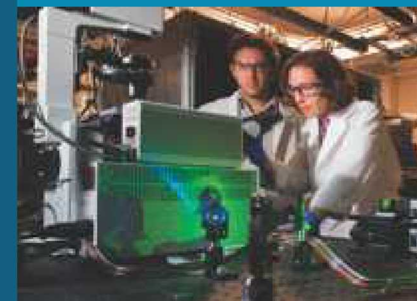
SAND2019-0953C

Energy Storage and Microgrids



PRESENTED BY

Ben Schenkman

SAND####-####

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March 12, 2019

Outline

- Sandia Energy Storage Program Overview
- Microgrid Resiliency Sandia
- Energy Storage Microgrid Application
- Energy Storage Evaluation
- Demonstrations and Lessons Learned

Energy Storage is a Major Crosscut

Hydrogen Storage

Hydrogen and Fuel Cells program is developing technologies to accelerate large-scale deployment of hydrogen storage.

Thermal Storage

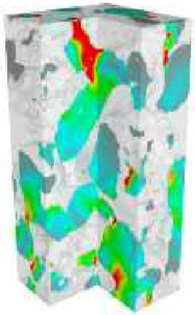
Sandia's Concentrating Solar Power (CSP) program is developing molten salt thermal storage systems for grid-scale energy storage.

Battery Materials

Sandia has a large portfolio of R&D projects related to advanced materials to support the development of lower cost energy storage technologies including new battery chemistries, electrolyte materials, and membranes.

Systems Modeling

Sandia is performing research in a number of areas on the reliability and safety of energy storage systems including simulation, modeling, and analysis, from cell components to fully integrated systems.



Systems Analysis

Sandia has extensive infrastructure to evaluate megawatt-hour class energy storage systems in a grid-tied environment to enable industry acceptance of new energy storage technologies.

Cell & Module Level Safety

Sandia has exceptional capabilities to evaluate fundamental safety mechanisms from cell to module level for applications ranging from electric vehicles to military systems.

Power Conversion Systems

Leveraging exceptional strengths in power electronics, Sandia has unique capabilities to characterize the reliability of power electronics and power conversion systems.

Grid Analytics

Analytical and multi-physics models to understand risk and safety of complex systems, optimization, and efficient utilization of energy storage systems in the field.

Wide ranging R&D covering energy storage technologies with applications in the grid, transportation, and stationary storage

Major R&D Thrust Areas

- **Materials Research –** Advancing new battery chemistries through technology development and commercialization.
- **Power Electronics –** Optimization at the interface between power electronics and electrochemistry. Power electronics including high voltage devices (SiC, GaN), high voltage passives and magnetics.
- **Energy Storage Safety –** Cell and module level safety test and analysis. Engineered safety of large systems. Predictive models for ES safety. Storage safety standards and protocols.
- **Energy Storage Analytics and Controls –** Analytics and controls for integration of utility class storage systems. Software tools for optimal use of energy storage across the electricity infrastructure. Standards development.
- **Energy Storage Project Development –** Support for demonstration projects.
- **Industry Outreach –** Outreach to utilities, regulators, and the industry.

DOE OE Energy Storage Projects and Analysis Team

What We Do and Why

- Work with Utility, Industrial, Commercial, Private, State and International entities to:
  - Provide **third party independent analysis** for cells and systems
  - Support the development and implementation of **grid-tied ES** projects
    - **Application/Economic analysis**
    - **RFI/RFPs**
    - **Design and Procurement Support**
    - **Commissioning Plan Development**
  - Monitor and analyze operational ES Projects
    - Differing applications
    - Optimization
    - Operational performance
  - Develop public information programs
- Goal
  - Inform the Public and encourage investment.

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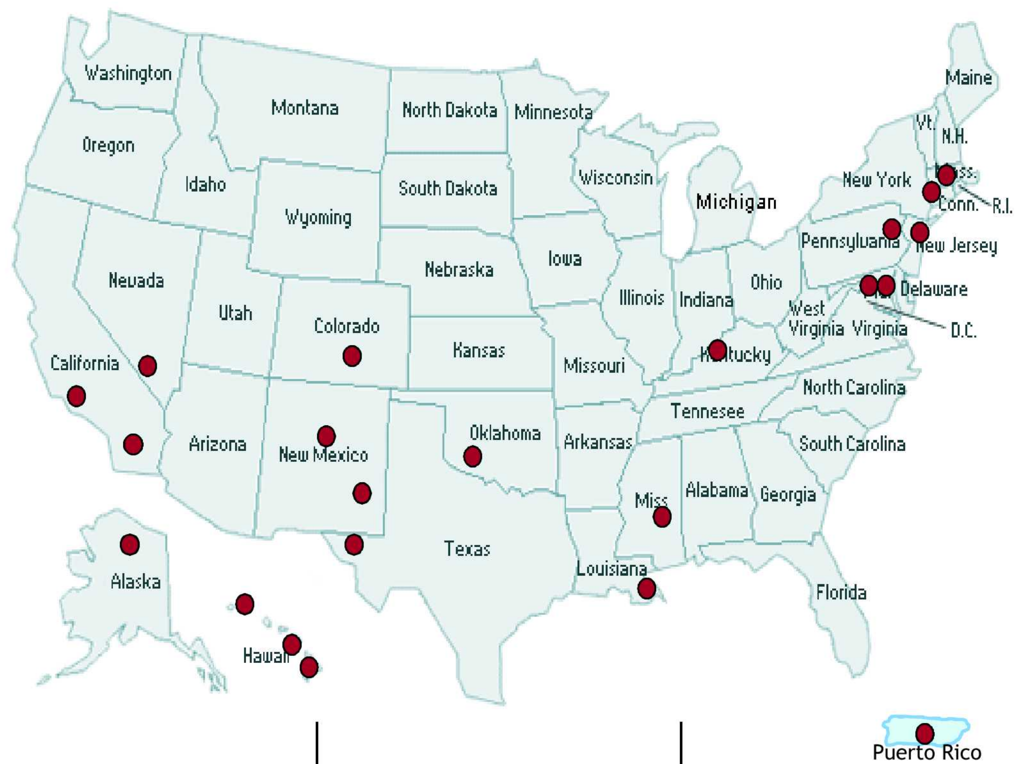
Energy Surety Microgrid Efforts

Conceptual Designs/Assessments	Small Scale Microgrid Demos	Large Scale Microgrid Demos	Operational Prototypes

• Creech AFB – FY12 DoD
• Soto Cano – FY12 DoD
• West Point FY12, DoD/DOE
• Osan AFB, FY 12, DoD
• Philadelphia Navy Yard – FY11, DOE OE/PIDC
• Camp Smith – FY10, DOE FEMP
• Indian Head NWC – FY09, DOE OE/DoD
• Ft. Sill – FY08, Sandia LDRD
• Ft. Bliss – FY10, DOE FEMP
• Ft. Carson – FY10, DOE FEMP
• Ft. Devens (99th ANG) – FY09, DOE OE/DoD
• Ft. Belvoir – FY09 DOE OE/FEMP
• Cannon AFB – FY11, DOE OE/DoD
• Vandenberg AFB – FY11, DOE FEMP
• Kirtland AFB – FY10, DOE OE/DoD
• Maxwell AFB – FY09, DoD/DOE
• Alaska Villages– FY12, DOE
• Bagram – FY13, DoD
• Kuwait – FY15, DoD
• 29 Palms – FY14, DoD
• Korea Naval Academy – FY16, DoD
• Kaui – FY15, DOE
• Northhampton, MA – FY14, DOE
• New Orleans – FY17, DOE
• UPS in KY – FY17, DOE
• Puerto Rico – FY19, DOE
	• Maxwell AFB – FY09, DoD
	• Ft. Sill – FY09, DoD w/ SNL serving as advisor
		• SPIDERS JCTD – FY11, DOE/DoD
		  • Camp Smith
		  • Ft Carson
		  • Hickam AFB
		• Cordova – FY19, DOE
			• H.R. 5136 National Defense Authorization Act



Resilience Definition

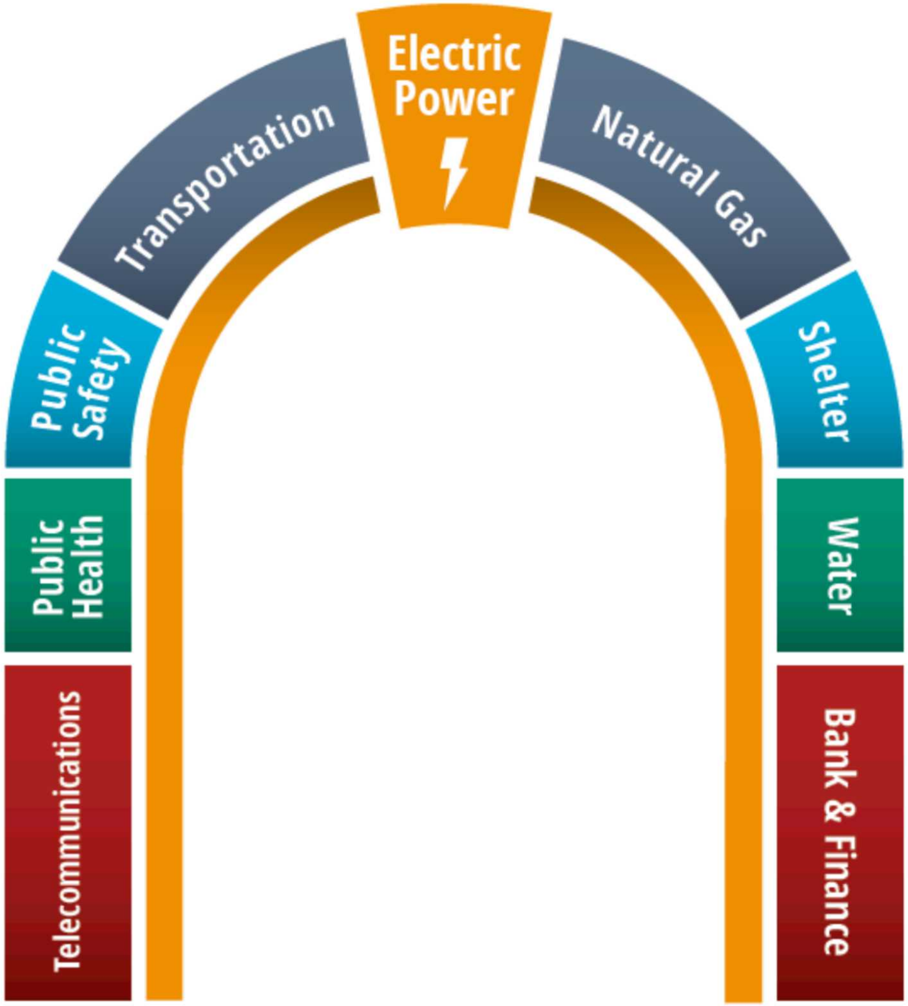
- **Presidential Policy Directive (PPD) 21**

"the ability to prepare for and adapt to changing conditions and withstand and recover rapidly from disruption. Resilience includes the ability to withstand and recover from deliberate attacks, accidents, or naturally occurring threats or incidents."

-PPD-21: Critical Infrastructure Security and Resilience

- Resilience is defined in context of multiple hazards and not to be confused with sustainability and efficiency which are also important

ENERGY RESILIENCE enables COMMUNITY RESILIENCE



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

STRAWMAN FRAMEWORK

Resilient Community Design Framework

1. Determination of Resilience Drivers

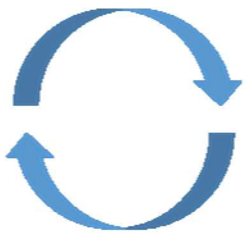
- Determine Resilience Metrics and Threats
- Threat and Impact Forecasting

Stakeholders Engaged

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

3. Resilience Alternatives Specification

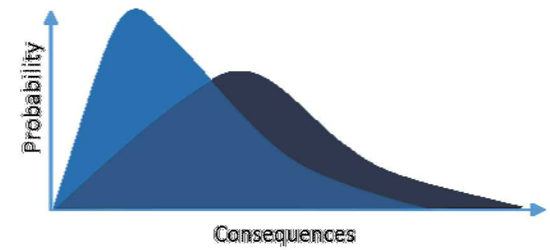
- Resilience Technology Screening
- Regulatory Framework Screening
- Resilience Service Screening



2. Community Resilience Analysis

- Multi-Infrastructure Performance Analysis
- Consequence Estimation

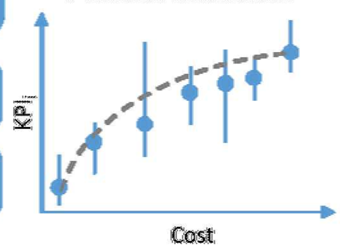
Resilience Performance Metrics



4. Evaluation of Resilience Alternatives

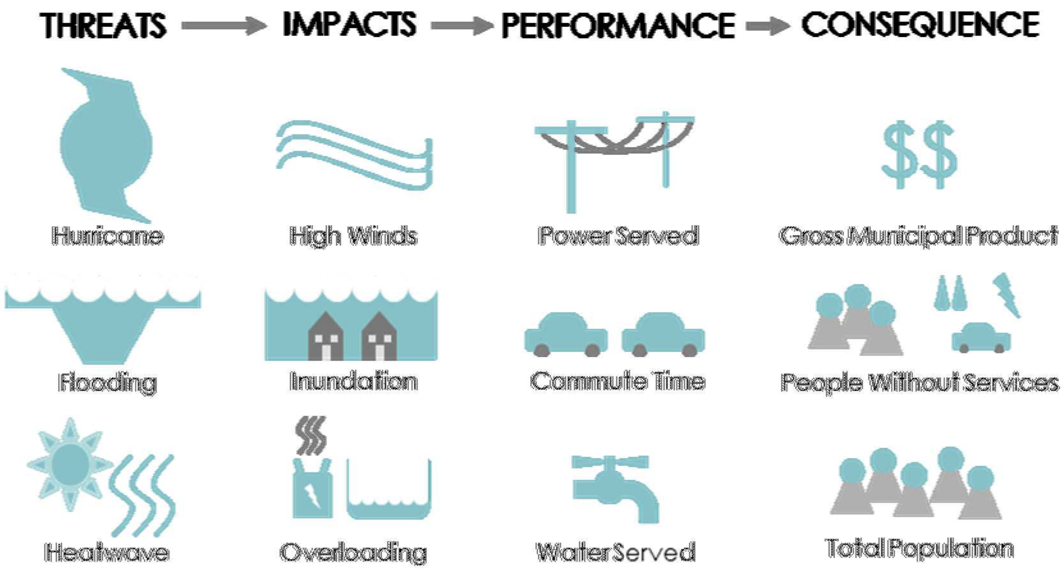
- Translation to Stakeholder KPI's
- Calculate Co-benefits (Reliability, Cost of Service, etc)
- Multi-Stakeholder Cost-Benefit
- Multi-Criteria Portfolio Evaluation

Portfolio Evaluation



Evaluating alternative regulatory decisions in the same manner that we evaluate investments

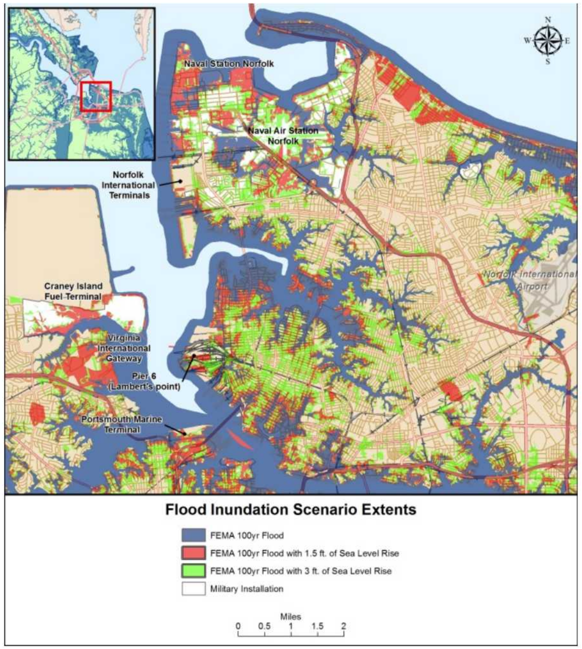
I. DETERMINATION OF RESILIENCE DRIVERS

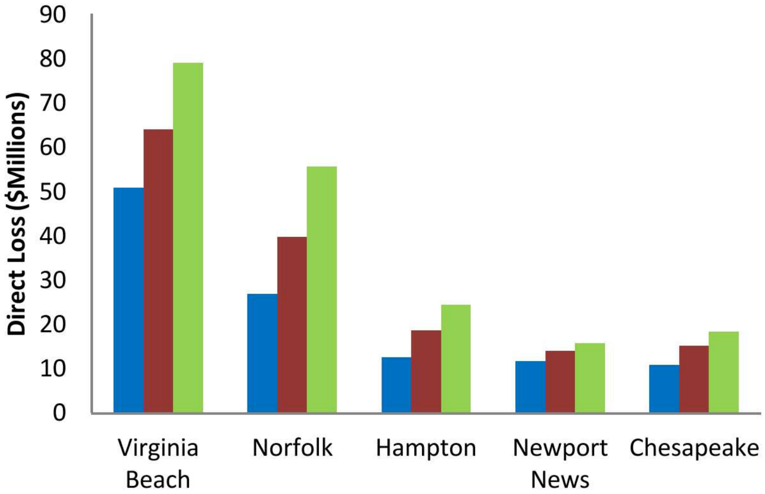


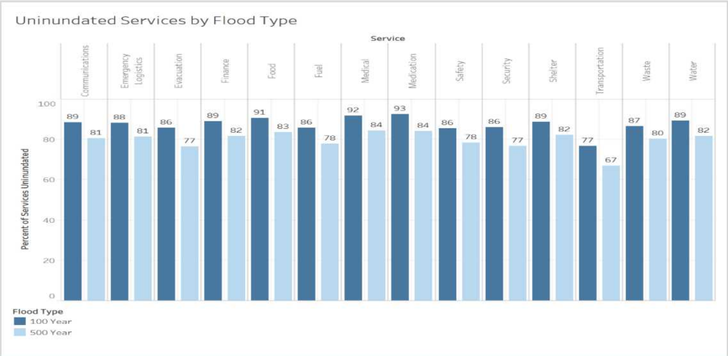
Measure Classification	Common Examples
Community Measures	Number of People Without Necessary Services
	Lives at Risk
	Societal Burden to Acquire Services
Economic Measures	Gross Municipal Product Loss
	Change in Capital Wealth
	Business Interruption Costs

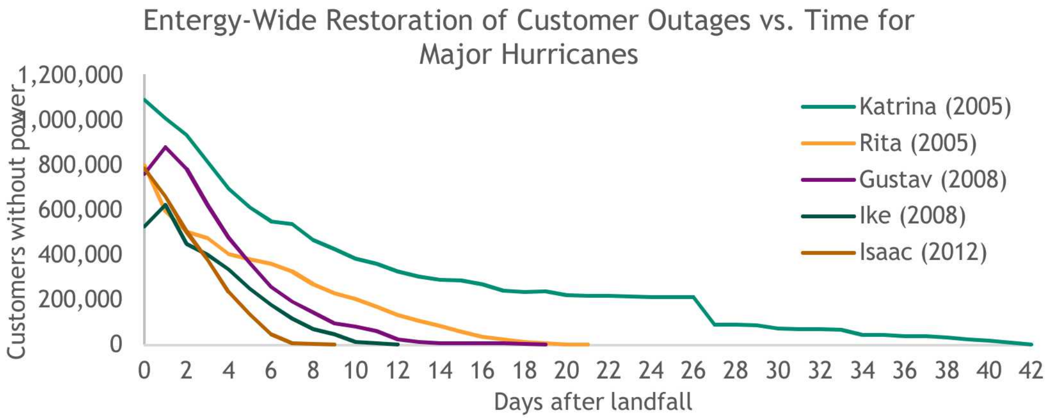
Deciding what we want to be resilient to, which infrastructure systems matter the most, and how we will determine consequence to our communities

2. COMMUNITY RESILIENCE ANALYSIS (BASELINE)



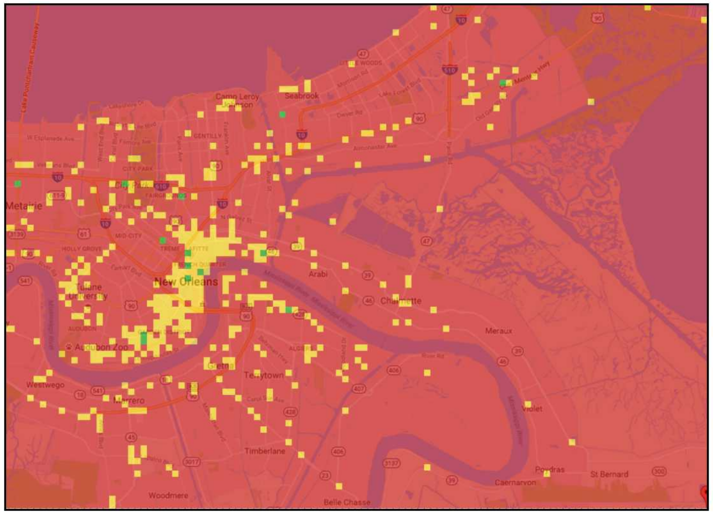


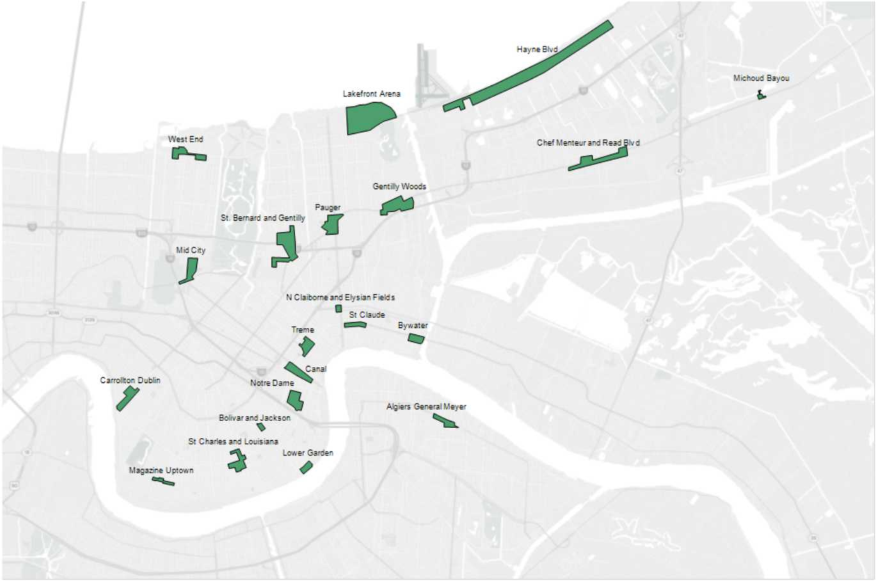


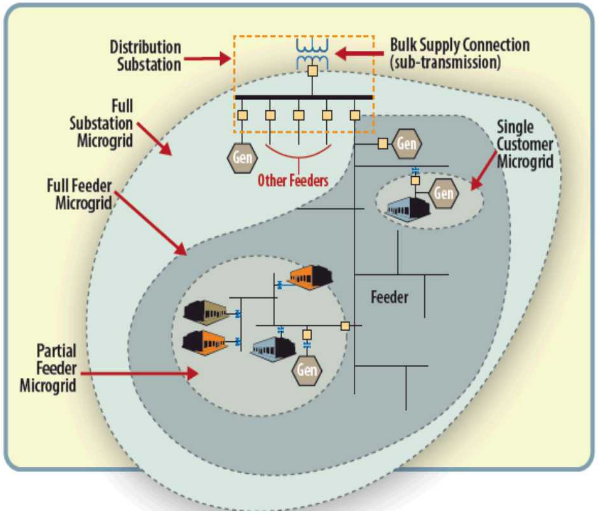


Understanding the current community risk – in units of consequence – to extreme events over a planning horizon

3.SPECIFICATION OF RESILIENCE ALTERNATIVES





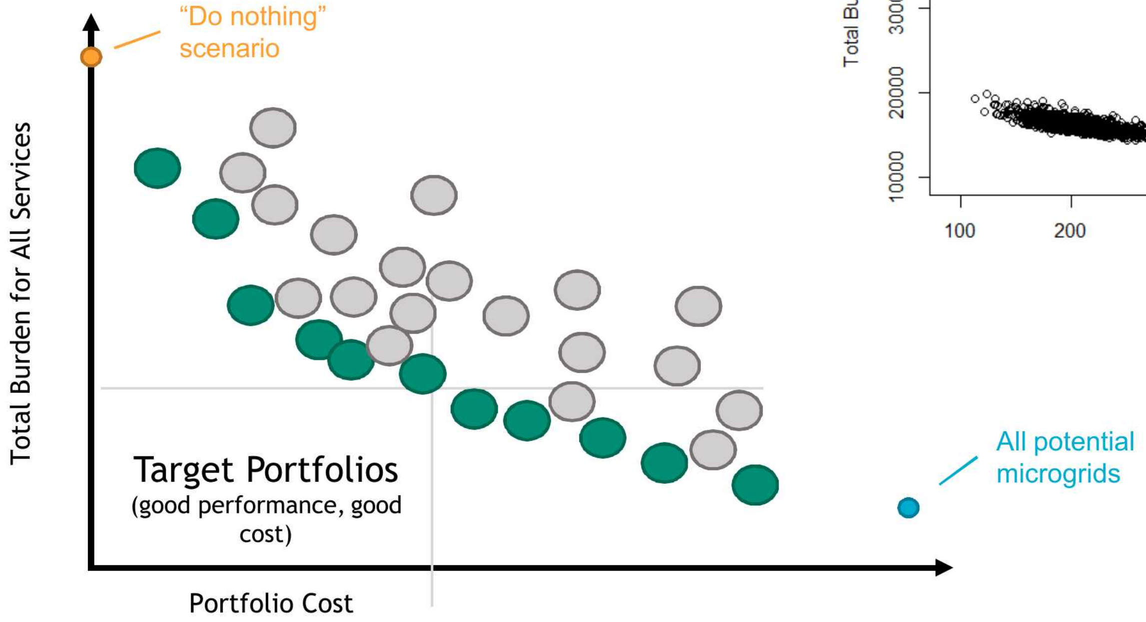


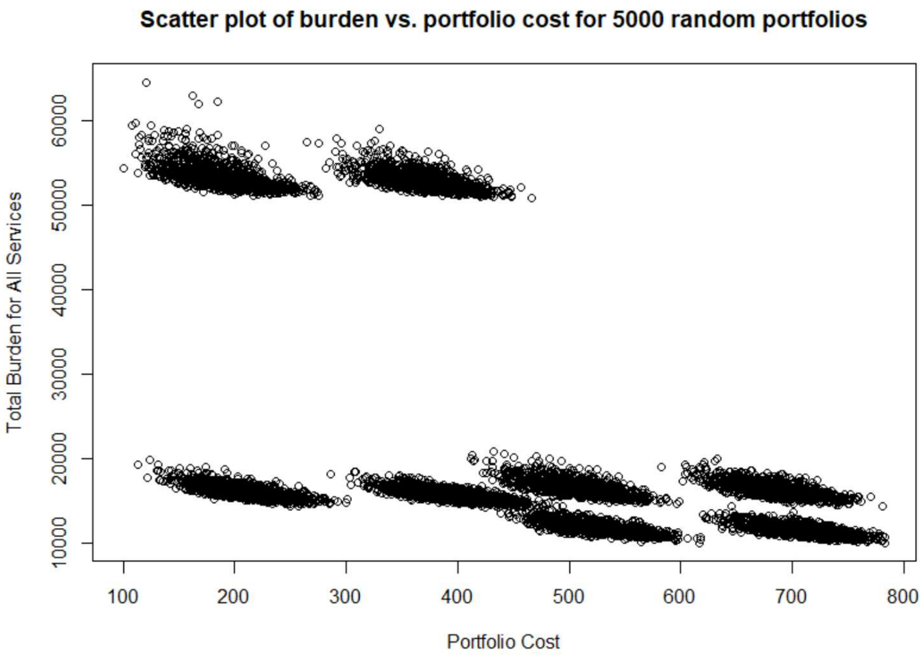
- Alternative investments
  - Utility, city, or third party
- Alternative regulatory approaches
  - Performance-based
  - Incentives-based
  - Cost causation
- Alternative utility business models
  - Resilience as a service
  - Increased integration with insurance products

Proposing alternatives requires design capabilities inclusive of consequence-based resilience metrics

4. EVALUATION OF RESILIENCE ALTERNATIVES

- Evaluation based on resilience performance in addition to:
  - Blue sky cost benefit
  - Sustainability metrics
  - Other?





Evaluation depends on the evaluator and the specific planning process.

Metrics to Evaluate Microgrid Portfolio (Puerto Rico)

Goal is to:

- Assess microgrid impact resilience
- Choose optimal portfolio of all the potential options

Sandia uses two primary metrics to evaluate resiliency of portfolio of microgrids:

- Percent of Services Covered (taking into account design basis threat such as floods)
- Burden to the community to acquire services

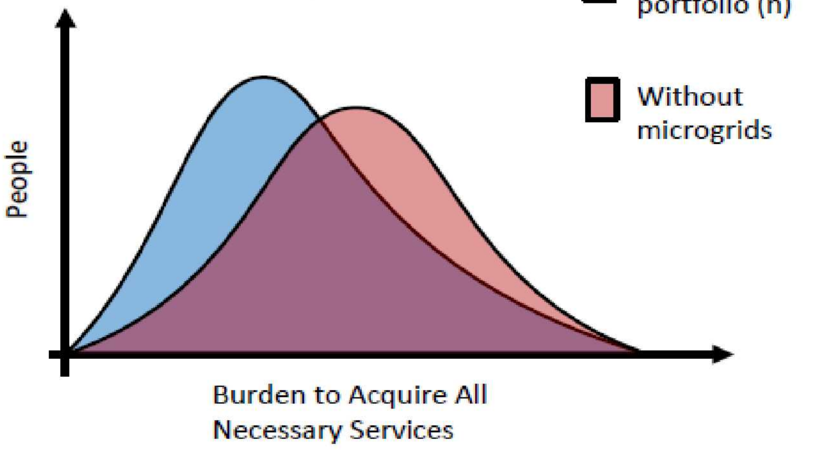
The cost for each microgrid in the portfolio is evaluated

Effort (Distance)
Overall time necessary to acquire service

Ability (Speed)
Median household income for census block

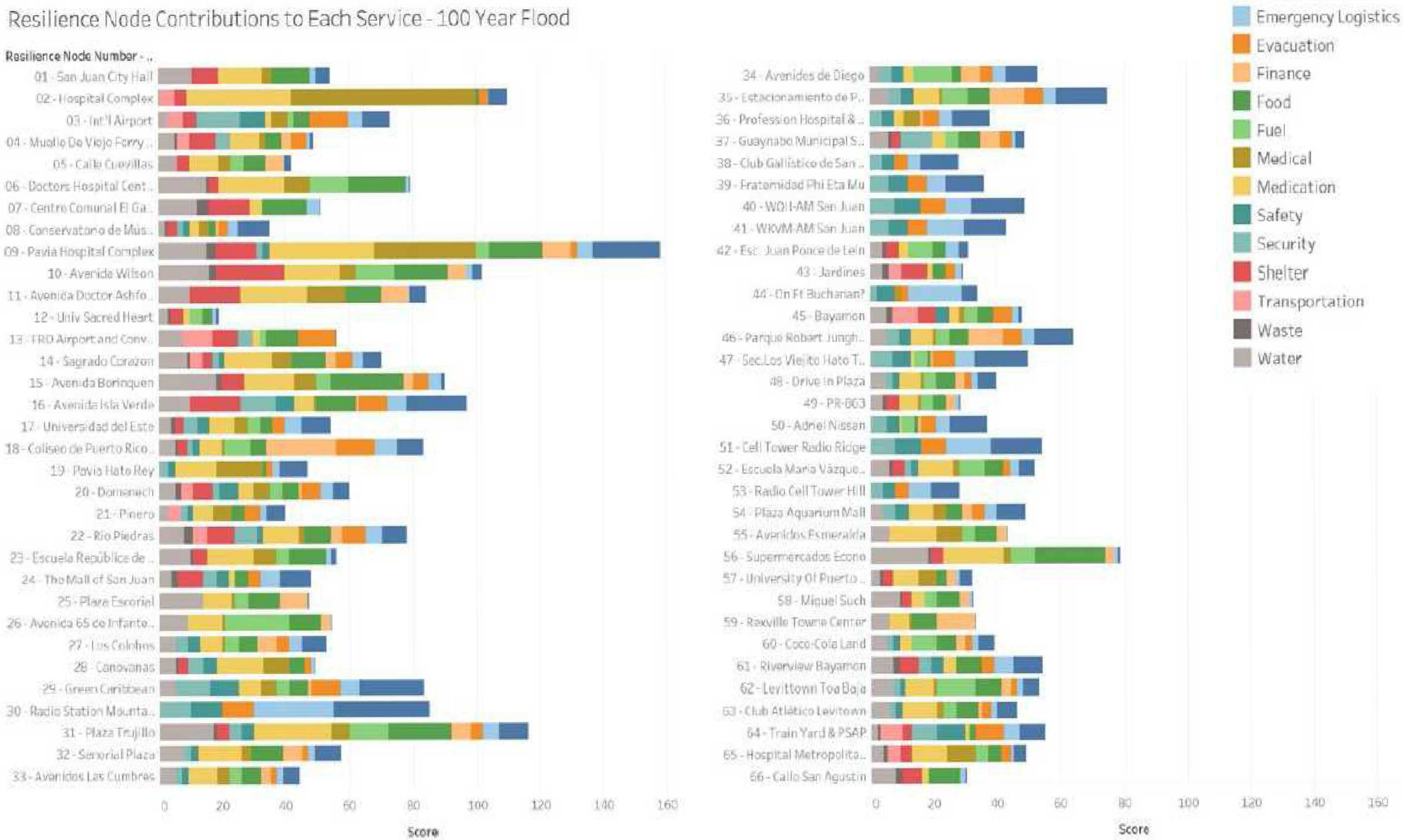
→ Burden

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



Services Covered by Microgrid (Puerto Rico)

66 Microgrid Identified

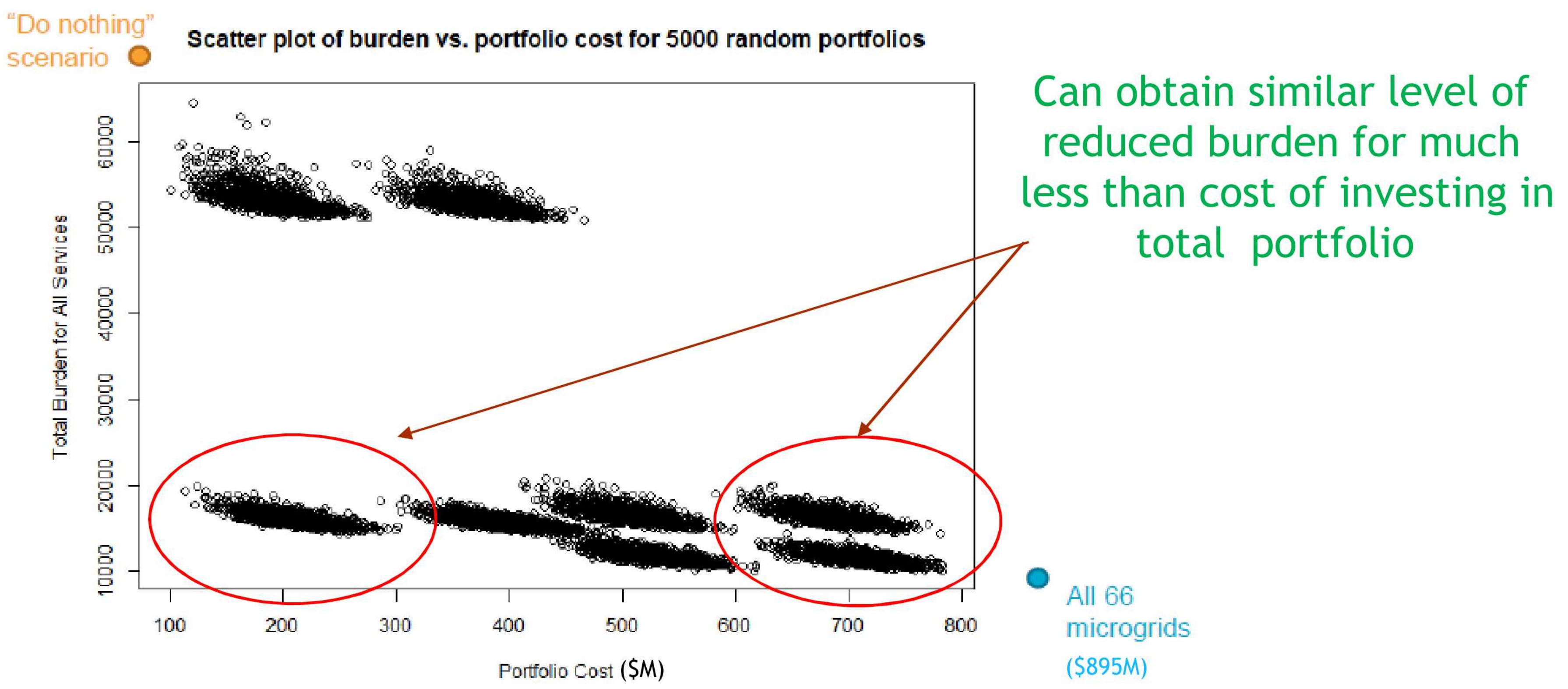


Evaluating Burden for Microgrid Portfolios

Recognize complementary nature of certain microgrids

Goal is to design a system of microgrids to decrease overall burden

Evaluating Burden for Microgrid Portfolios (Puerto Rico)



- The random portfolios shown here have on average 33 microgrids and range of 16-50
- A large decrease in burden can be achieved for relatively low cost compared to all 66 microgrids

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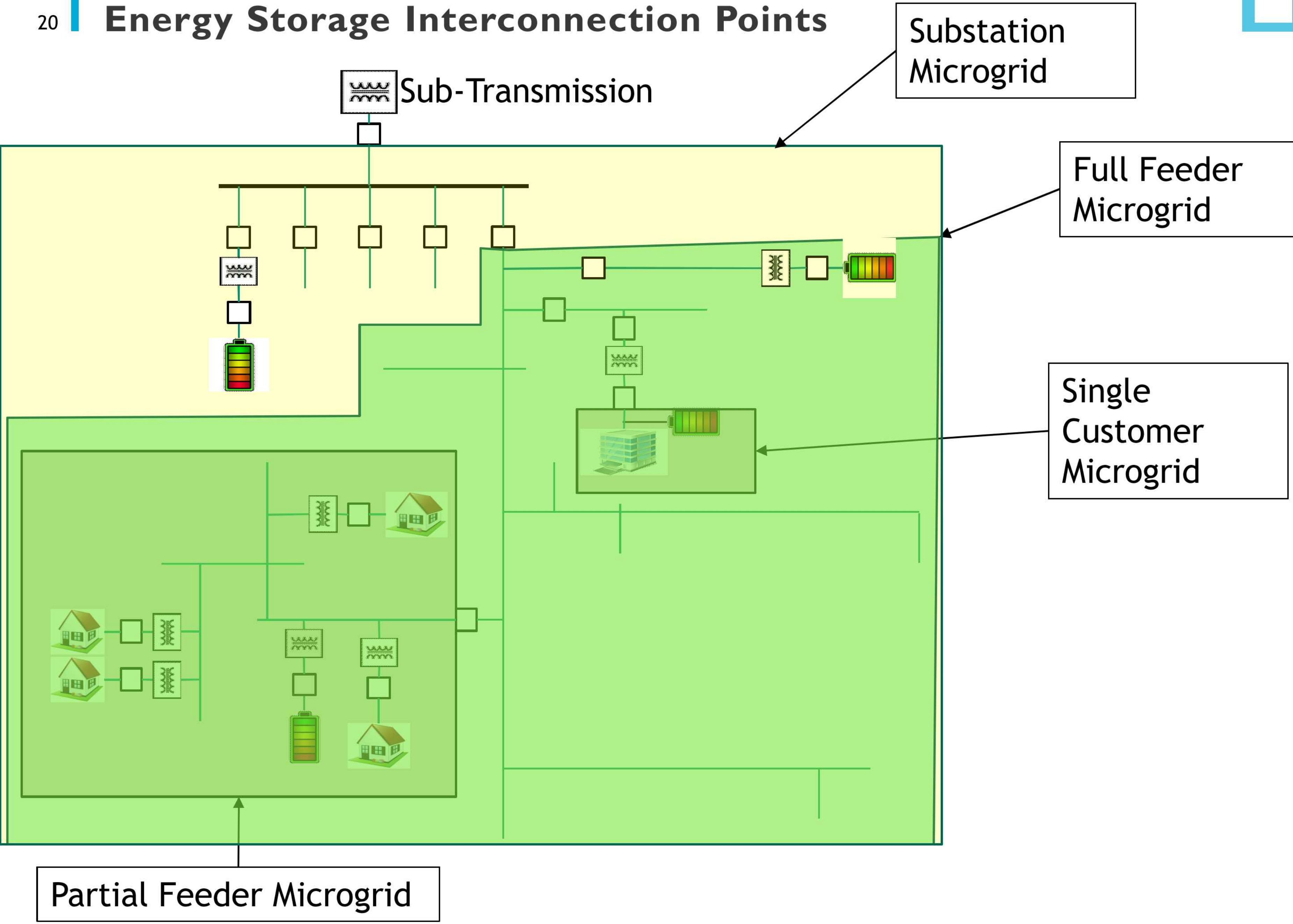
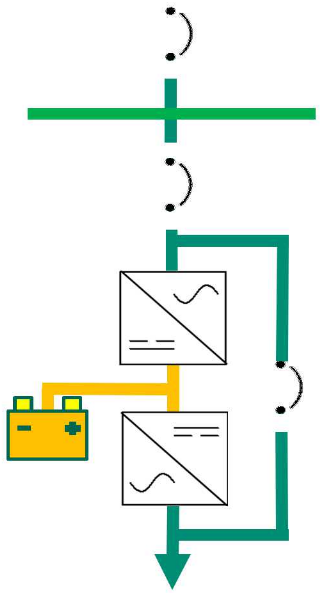
Energy Storage Interconnection Points



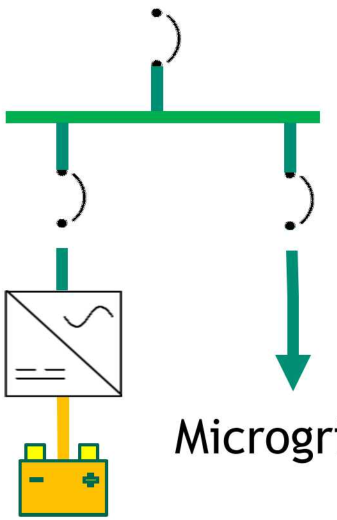
Energy Storage Connection

Series



Microgrid
Load

Parallel



Microgrid Load

- Seamless Transition is Possible
- Does not require external signal to trigger Voltage source mode

- Less Equipment = Lower Capital Cost
- Easily Expandable
- Simple Controls

Energy Storage Technology

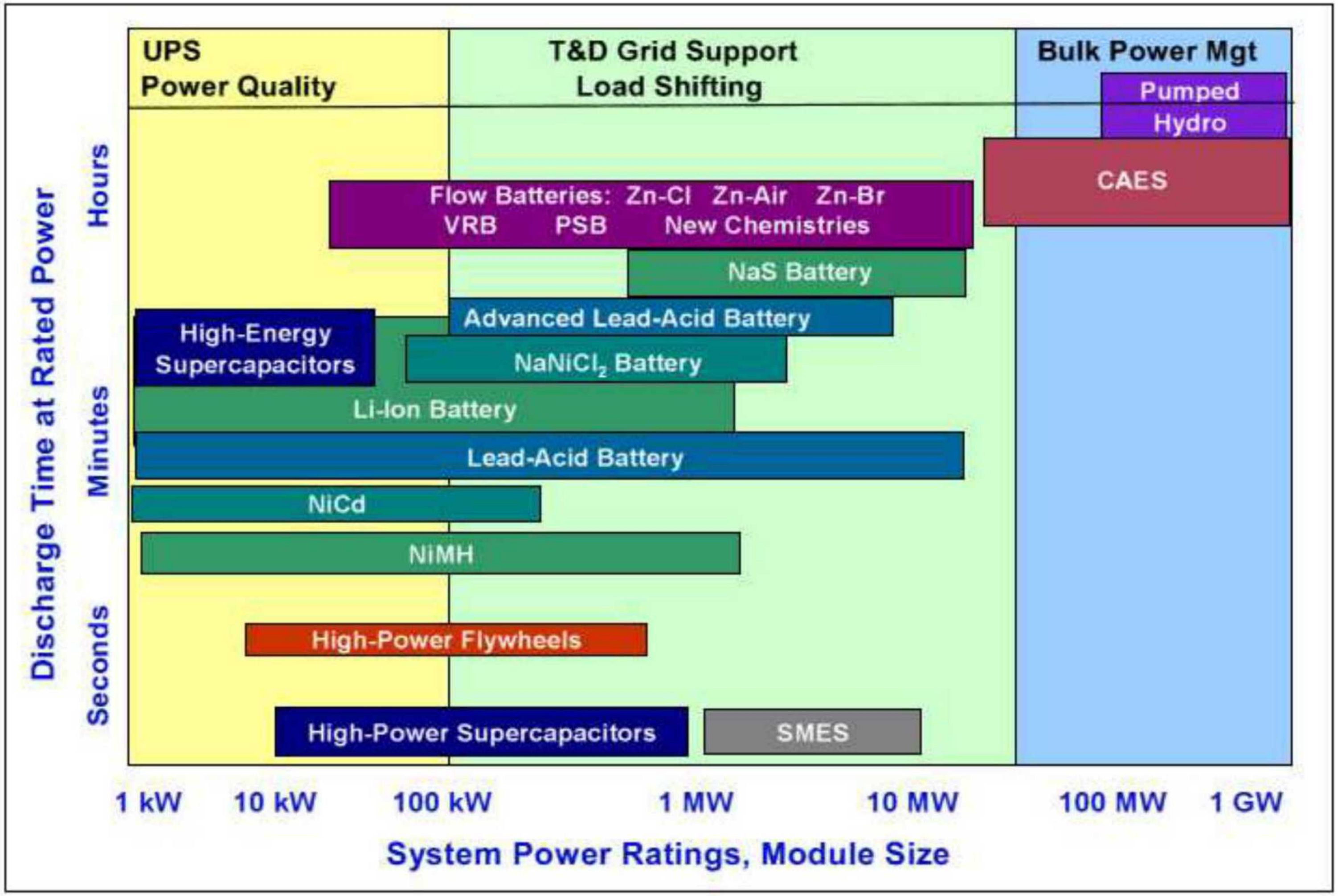


Image Credited to DOE/EPRI 2013 Electricity Storage Handbook

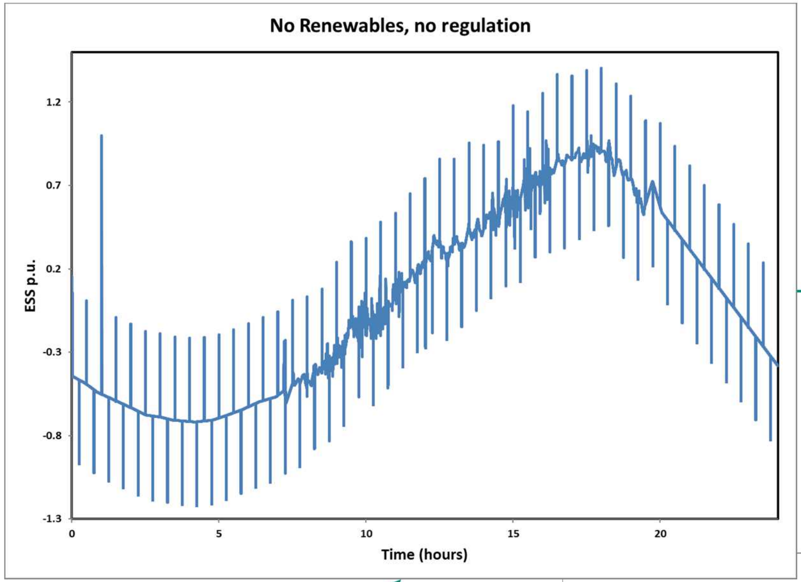
Topology Evaluation

- Central (Big) vs Distributed (Multi-Small)

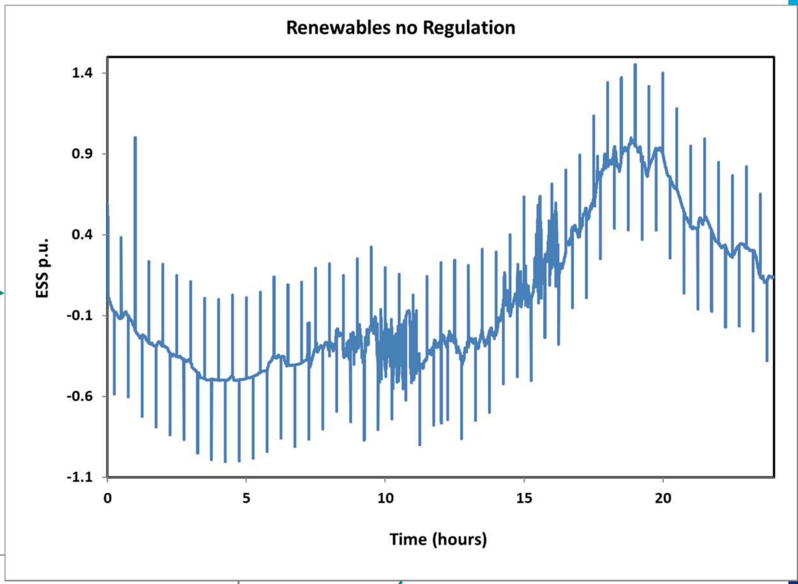
Grid Tied Applications

- Energy Storage in Microgrid Application While Grid Tied
  - Peak Shaving
  - Frequency Regulation
  - Renewable Smoothing/Firming
  - Voltage Support
  - Power Quality
  - Demand Response
  - Distribution/Transmission Upgrade Deferral
  - Transmission Congestion Relief
  - Spinning Reserve
  - Arbitrage
  - Generation Fuel Deferral
  - Load Following (Ramp Rate Mitigation)
  - Uninterruptible Power Supply

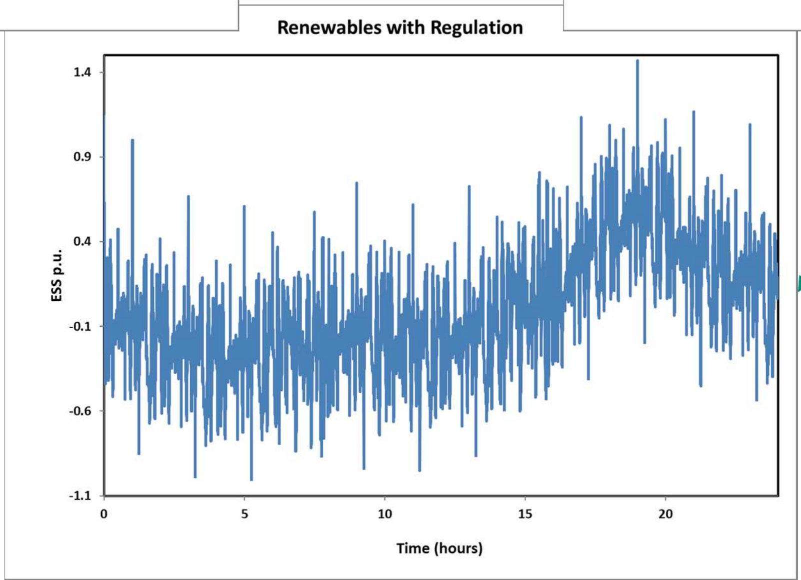
Energy Storage Duty Cycle in Microgrid



Add Renewables



- Peak Shaving
- VAR Support
- Power Quality



- Add Frequency Regulation
- Remove VAR Support and Power Quality

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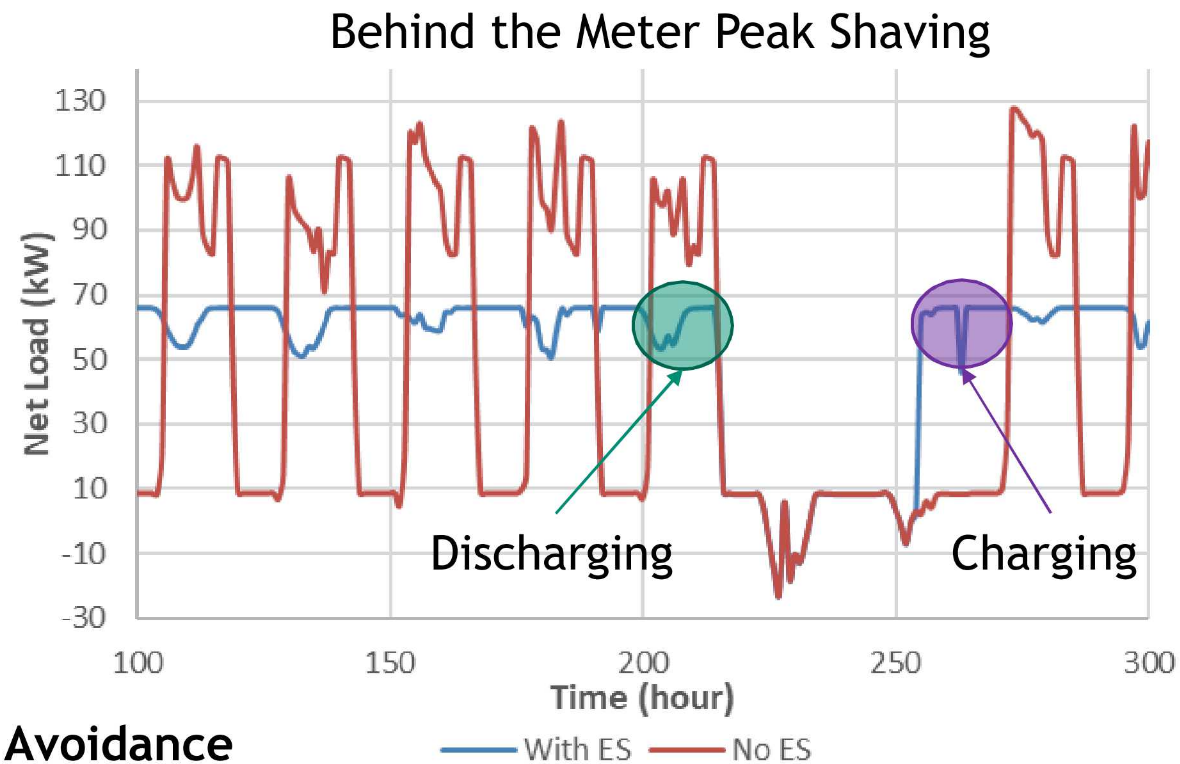
Energy Storage Before Economic Analytics

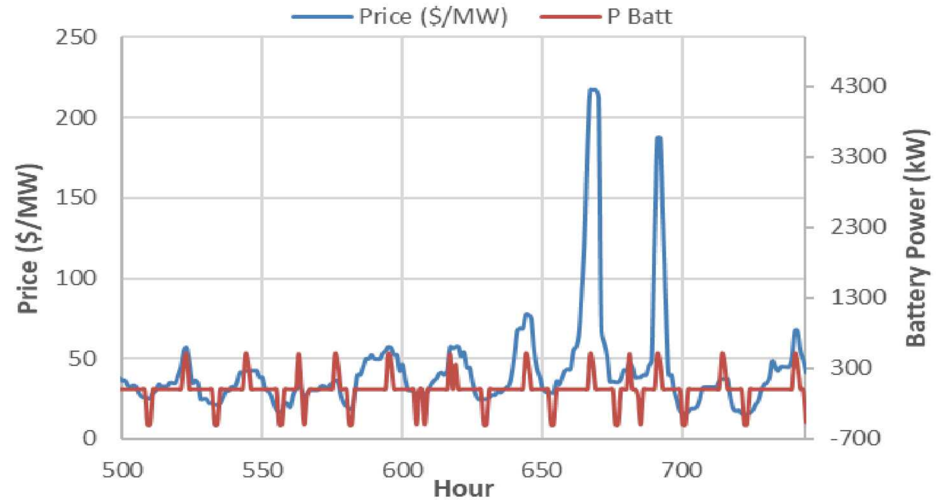
- Network Transmission Integration Customer
- 500kW/1MWh Lithium Ion Installed
- Integrated with Rooftop PV (Approximately 50kW)
- Designed to backup power for an emergency shelter and demand management

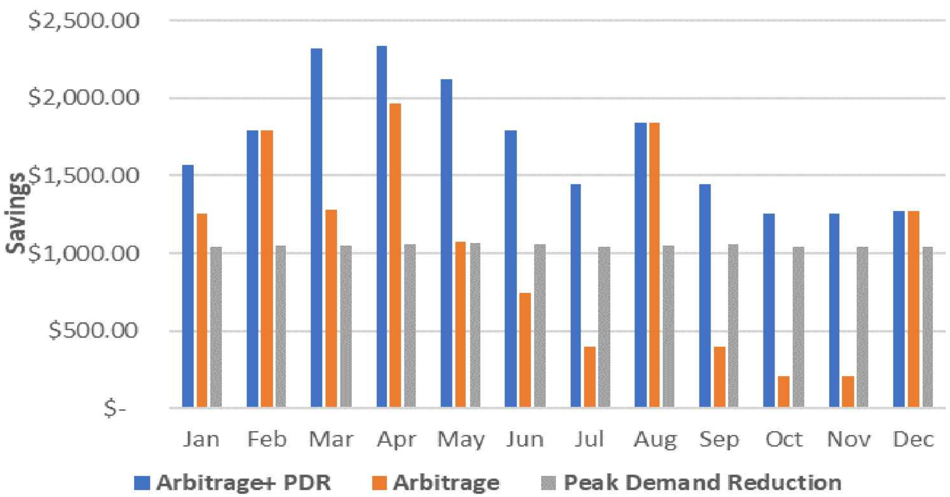


$6,000 Cost Avoidance

Energy Storage Before Economic Analytics

- In Front of Meter
- Energy Arbitrage and Peak Demand Reduction
- Performed at Full Charge and Discharge Profile
- Approximately $20,000 annual Cost Avoidance
- $NPV_{12\ @\ 5\%discount}$ ~ $-1.322M
- Simple Payback is **75** years





Energy Storage Analytics

Estimating the value of energy storage

- Production cost modeling
  Stochastic unit commitment/planning studies
  Linear Programming Optimization Control
  strategies for distributed storage
- Wide area control
- Control and architectures for kWh-GWh
  Energy Storage Systems

T&D simulation with energy storage (PSLF, OpenDSS, MATLAB)

Supporting Public policy: identifying and mitigating barriers

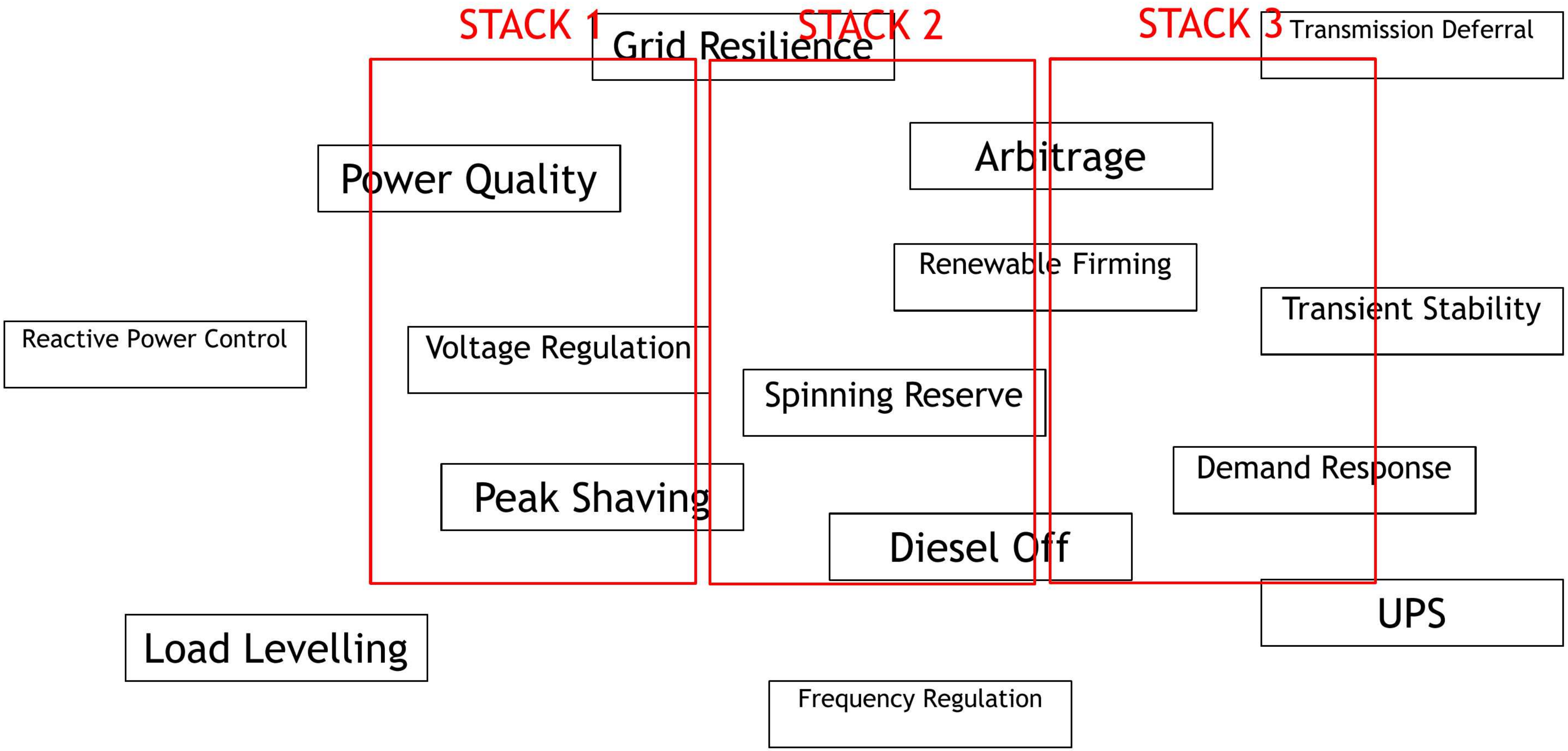
Standards development and DOE Protocols

Project evaluation

- Technical performance
- Financial performance

Energy Management and Dispatch Controls

- Optimized economic dispatch algorithm development for grid tied and islanded systems
- Resilient and Stacked application development
- Validation through real time power hardware-in-the-loop and field validation



QuEst Energy Storage Software Suite

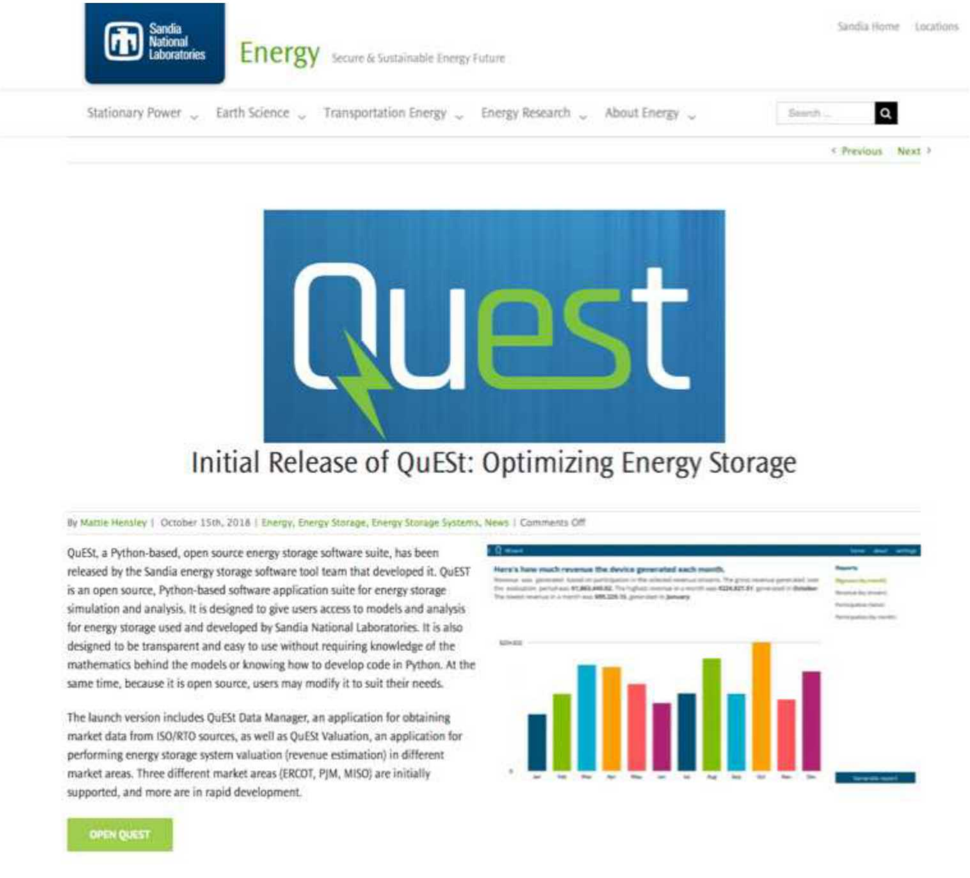
https://energy.sandia.gov/quest-optimizing-energy-storage/

- Open source, Python-based energy storage analysis software application suite.

- Developed as a graphical user interface for optimization and analysis capabilities of SNL's energy storage group.

- Initial development driven by Pyomo models for energy storage valuation in market areas.
  - Behind the Meter and Market Areas

- Now publicly available on GitHub
  - https://github.com/rconcep/snl-quest



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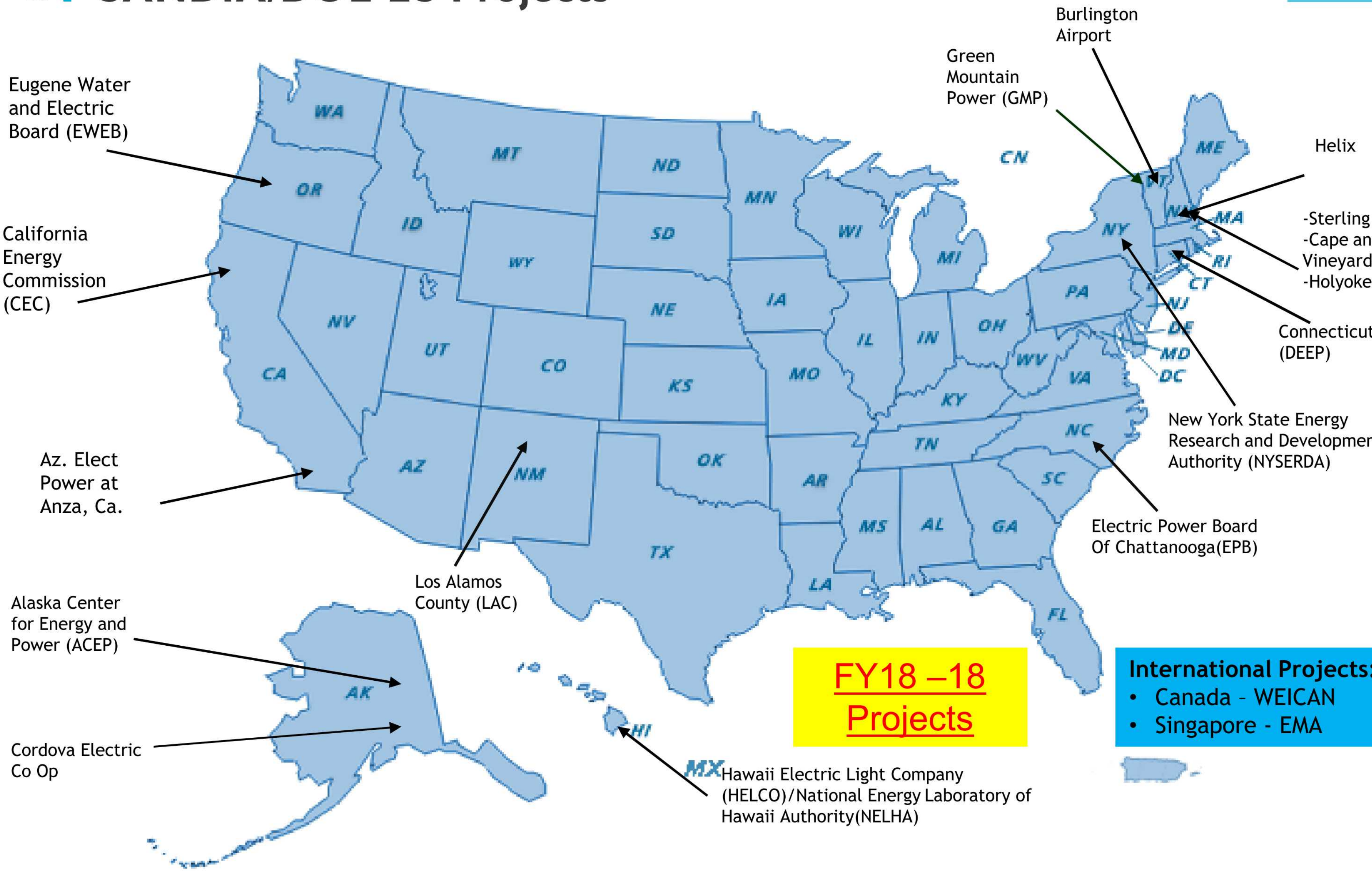
SANDIA/DOE ES Projects



Sterling Municipal Light Department

Installed a 2 MW/ 3MWh battery storage system in Sterling Massachusetts

The system can isolate from the grid in the event of an outage

Along with the existing PV array, it can provide 12 days of backup power to the Sterling police station

Saves the town ratepayers $400,000 per year by decreasing the costs associated with capacity and transmission charges

Image Credit: Sterling Municipal Light Department

Image Credit: Sterling Municipal Light Department

SMLD Issues and Lessons Learned

Issue

- Lack of knowledge and experience regarding procurement of a combined system lead to a difficult and arduous process for vendors

Lessons Learned

- For successful integration of storage, it can be helpful to have 1 project combining PV and Storage done by 1 company rather than 2 separate projects done by 2 companies
- There is a growing need for companies who can do both

Green Mountain Power

Installed in Rutland, Vermont

4MW/3.4MWh of a combined lead-acid and li-ion system

Integrated with 2.5 MW of PV

Helps with ancillary services, backup power for an emergency shelter, and demand management

Saved approximately $300,000 by reducing annual and monthly peak

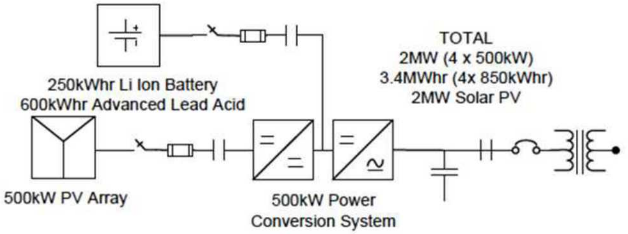


Image Credit: Green Mountain Power

GMP Issues and Lessons Learned

Issues

- Project built with 4 - 500KW multi input (DC) inverters
- 500KW ea. of LA and Li-ion, plus ~500KW of PV per inverter
- Inverters limit output
  - Reduced demand reduction capability

Lessons Learned

- Not designing for flexibility of applications limited DR value

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BACK UP SLIDES

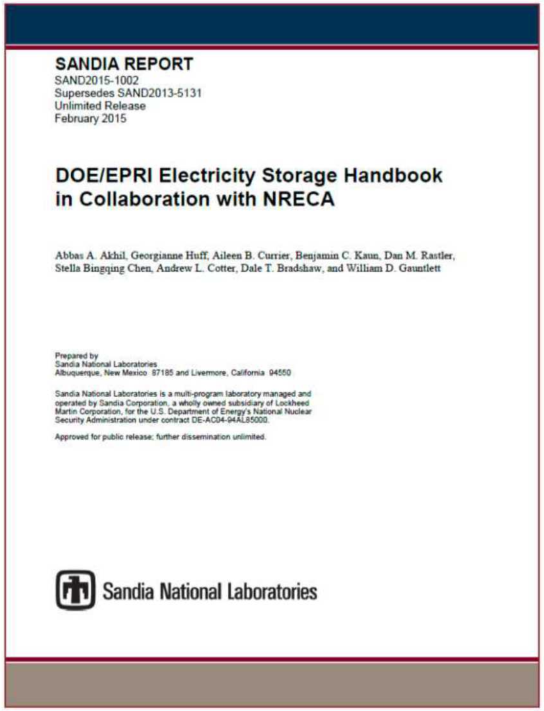
Outreach and Industry Tools

DOE/EPRI Electricity Storage Handbook is a how-to guide for utility and rural cooperative engineers, planners, and decision makers to plan and implement energy storage projects safety in communities

DOE Energy storage program website

- Publications
- Project information
- Archive of DOE Peer Review presentations

www.sandia.gov/ess



SANDIA REPORT
SAND2015-1002
Supersedes SAND2013-5131
Unlimited Release
February 2015

DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA

Abbas A. Akhil, Georgianne Huff, Aileen B. Currier, Benjamin C. Kaun, Dan M. Rastler, Stella Bingqing Chen, Andrew L. Cotter, Dale T. Bradshaw, and William D. Gauntlett

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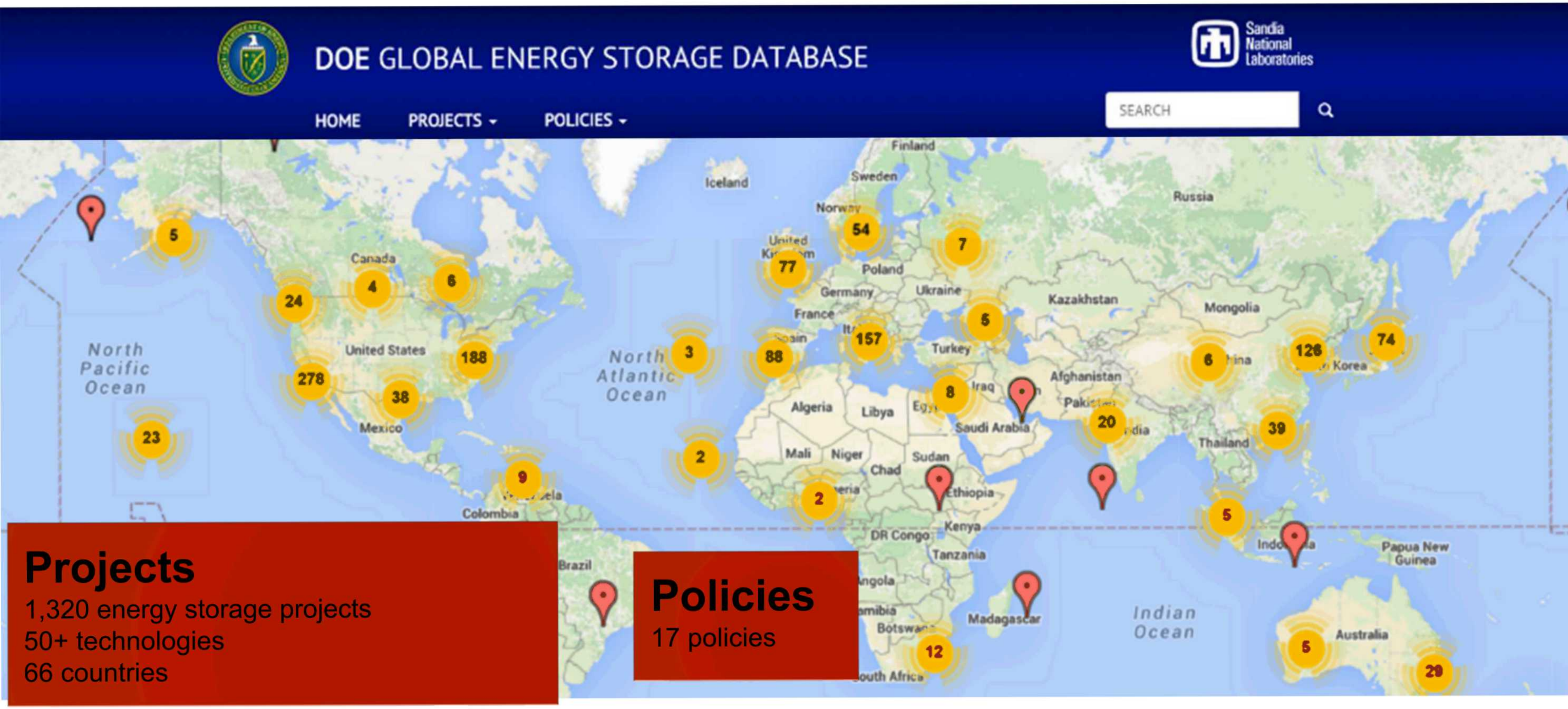
Sandia National Laboratories

Outreach and Industry Tools

DOE Global Energy Storage Database provides free, up-to-date information on grid-connected energy storage projects and relevant state and federal policies.



Projects

1,320 energy storage projects
50+ technologies
66 countries

Policies

17 policies

ANZA Electric Cooperative Energy Storage

- National Rural Electric Cooperative Association (NRECA)
- Arizona Electric Power Cooperative (AEPCO)
- Anza Electric Cooperative
- Sandia National Labs

ANZA Electric Cooperative Energy Storage

Objectives

- Provide an assessment of using energy storage to ***deferring transmission upgrades***

- Provide an assessment of using energy storage to ***increase resilience***

ANZA Electric Cooperative Energy Storage

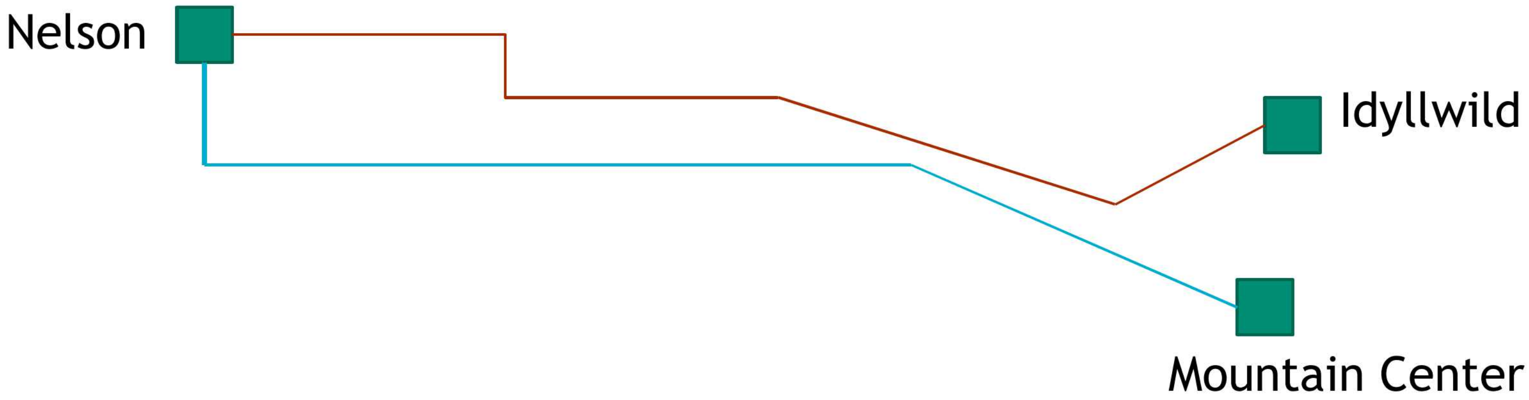
Overview of the ANZA Service Area

ANZA is located in southern California within the San Bernadino Forest

It's territory is served via two 33kV circuits from SCE's Nelson substation:

- 1. The **Resort 34.5 kV line** - ~20 mile line connecting to Anza's Mountain Center Substation.
- 2. The **Canal 34.5 kV line** - ~21 mile line connecting to ANZA's Idyllwild substation.

Thermal capacity into ANZA is 19 MW.



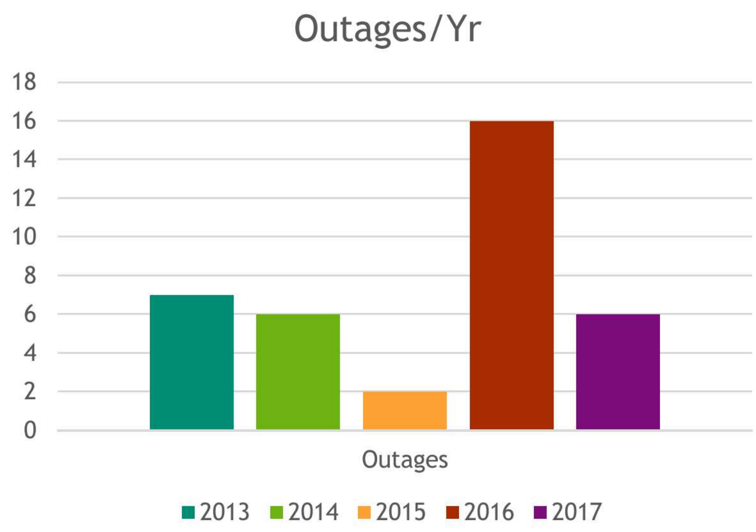
ANZA Electric Cooperative Energy Storage

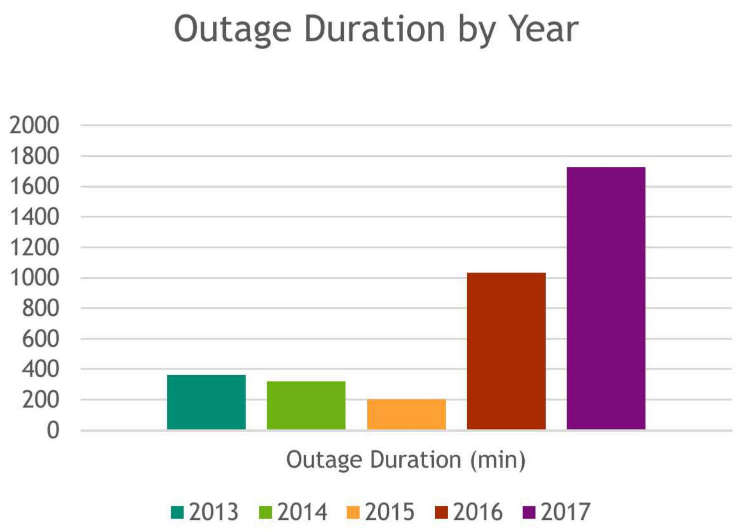
SAIDI Information

(System Average Interruption Duration Index)

These outages are ALL due to problems in SCE. And all of these outages knocked out ALL of ANZA.

On top of this, load is growing and will soon exceed line capacity





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So what has ANZA done so far?

- ✓ Rebuilt sections of line that accounted for 14% of outage duration since 2013
- ✓ Installed a remote automatic recloser on the Resort line that would have reduced outage duration by 23%
- ✓ Upgraded lines to achieve higher thermal capacity

The **next step** is a $20+ million dollar line addition…

ANZA Electric Cooperative Energy Storage

Rather than spend $20+ million dollars to increase capacity into ANZA, they have decided to explore using energy storage to **defer transmission upgrades** and to feed critical loads duration outages.

Sandia evaluated the **potential benefits** of **transmission deferral**, **energy arbitrage** opportunities, and direct costs to ANZA due to outages.

Three load growth scenarios were examined to bound revenue expectations: low, medium, high for the years from 2018 to 2028.

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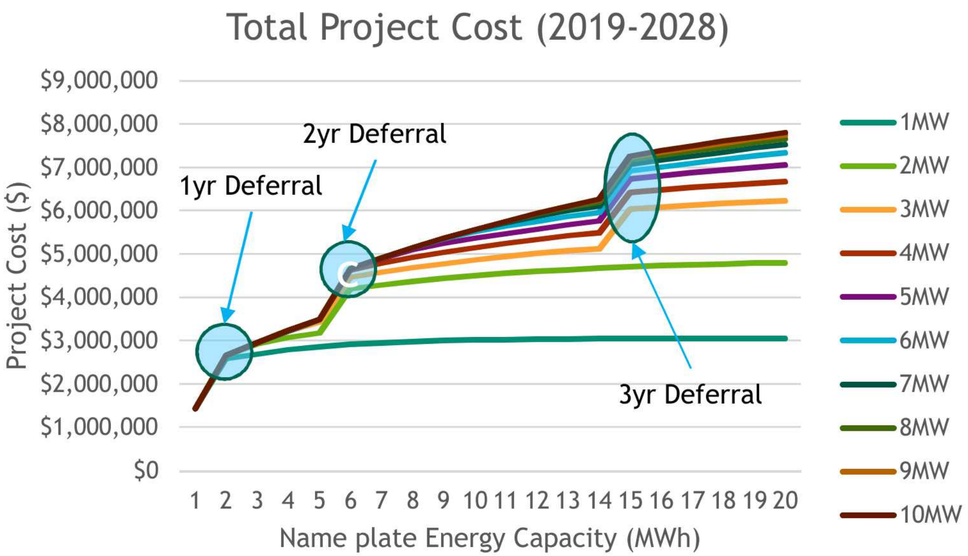
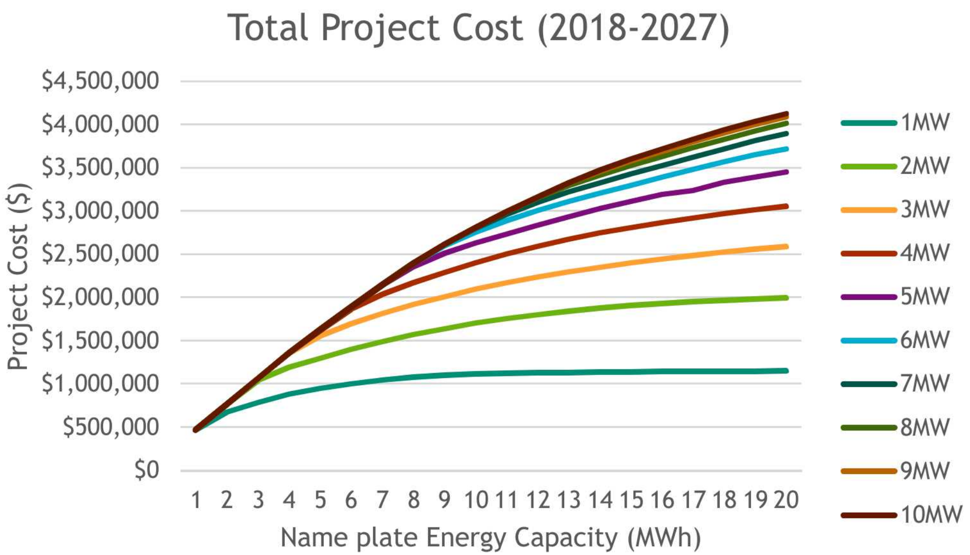


High Load Growth

Low Load Growth



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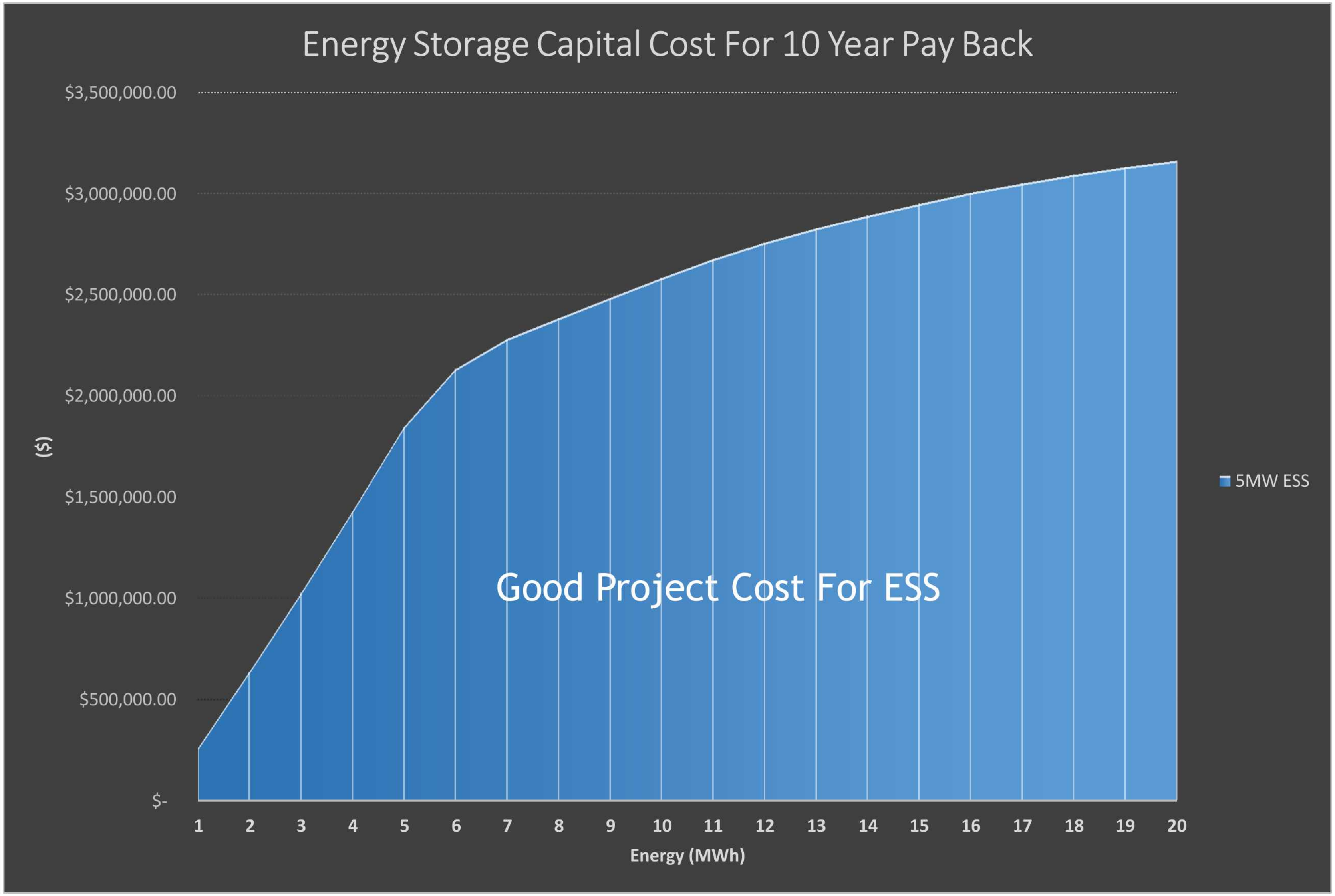

** Graph is based on Low Load Growth Profile

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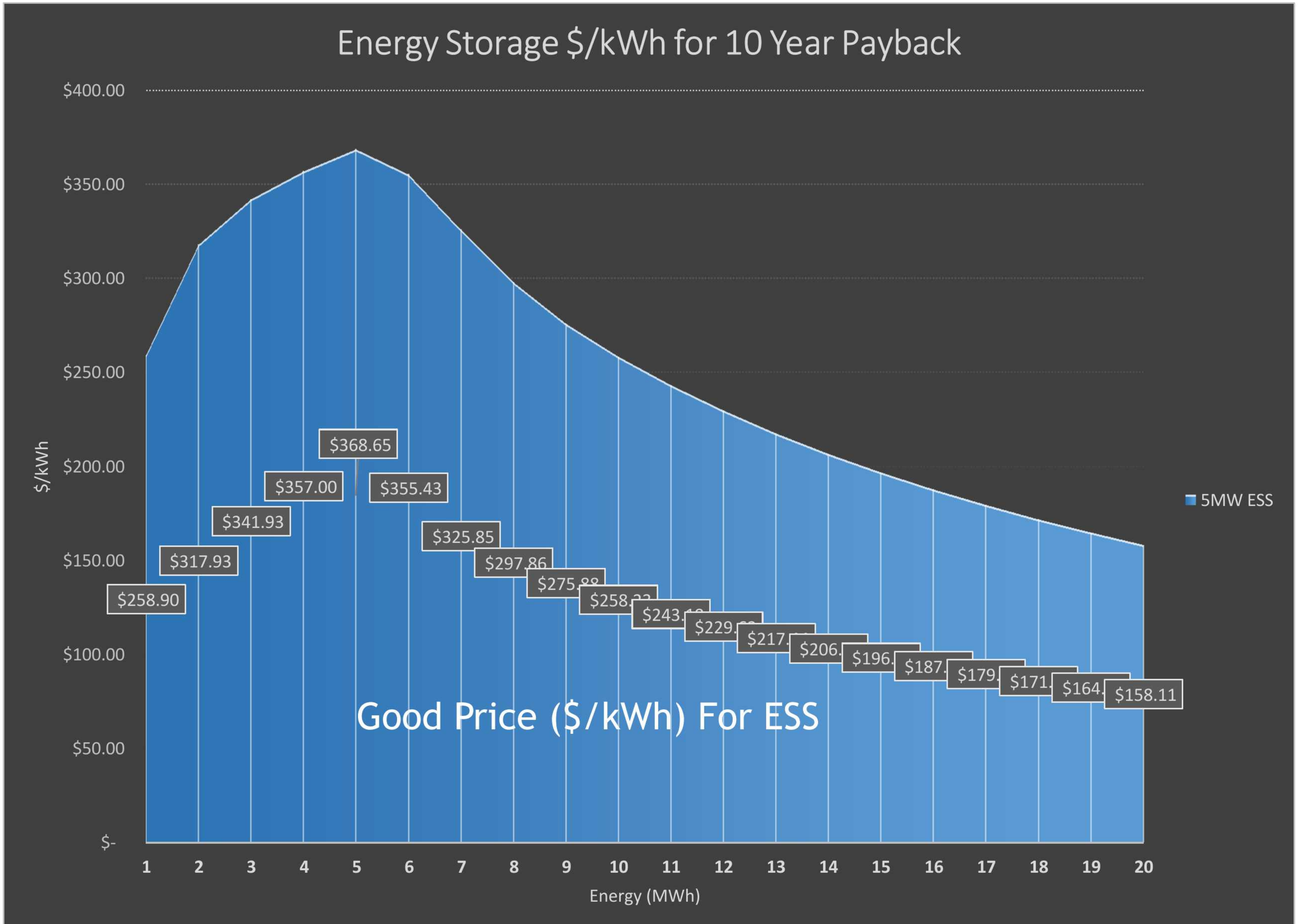

** Graph is based on Low Load Growth Profile

ANZA Electric Cooperative Energy Storage

Summary

- The majority of potential cost avoidance comes from transmission deferral, although…
- There was no transmission deferral opportunity in the low load growth scenario.
- Any energy capacity in the medium growth scenario pushed transmission additions back by a maximum of 3 years.
- In the high load growth scenario, the minimum size Energy Storage System that deferred transmission by 3 years was 2 MW/6 MWh, and a maximum of 4 years of deferral could be achieved with a 3 MW/15 MWh system.