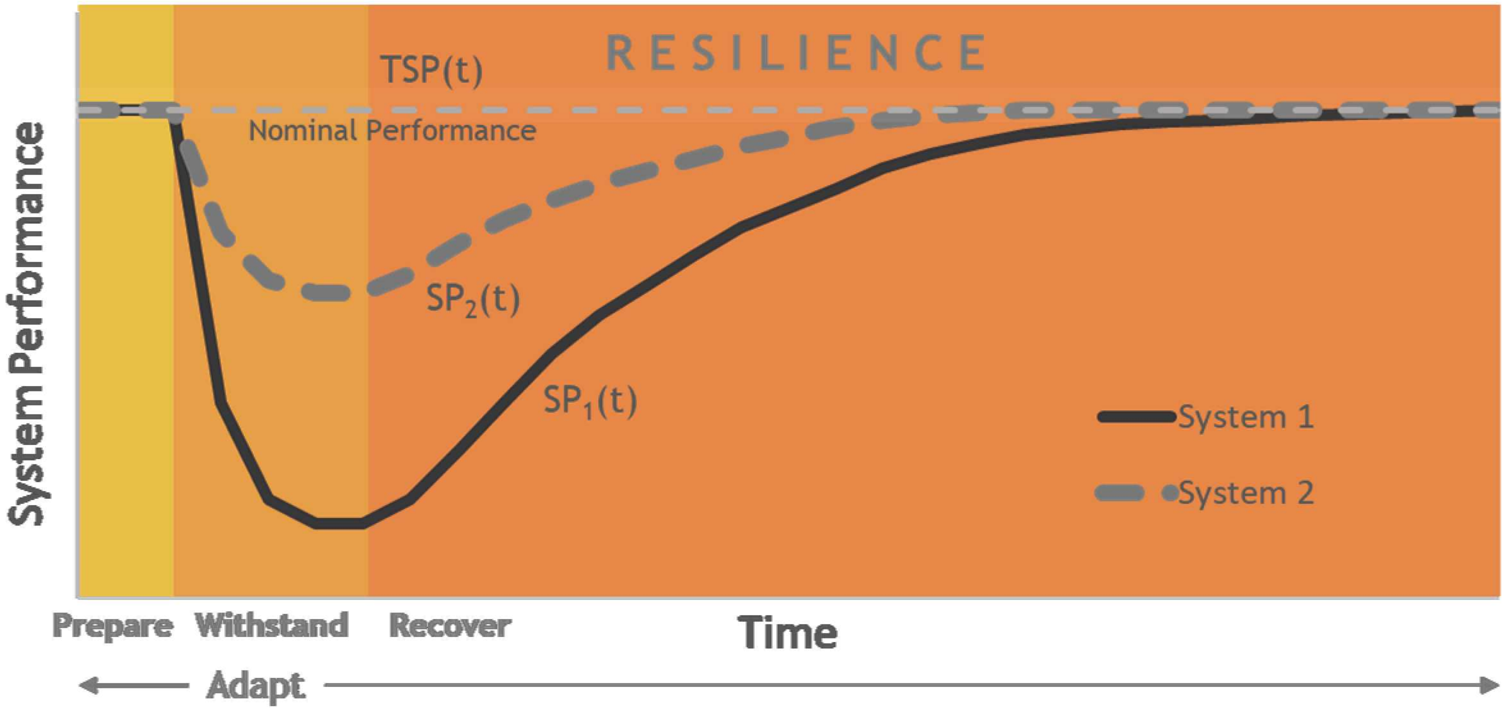
Attribute-based: What makes my system more resilient?

- More qualitative – describes robustness, resourcefulness, adaptability, recoverability
- Collect surveys, developing weighting values, develop numerical scores
  - Supply Chain Resilience Assessment and Management (SCRAM™)
  - Argonne National Labs Resilience Measurement Index

Performance-based: How resilient is my system?

- More quantitative – data intensive interpretation of system outputs given various disruptions
  - Measuring Resilience of Energy Distribution Systems, H. Willis and K. Loa, RAND, 2016
  - Critical Infrastructure System Security and Resilience, B. Biringer et al., 2013
  - A Resilience Assessment Framework for Infrastructure and Economic Systems, E. Vugrin et al., Process Safety Progress 2011
  - Economic Resilience to Natural and Man-Made Disaters, A. Rose, Environmental Hazards 2007
  - A Framework to Quantitatively Assess and Enhance the Seismic Resilience of Communities, M. Bruneau et al., Earthquake Spectra 2003

PERFORMANCE-BASED RESILIENCE METRICS



1. Resilience is contextual – defined in terms of a threat or hazard
   - 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

What is your system? How do you define performance? What threats do you want to be resilient to?

RESILIENCE ANALYSIS PROCESS

Resilience is contextual – a system resilient to flooding might not be resilient to cyber attack

Quantifying Consequences

Community Metrics

- Number of people without services
- Lives at risk
- Societal burden to acquire services

Economic Metrics

- Net economic losses (GDP)
- Capital losses/costs to rebuild
- Business interruption costs

Security Metrics

- Ability to serve critical missions, like police/fire & rescue, telecommunications, etc.

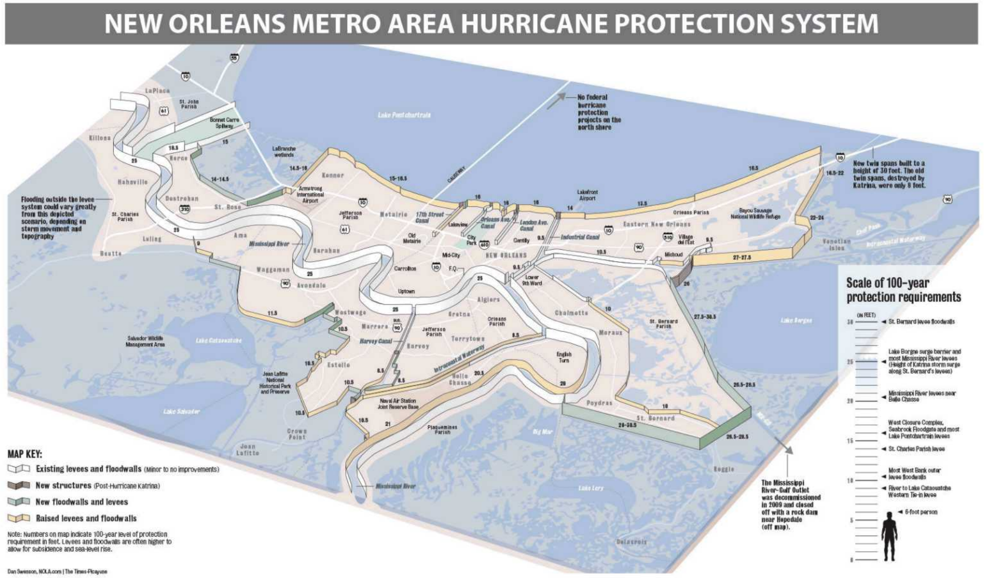
CASE STUDY: NEW ORLEANS, LA

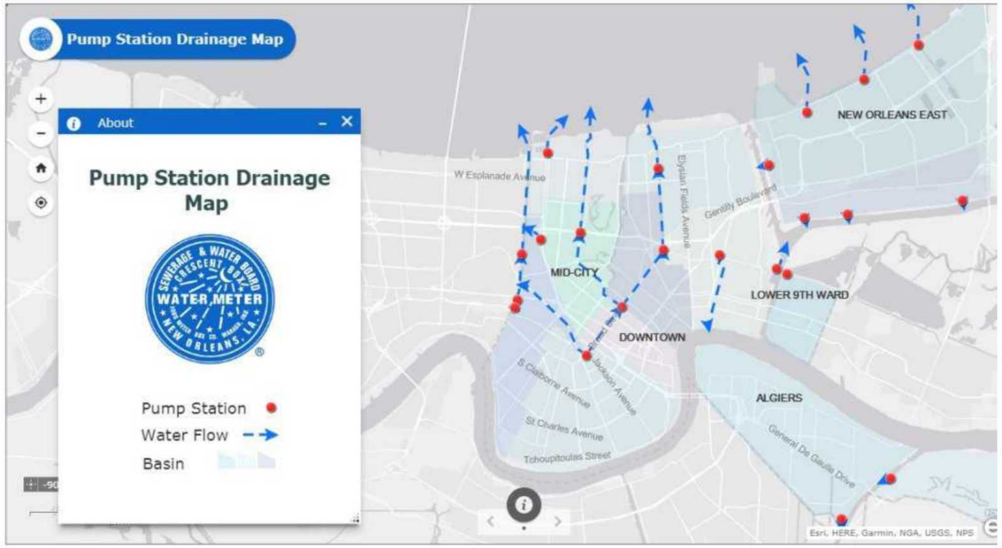
Partners / Stakeholders

- City of New Orleans:
    - Office of Resilience and Sustainability (ORS)
    - Office of Homeland Security & Emergency Preparedness (NOHSEP)
    - Sewerage and Water Board of New Orleans (SWBNO)
    - Utility, Cable, Telecom, and Technology Committee of City Council
- Entergy New Orleans:
    - Resource Planning and Market Operations
    - Economic Development and Technology Innovation

Application to New Orleans

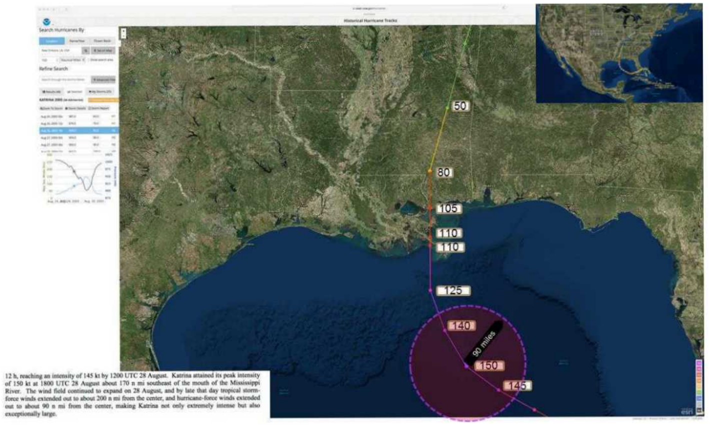
- What keeps you up at night?
    - High Cat2, Low Cat3 -> no mandatory evacuation
    - Stalls and drops >20" of rain quickly
    - Dewatering system operates at less than max capacity
- What can we do about it?
    - Distribution system investments on the power system
    - Ensure citizens have access to lifeline services
    - Unsure of the investment mechanism
        - Utility, City, Federal, etc.



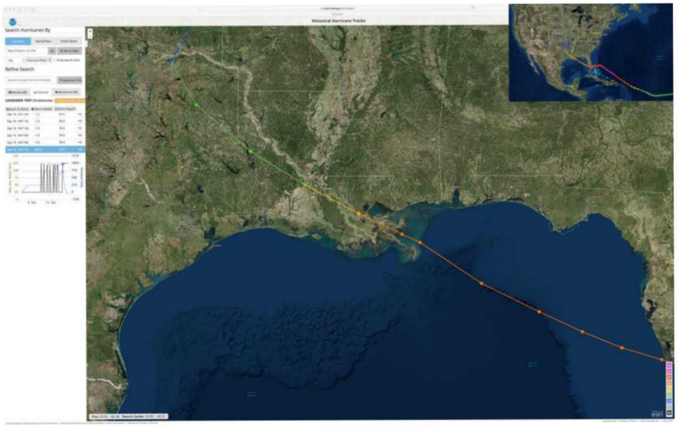


THREAT CHARACTERIZATION

Simulated hurricane tracks

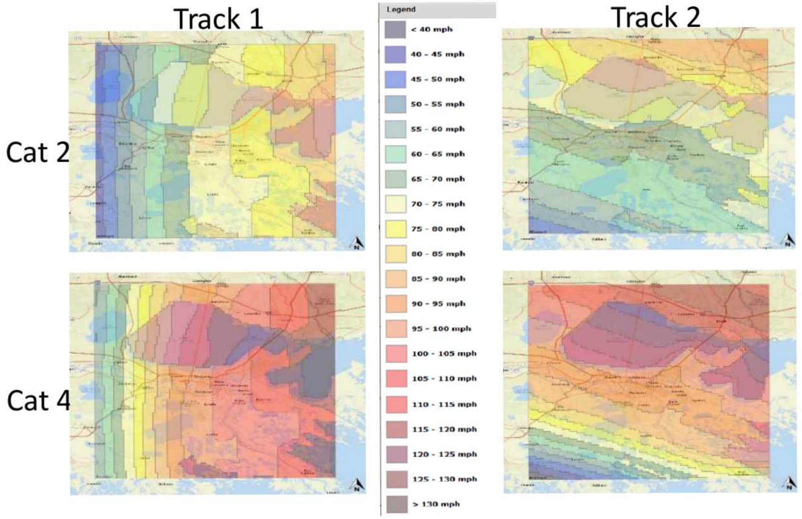


Track 1

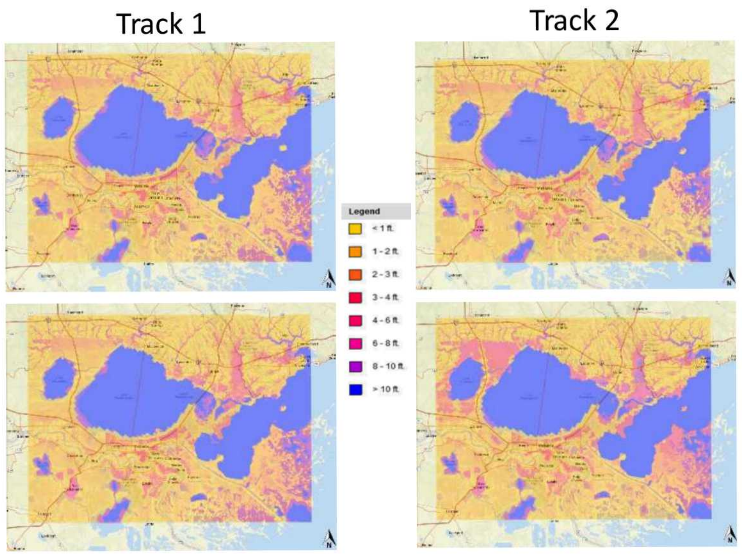


Track 2

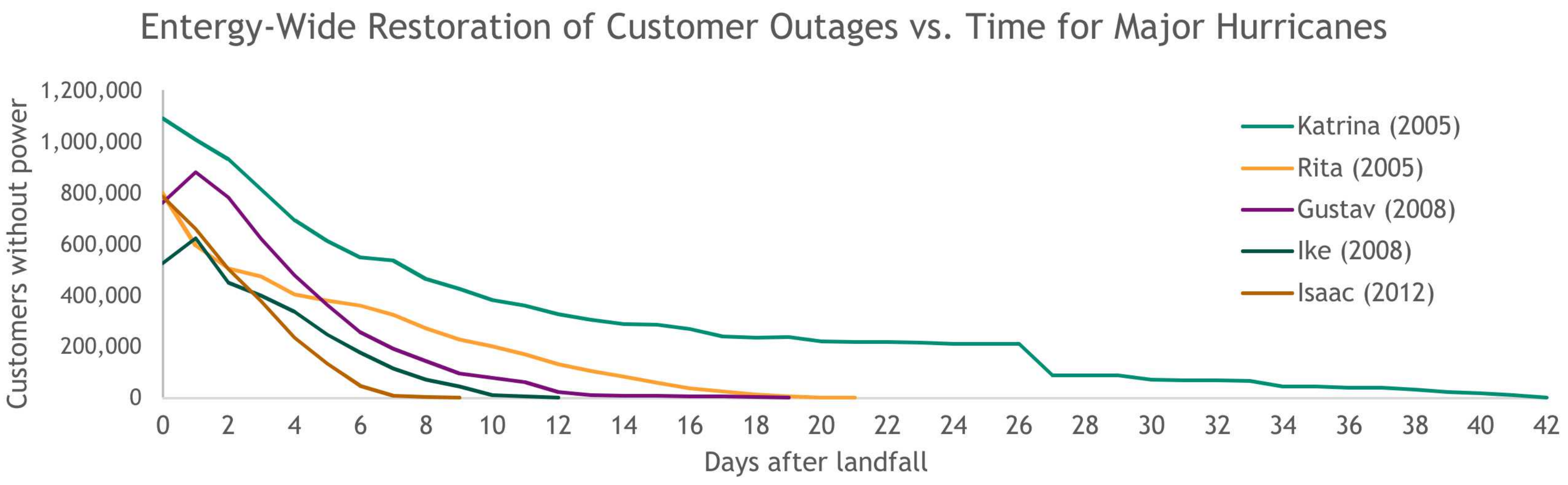
Max Windspeeds

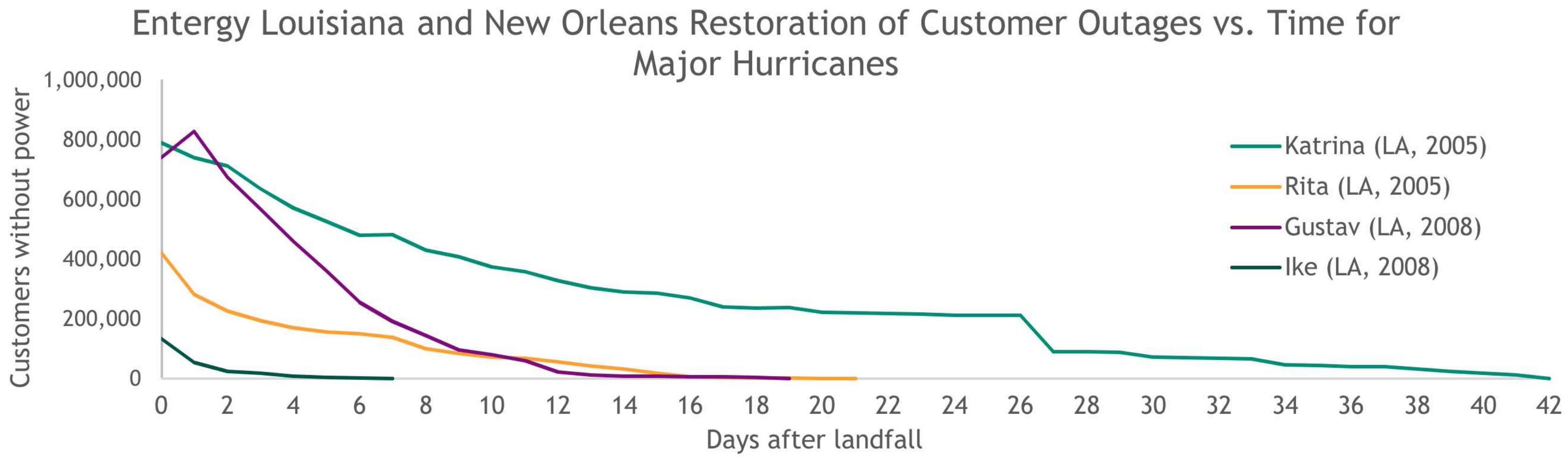


Max Flood Depths

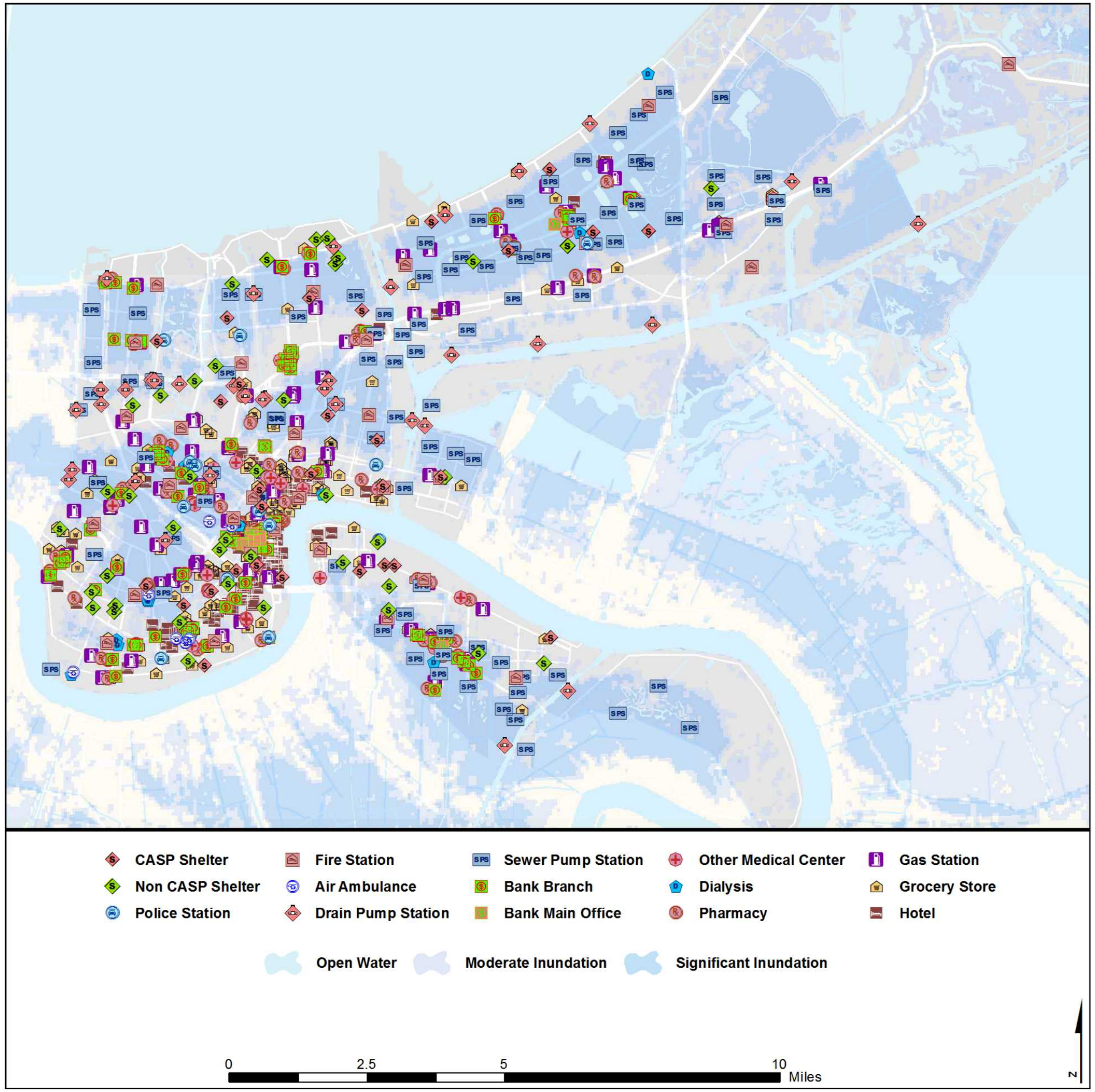


BASELINE OUTAGE ESTIMATION

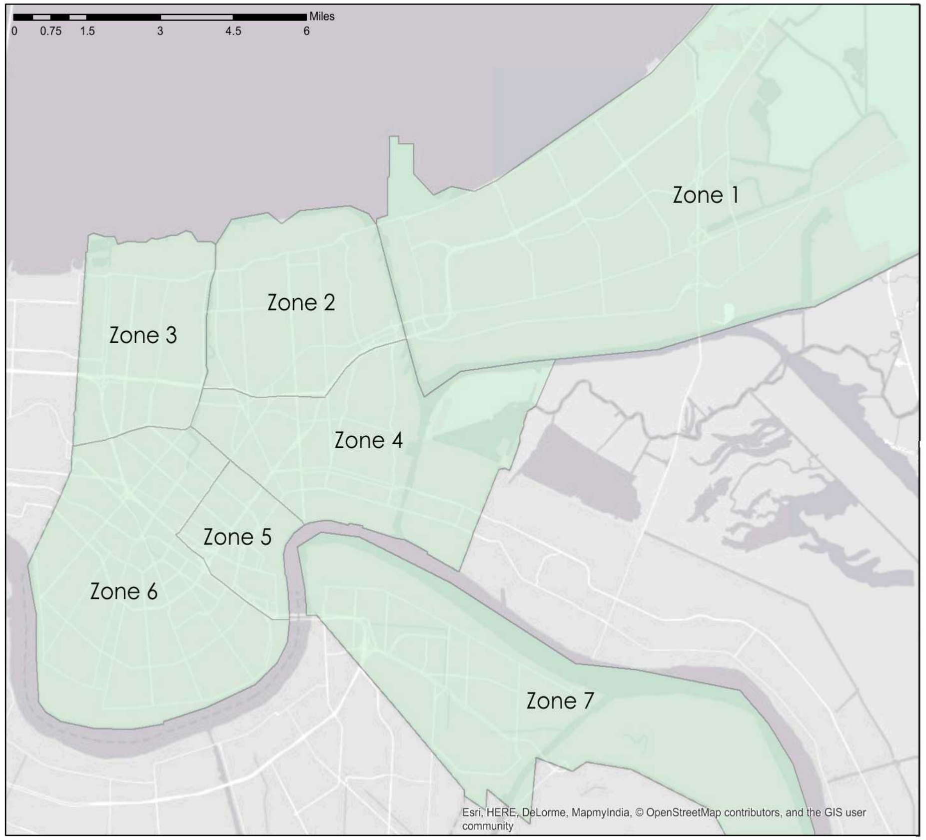


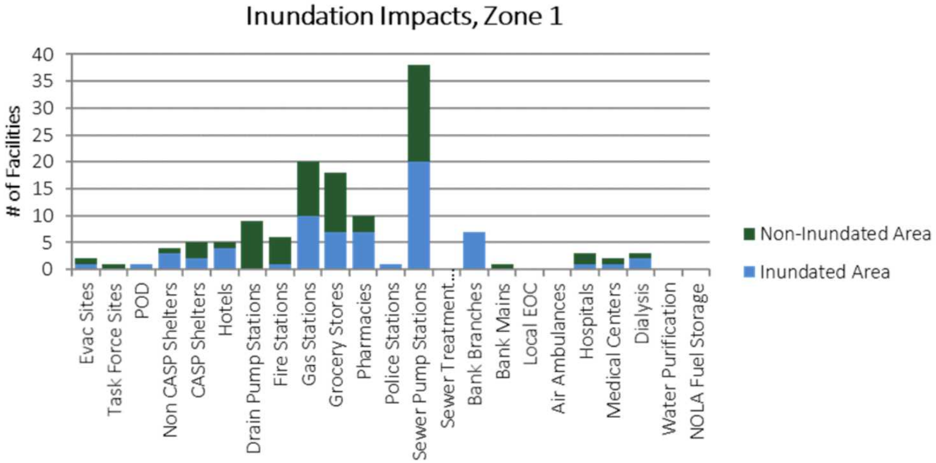


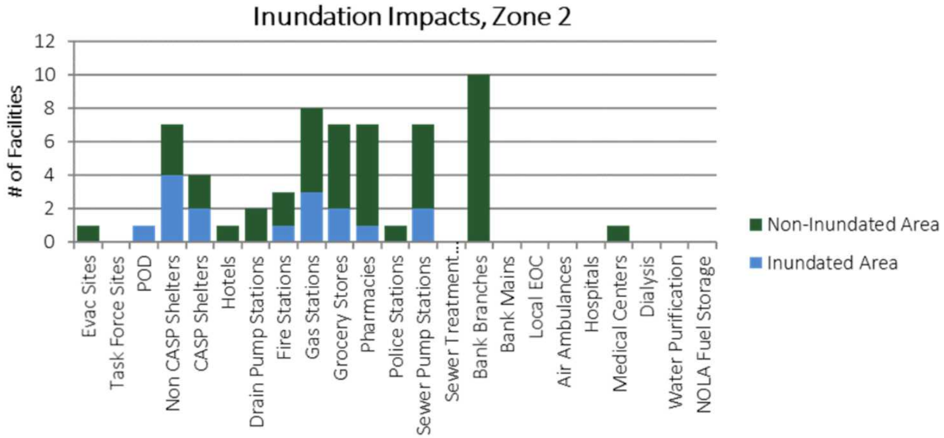
CRITICAL ASSET LOCATIONS



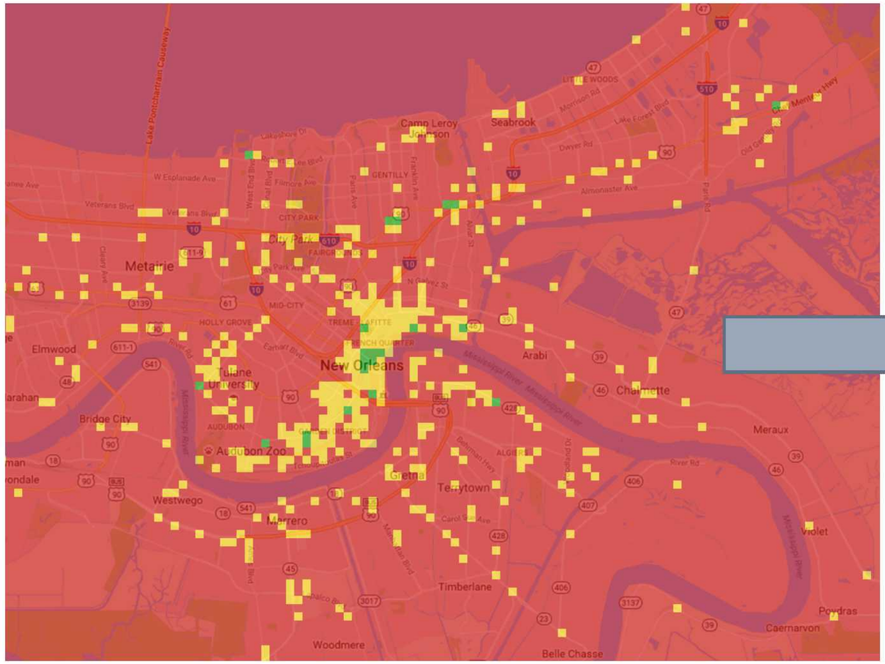
BASELINE CONSEQUENCE

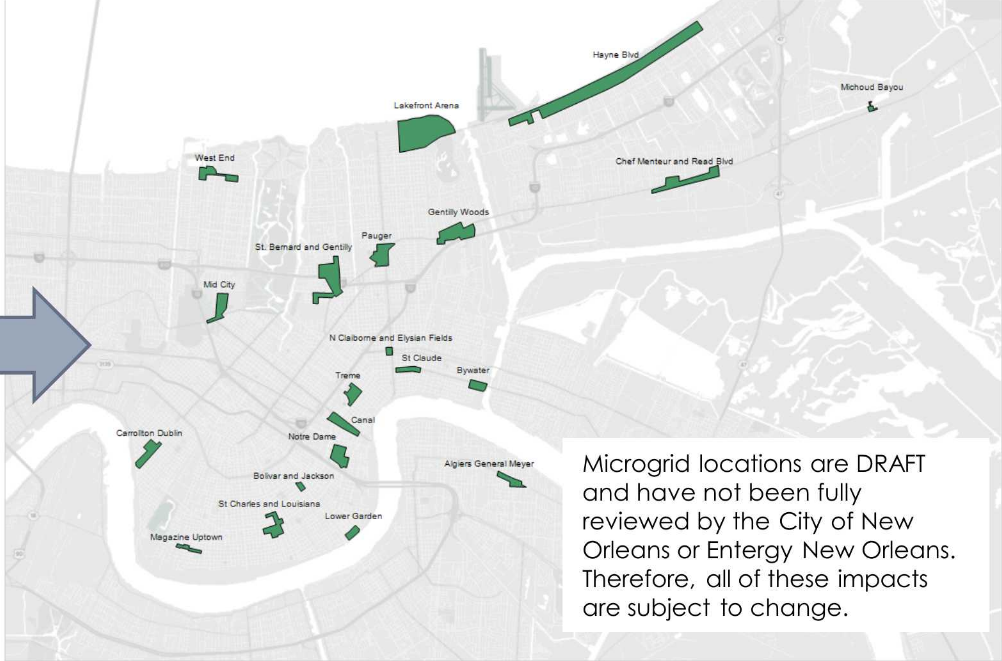






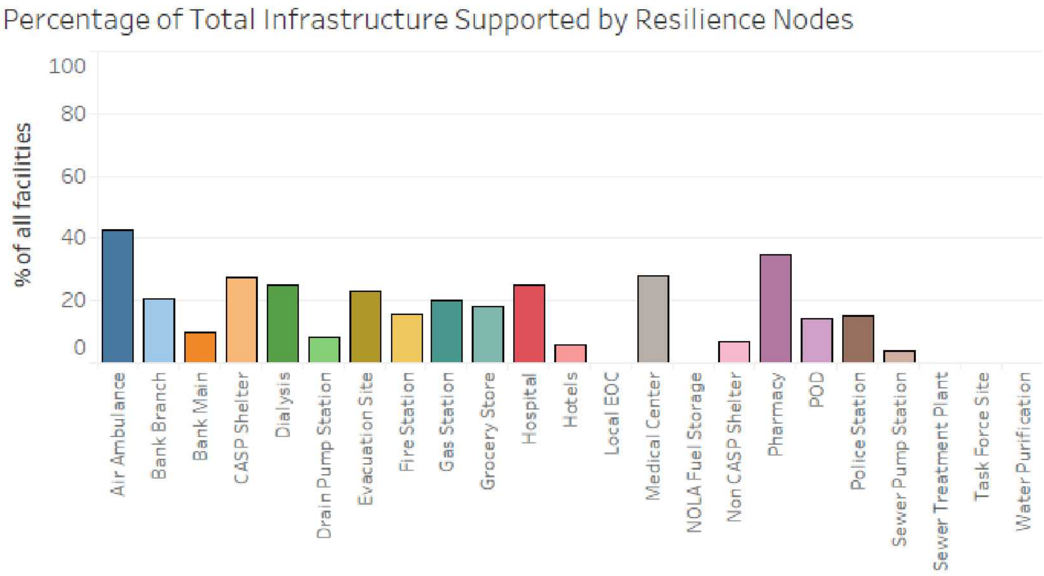
SPECIFYING ALTERNATIVES

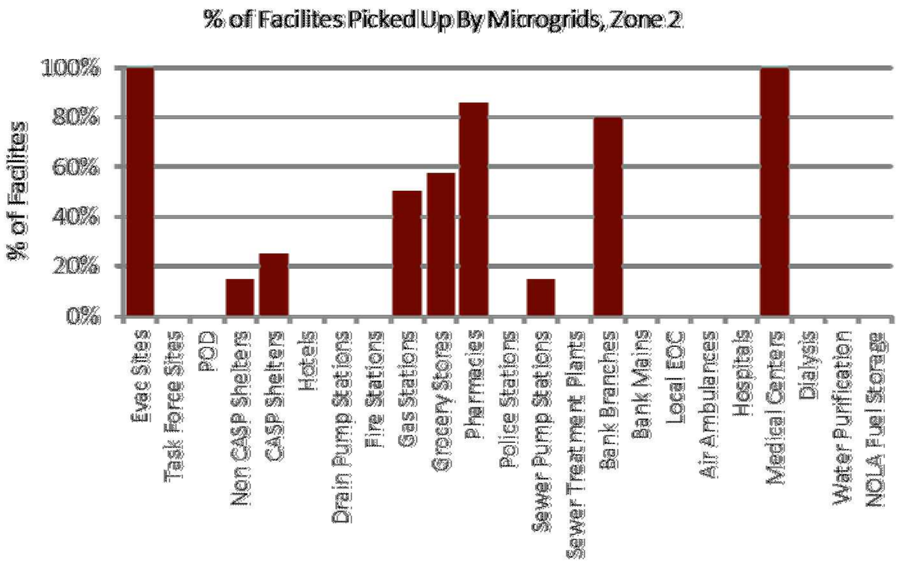


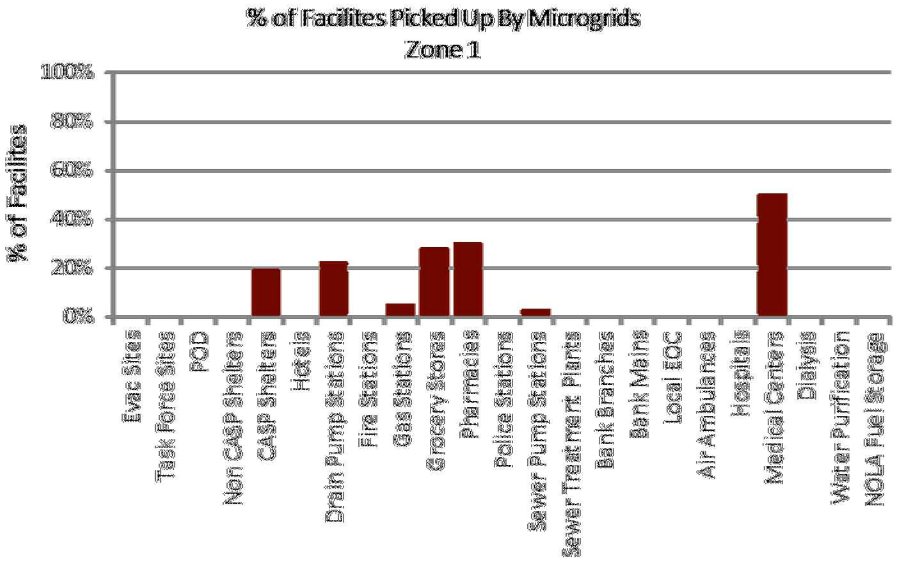


Microgrid locations are DRAFT and have not been fully reviewed by the City of New Orleans or Entergy New Orleans. Therefore, all of these impacts are subject to change.

EVALUATING ALTERNATIVES

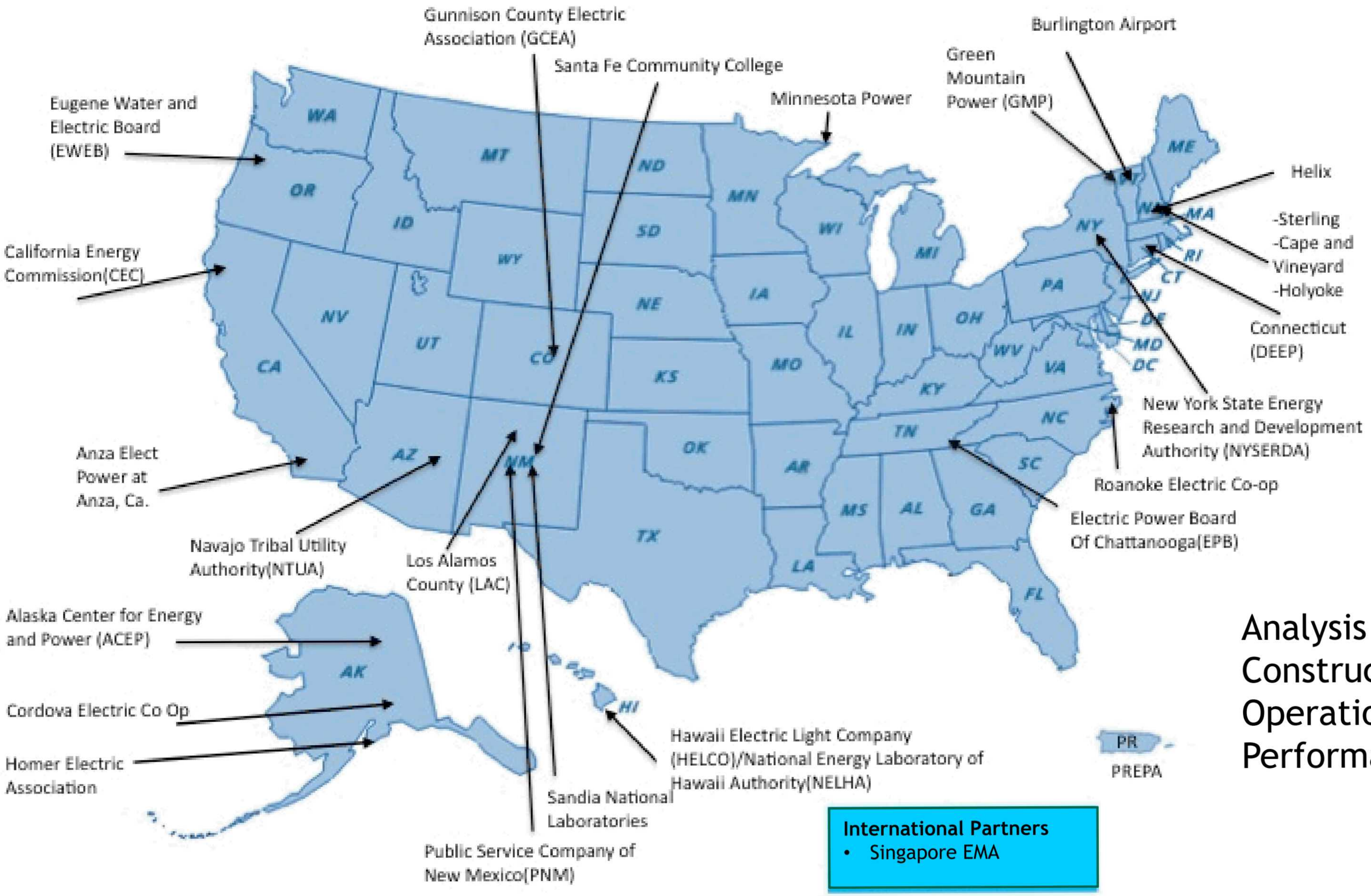






And then choose different alternatives and run the models all over again . . .

DOE/SNL Energy Storage Projects



Analysis
Construction
Operation
Performance analysis

Projects with some Resiliency Function

Project / location	Size (MW / MWh)	Normal Operation	Resiliency Operation
Sterling Municipal Light Department / Mass	4 MW / 3.9 MWh	Peak Shaving for Forward Capacity Market and RNS	Back-up power for police station
Green Mountain Power / Vermont	4 MW / 3.4 MWh	Peak shaving for Forward Capacity Market, RNS, frequency regulation	Back-up power for Emergency Shelter
Eugene Water and Energy Board / Oregon	0.5 MW / 1 MWh	Daily Peak Shaving and Demand Charge reduction	Back-up power for emergency shelter; microgrid testbed
Cordova Electric Co-op / Alaska	1 MW / 1 MWh	Hydro capacity increase and Diesel deferral; eliminate spinning reserve	Back-up power for hospital
Albuquerque Public Schools	250kW/500 kWh	Demand Charge reduction	Back-up power for emergency shelter
Santa Fe Community College / NM	100 kW / 170kWh	Renewable Energy Shift, Fossil Fuel Reduction	Fossil Fuel Reduction for food protection in emergency
ANZA Electric Cooperative / CA	In Contract	Transmission Deferral	Back-up power for critical substation feeder
McKnight Lane, VT	6kWh / 4kW each	Net-zero energy PV+battery modular homes	Essential appliances, heating, cooling ventilation

Resiliency = ES & Microgrids

Industrial, commercial, police & fire users install batteries to bridging the gap between grid outage and their own diesel or NG generators ramping up.

These are microgrids, requiring the ability to “island” from the grid. But . . .

--diesel has air quality issues
--diesel has to be stockpiled
--diesel can be expensive

“Batteries are the bacon . . .”

A grid-tied ESS without the ability to “island” has no resilience value.

Sterling Municipal Light Department 2 MW, 3.9 MWh system

ESS operation in microgrids: grid stability, diesel deferral, renewable firming, renewable smoothing, energy time shift, ramp rate control, UPS.

ES for resilience complicates ES management

What does resilience mean to you and your community?
How do you plan for scheduled vs. unscheduled outages

Three ways to manage your ESS with regards to resilience:

- Stack benefits and if you need it for resilience use whatever power you have left for emergency backup
- Plan for a crisis you know is coming
  -- A hurricane is forecast, so you abandon other benefits, charge your battery and keep it charged
- A crisis you don't know is coming
  -- An earthquake or cyber attack occurs.
  Is your battery charged?

Sterling Municipal Light Department (SMLD)

Designed for resilience to hurricanes and ice storms, which are predictable.

Battery is a 2MW, 3.9 MWh, includes PV

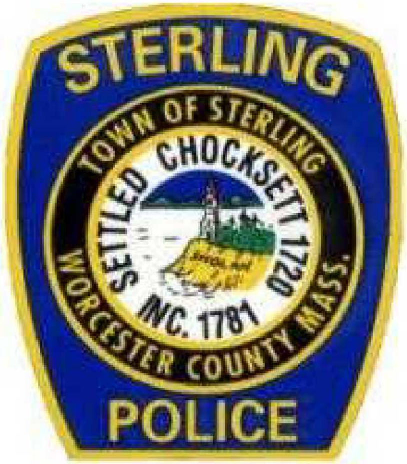
Load is ~10 kW for police and fire communications 16 days)

4000 kWh/10 kWh = 400 hours/24 = 16.6 days

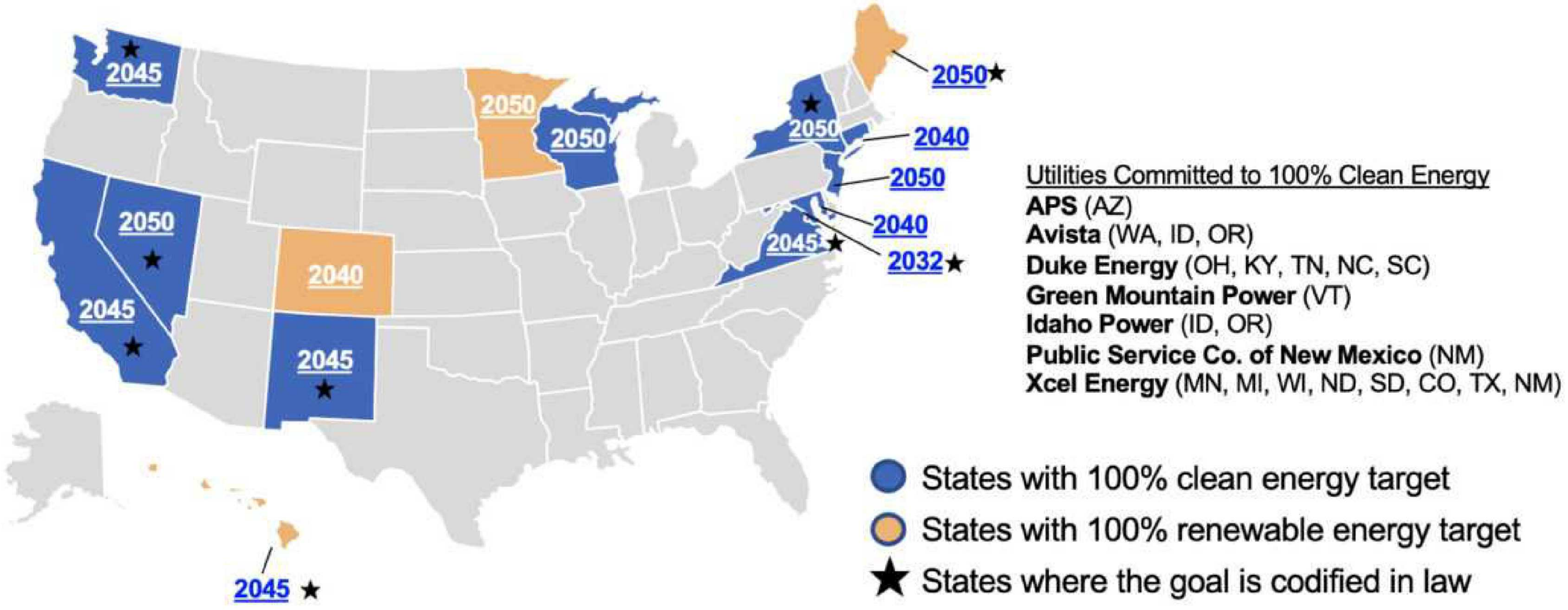
Otherwise, value streams include energy arbitrage, reduction in monthly network service and capacity payments, and frequency regulation

System cost ~ $4m, yielding ~ $1M annually in revenues = 4-6 year payoff, and battery will last ~ 12 years

DOE and grant money helped defray the cost . . .



States and utilities with 100% decarbonization or RE targets



Source: Advanced Energy Economy, March 2020

States Procurement Mandates further up the ante – Virginia Clean Energy Act requires 3100 MW of ES by 2035

Optimal PV, wind, and energy storage capacity required for meeting NM's 100% carbon free goal

	Now	Needed[4]	% Increase
Energy Storage	3.75 MW[1] (0.00375 GW or 0.08%)	5 GW/25 GWh	133,000%
Solar PV	818 MW[2] (0.818 GW or 8%)	10 GW	1,122%
Wind	1,953 MW[3] (1.953 GW or 40%)	5 GW	156%

[1] Global Energy Storage Database 2019; [2] Solar Energy Industries Association 2019

[3] American Wind Energy Assoc. 2019; [4] Copp et al., in press

Optimal Sizing of Distributed Energy Resources for 100% Renewable Planning

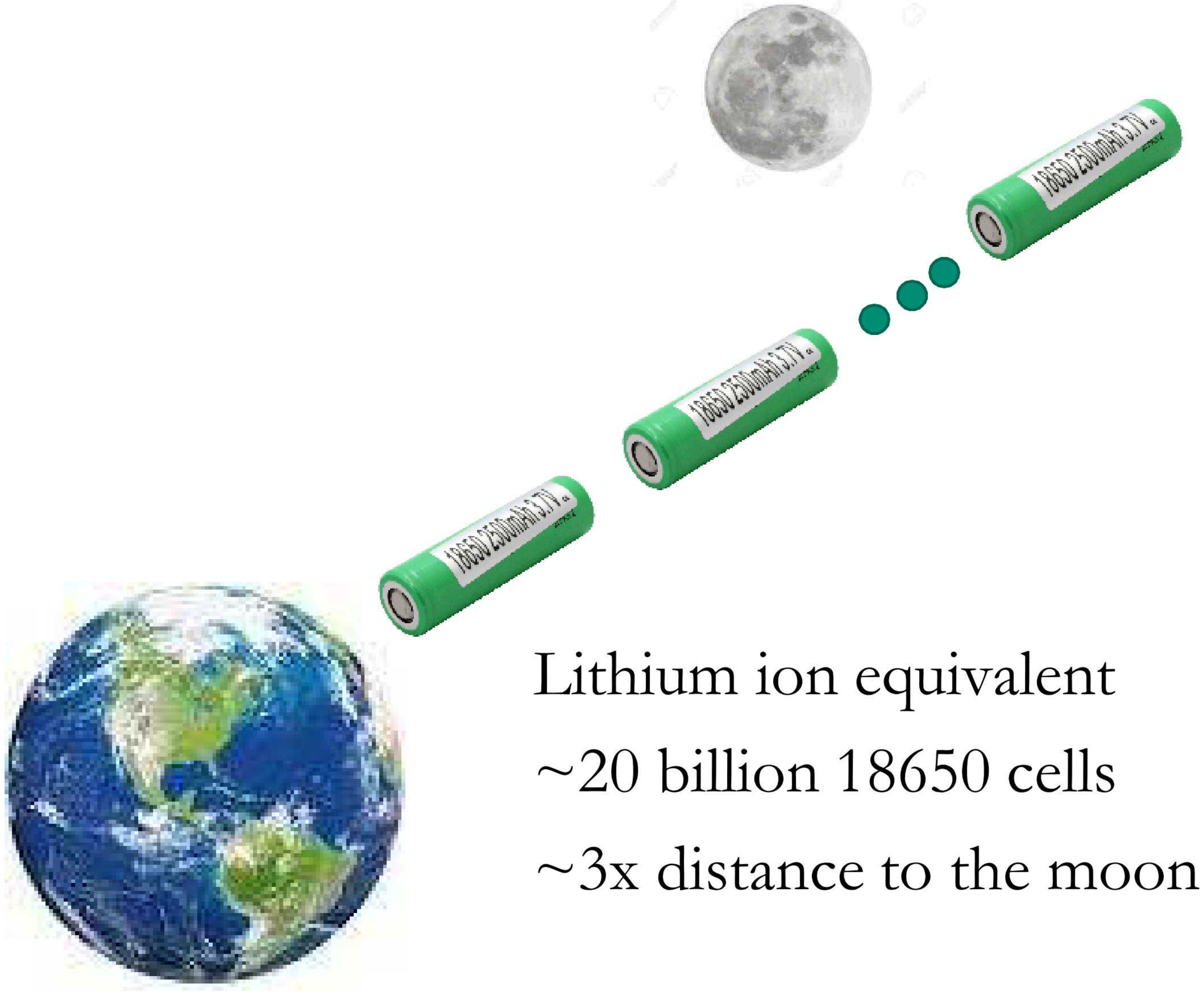
David A. Copp[a,*], Tu A. Nguyen[a], Robb Thomson[b], Raymond H. Byrne[a], Babu R. Chalamala[a]

[a] Sandia National Laboratories, P.O. Box 5800, Albuquerque, NM 87185-1108, USA
[b] Retired Fellow, NIST, Gaithersburg, MD; Current address, 250 E Alameda Apt 523, Santa Fe, NM 87501,USA

LOTS of storage required for 100% mandates

Racoon Mountain pumped hydro

1,652 MW -- 22 hours



Lithium ion equivalent

~20 billion 18650 cells

~3x distance to the moon

Selected materials required for RE & ES, and increasing demand

Lithium
Cobalt
Graphite
Indium
Vanadium
Nickel
Silver
Neodymium (and other REEs)
Molybdenum
Aluminum
Copper
Manganese
Cadmium

Projected increases in demand between 2015 and 2060:

Light duty passenger EVs	80,316%
Energy storage capacity (GWh)	2.48M%
Installed PV	3083%

International Renewable Energy Agency (IRENA), "Global energy transformation: A roadmap to 2050" (IRENA, Abu Dhabi, 2018).

EV Batteries materials	87,000%
Wind materials	1,000%
Photovoltaics materials	3,000%

A. Månberger, B. Stenqvist, *Energy Policy* 119, 226 (2018).

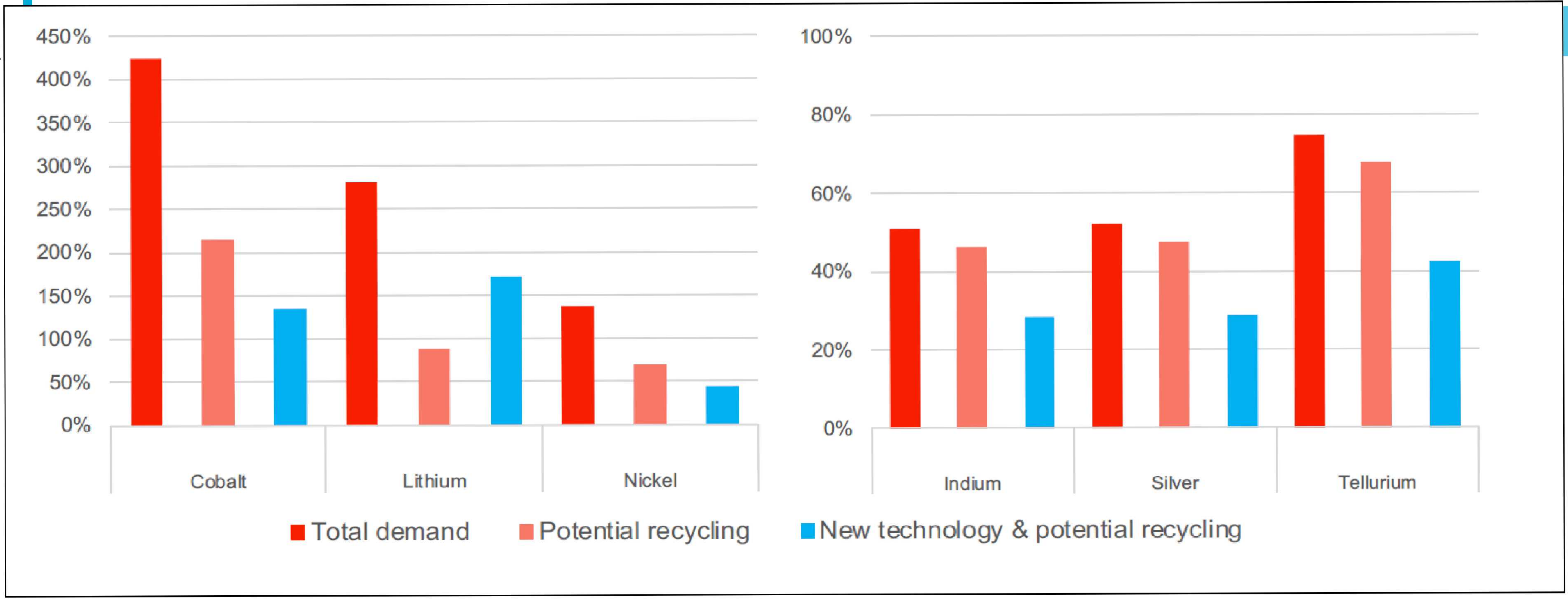
Supply chain issues are one challenge

Rare Earth Elements

- 17 metals not really rare but widely distributed in small reserves
- Toxic mining
- Many uses – wind turbine generators, PV, batteries, cell phones, fuel rods, missile guidance
- Poor substitutability
- China is leading source with 80-90%
- Poor recycling (<1%)

Mt. Pass Mine – raw materials go to China.

Rare Earth Elements
Scandium, Yttrium, Lanthanum, Cerium, Prasedymium, Neodymium, Promethium, Smarium, Europium, Gadolinium, Terbium, Dysprosium, Holmium, Erbium, Tjulium, Ytterbium, Lutetium



Cumulative demand from RE and ES by 2050 relative to known, economically extractable reserves for selected battery metals (left) and solar PV metals (right), based on current projections.

Dominish, E., Floin, N., and Teske, S., 2019. Responsible Minerals Sourcing for Renewable Energy. Institute for Sustainable Futures, University of Technology Sydney.

Other Supply Chain Bottlenecks

- Toxic mining
- Toxic post consumer waste
- Insufficient LCA
- Child labor
- Energy inequity/injustice
- Inadequate recycling
- Inadequate substitutes
- Inadequate cradle-to-cradle design and production

Bloomberg

How can transmission play in the solution?

Some argue that more transmission can solve the problem – that sufficient clean energy can be produced in the West and then sent East, if we had the transmission.

High voltage DC transmission is a promising technology

But transmission faces it's own challenges

--Citing, jurisdictions, environmental reviews

--Costs

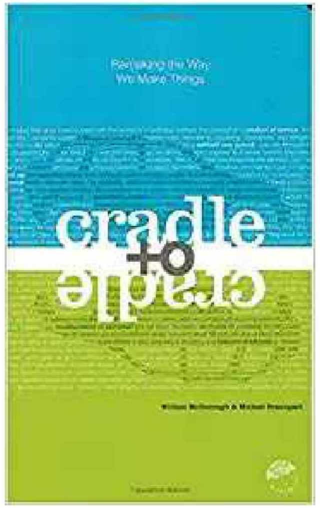
--Materials and supply chains

The Linear Economy -- Extract resources (metals, wood, fiber, water, nutrients, energy), use once, throw it away . . .

- Works ok with low human population, low consumption, and resource abundance

The Circular Economy -- Design and manufacture products so that they can be disassembled at end-of-life and used again, and again.

- Recycling is a subcategory. . .



2002, William McDonough and Michael Braungart

The Circular Economy . . .

- Reduces future extraction, conserving energy and materials and reducing pollution
- Reduces waste stream, relieving pressure on landfills and relieving pollution
- Reduces future supply chain bottlenecks and increasing costs due to scarcity
- Enhances resilience, sustainability, reliability
- In a world of increasing demand and decreasing supply for use in critical infrastructure, it is a national security issue

But, the Circular Economy requires . . .

- Greater ingenuity and expense in design and manufacturing
- Better life cycle analysis (LCA) and techno-economic analysis, and "systems" solutions
- R&D for substitutes
- Greater investment into end-of-life tracking, collection, transport, disassembly, and reassembly
- An economic or resilience incentive
- Legislation & policy, rebates, tax credits, incentives, standards & codes, public/private R&D and partnerships
- A paradigm change in the way humans deal with materials and production

Possible solution space

Lithium ion may not be the solution; batteries may always provide short term storage (i.e., not seasonal); other ES technologies can provide longer term storage (pumped hydro, compressed air, hydrogen) but they all have limitations. Transmission has its limitations.

It's okay to have objectives and no idea how to reach them, but this would be a good time to be working on strategy . . .

"All of the above" might be the ticket.

- Non Wires Alternatives
- High Voltage DC Transmission
- Cleaner batteries for short duration ES
- New ES technologies
- More wind and PV,
- better "end of life" solutions
- reduced consumption and greater efficiency.

Unintended consequences

If you were in a shipwreck and a piano top came floating by, you might climb up on top of it and use it as a life preserver. But if you were in the business of designing life preservers, you probably would not make one in the shape of a piano top.

Buckminster Fuller, Operating Manual for Spaceship Earth, 1969

- Ammonia for refrigeration
- CFCs for refrigeration
- Collatoralized Debt Obligations
- Cars, Modern Medicine, Industrial Fertilizer . . .
- Corn for Ethanol
- DDT
- Fossil fuels
- Forest fire control

Acknowledgements

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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

Additional slides

Breakout Topic 1: Defining and Measuring Resilience

- How are existing definitions of resilience operationalized?
- Is resilience threat-agnostic or threat-informed? Are threats acute or chronic?
- Are metrics attribute or performance-based? Do metrics measure performance and consequence?

Breakout Topic 2: Valuing Resilience

- How is resilience prioritized relative to other goals/mandates (e.g., reliability, sustainability)?
- How are different resilience metrics/consequences prioritized?
- What are the methodological/implementation challenges associated with valuing resilience?

Breakout Topic 3: Regulatory Approaches for Resilience

- How are commissions currently incorporating resilience into regulatory processes? Given existing authorities and resources, what are some (potentially unrealized) options?
- How does the regulatory process in which resilience is embedded affect how it is measured (e.g., cost-benefit analysis requirements)?
- Which aspects of resilience involve entities outside the commission? Who are the key stakeholders and what are the mechanisms (existing or needed) of coordination?

Breakout Topic 4: Resilience Mitigations and Investments

- What potential resilience mitigations exist (e.g., physical, policy, procedure)?
- How should potential investments be evaluated? What would we need to feel confident that they could be applied?
- Are there no-regrets, high bang-for-buck investments?

Demonstration Partner Template

Step 1: Resilience Drivers Determination

Step 1 Description

1.1. System

- System scope:
- Planning process (and role of resilience):

1.2 Threats

- Threats to resilience:

1.3 Goals

- Resilience goals:
- Other complementary or competing goals:

1.4 Metrics

- Consequence categories:
- Consequence-focused performance metrics:

Stakeholders Engaged

Tools/Resources Used

Challenges and Opportunities

Step 2: Baseline Resilience Analysis

Step 2 Description

2.1 Baseline Impact Analysis

- Threats/disruptions:
- Component impacts and aggregation to infrastructure system impacts:
- Multi-infrastructure impacts:

2.2 Baseline Resilience Metrics

- Baseline consequence-focused performance metrics (*without* mitigations under consideration):

Stakeholders Engaged

Tools/Resources Used

Challenges and Opportunities

Step 3: Resilience Alternatives Specification

Step 3 Description

3.1 Technology, Policy, and Market Screening

- Alternative technologies:
- Constraints:

3.2 Resilience Mitigations Identification

- Technology investment portfolios:

Stakeholders Engaged

Tools/Resources Used

Challenges and Opportunities

Step 4: Resilience Alternatives Evaluation

Step 4 Description

4.1 Resilience Metrics Improvement Analysis

- Consequence-focused performance metrics (*with* mitigations):

4.2 Multi-Stakeholder Investment Optimization

- Investment optimization:

Stakeholders Engaged

Tools/Resources Used

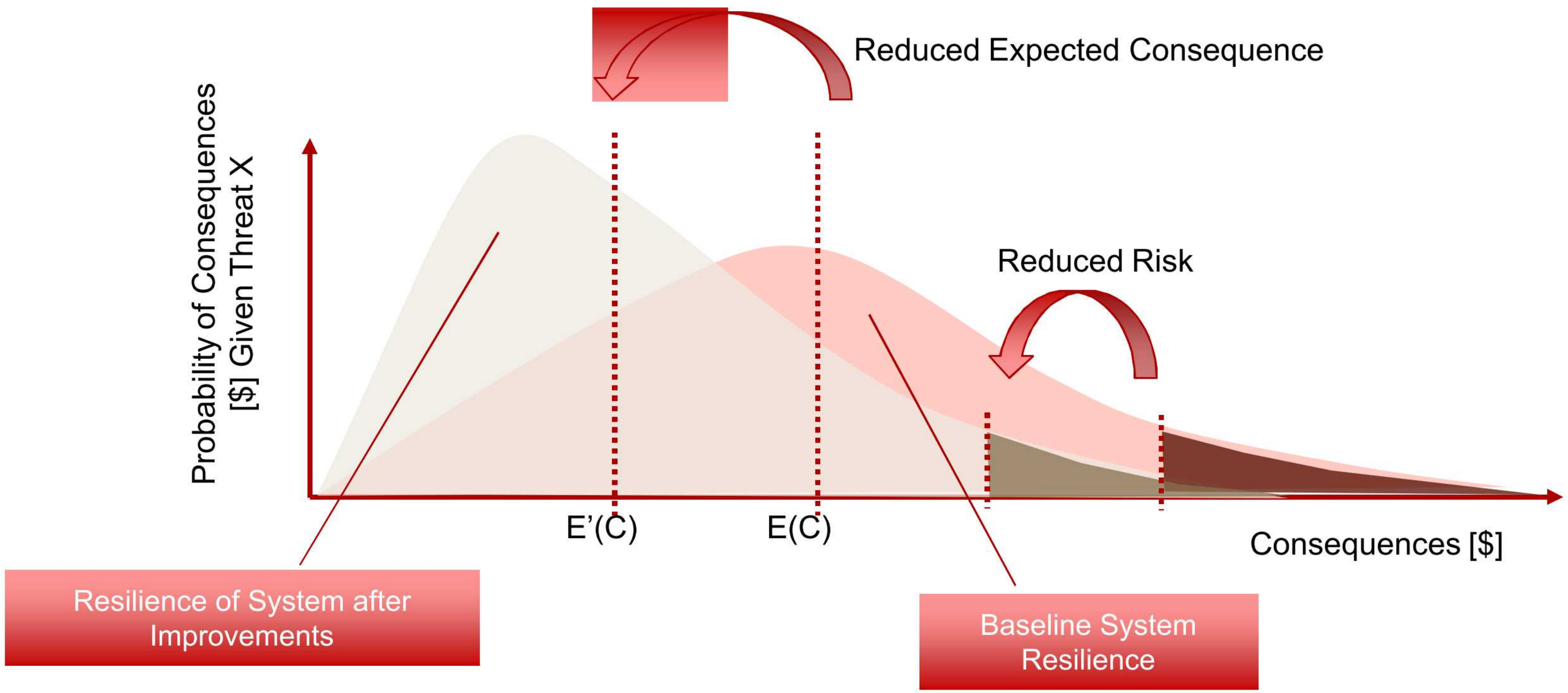
Challenges and Opportunities

QUANTIFYING THE CONSEQUENCES

Measure Classification	Common Examples
Community Measures	Number of People Without Necessary Services
	Lives at Risk
	Societal Burden to Acquire Services
Economic Measures	Gross Product / Net Economic Losses
	Change in Capital Wealth
	Business Interruption Costs
National Security Measures	Ability to serve critical missions…

Planners can be using metrics of consequence to their communities to define and plan for resilience

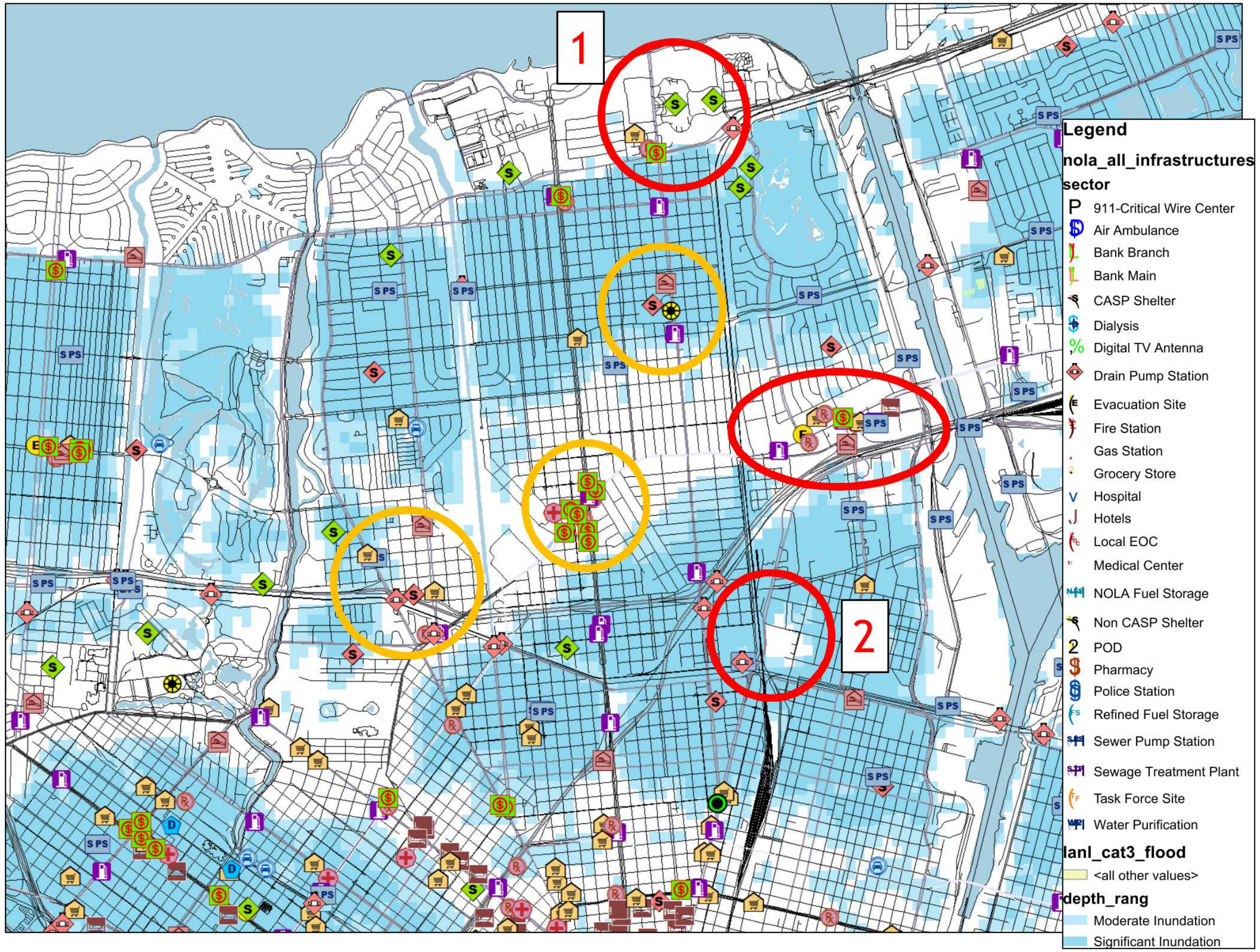
COMPARING METRICS FOR PLANNING



Using a probabilistic risk analysis approach:

- Model or measure the performance of the power system subject to threats
  - Cover a range of events from low-probability/high-impact to high-probability/low-impact
- Generate histogram of outage duration vs. frequency at all nodes
- Convert histogram of outage duration to consequence-focused metric
  - Often uses another model
- Propose investments and perform these steps again
- Optional: weigh resilience metrics against other goals such as efficiency and sustainability

SECOND SPIRAL

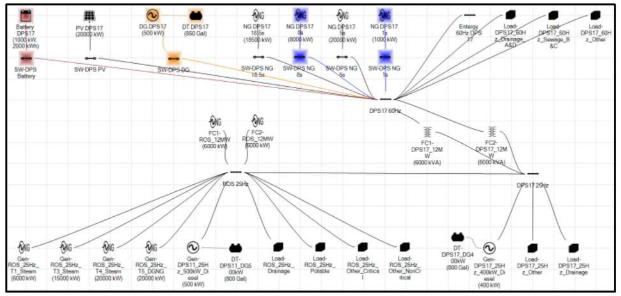


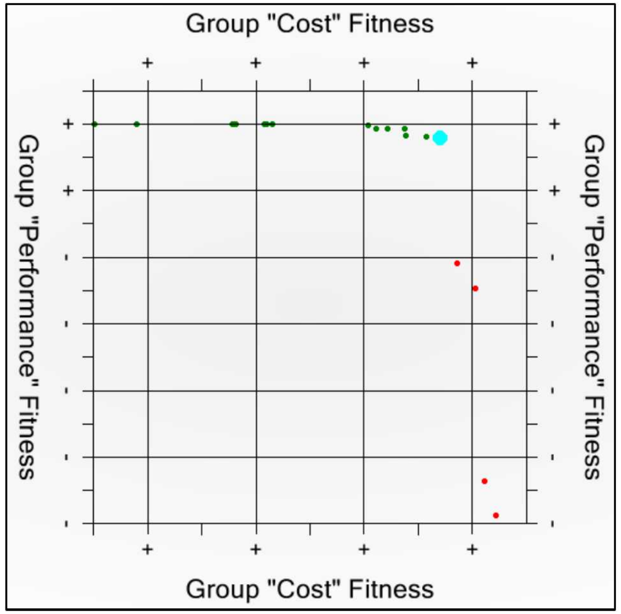
1. Lakefront Arena

2. DPS17/Almonaster

CO-OPTIMIZED DESIGN for BLUE-SKY and RESILIENCE VALUE

Resilience Optimization





Integration

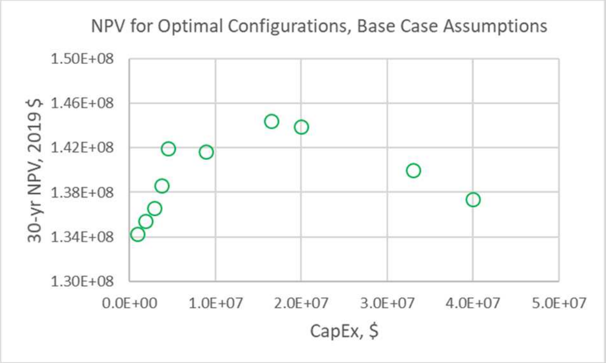
Run blue sky model, include a value of:

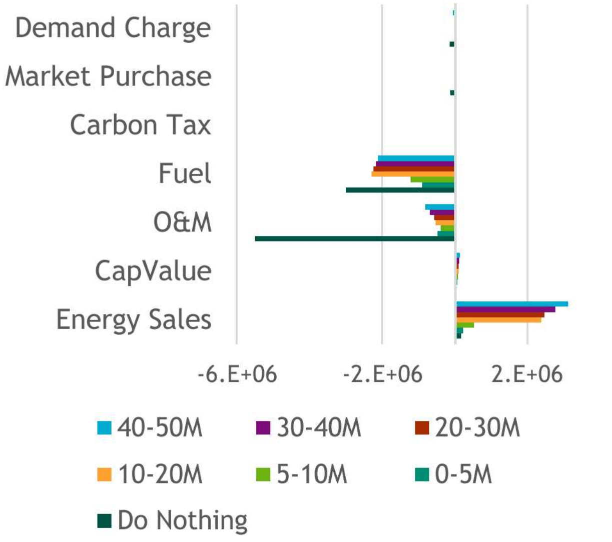
- Sustainability: \$0.01 / kg avoided CO2 (discuss)
- Resilience: \$50/kW capacity value (discuss)

City most interested in:

- Payback period
  - (6-10 years)
- Net present value
  - (\$150-270M over 30 yrs)
  - ~\$100M CapEx
- CO2 avoided
  - (6.2 M tonnes)
- Improved resilience
  - From ~74% to ~99% energy availability to critical loads

Blue Sky Optimization





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