INTRODUCTION TO THE ECONOMIC AND RESILIENCE BENEFITS OF MICROGRIDS

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MICROGRIDS AND ENERGY STORAGE FOR EMERGENCY GRID RESILIENCE

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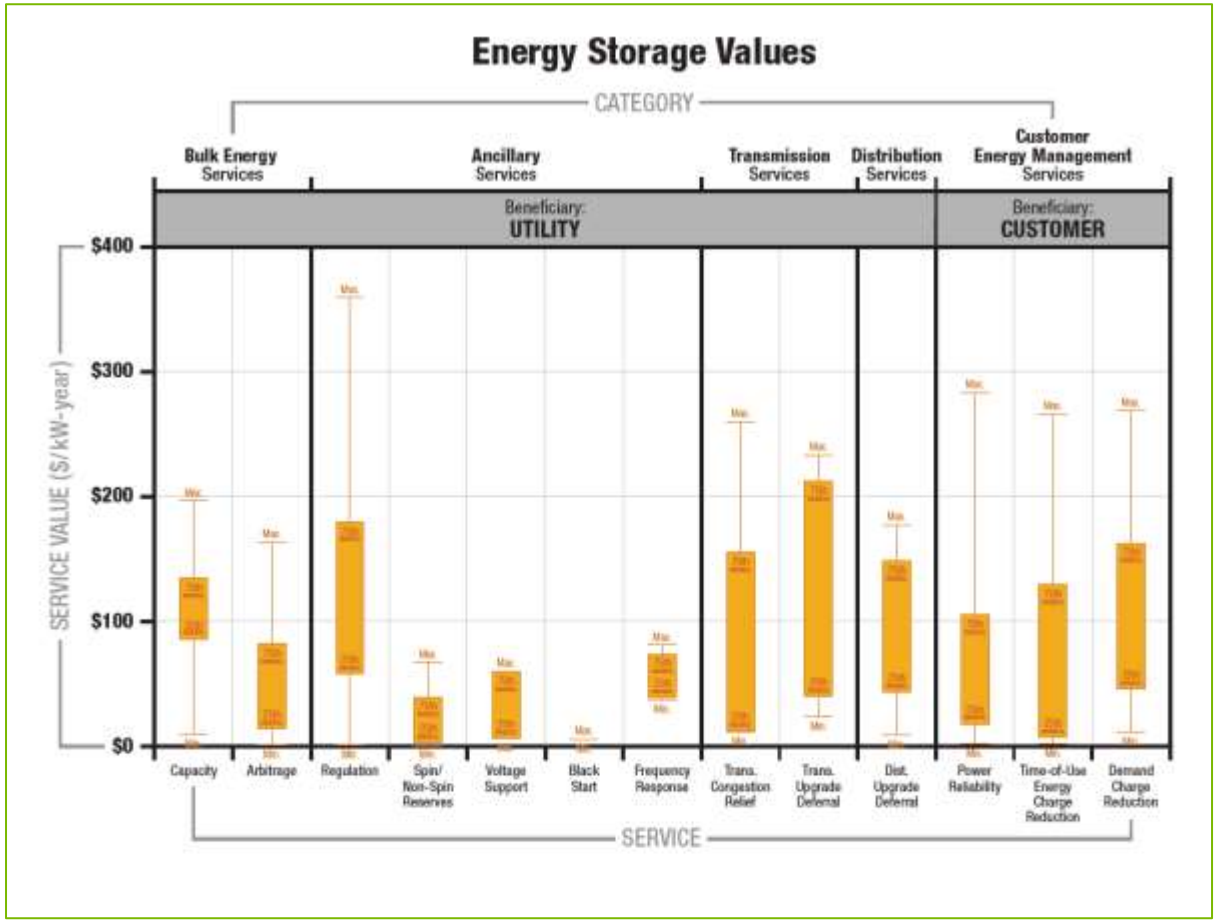
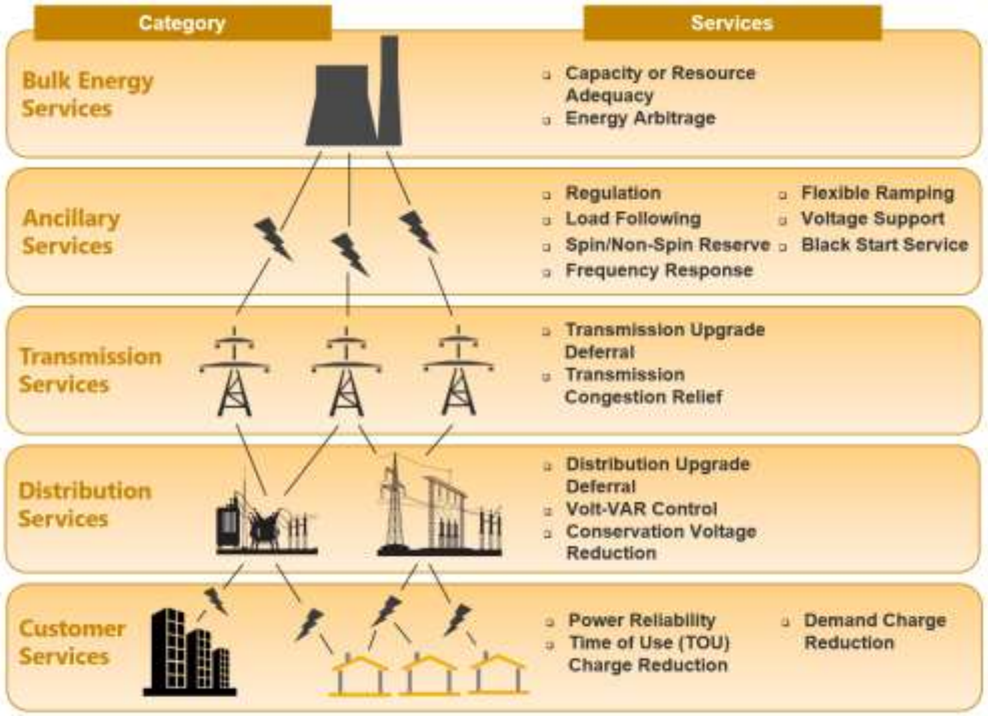
ENERGY STORAGE HOLDS TREMENDOUS VALUE



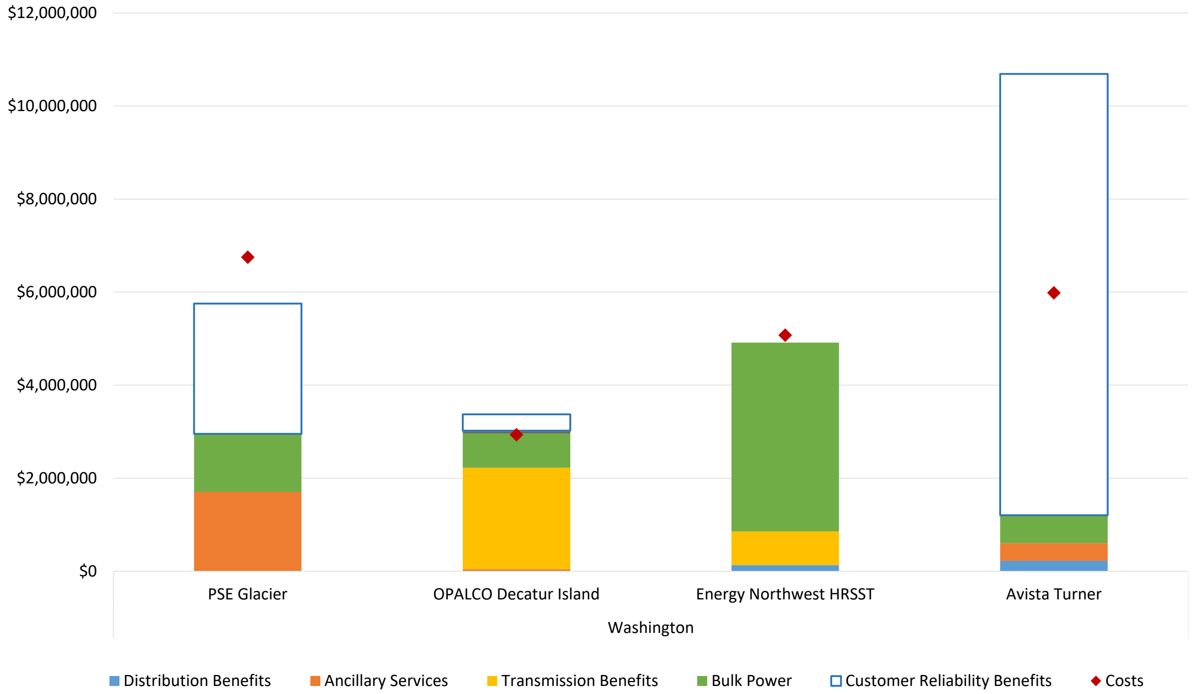
Key Lesson: The value of distributed energy resources (DERs) accrues at multiple levels of the electric grid, and there are no existing tools with all the required features to fully capture these values.

Source: Balducci, P., J. Alam, T. Hardy, and D. Wu. 2018. Assigning Value to Energy Storage Systems at Multiple Points in an Electrical Grid. Energy Environ. Sci., 2018, Advance Article. DOI: 10.1039/C8EE00569A. Available online at http://pubs.rsc.org/en/content/articlelanding/2018/ee/c8ee00569a#!divAbstract.

DEFINING AND MONETIZING THE VALUE OF ENERGY STORAGE AND DISTRIBUTED ENERGY RESOURCES



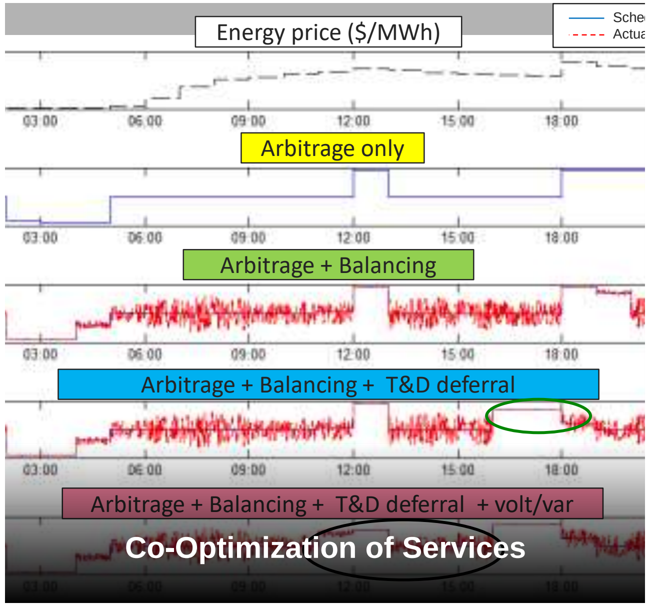
Category	Services
Bulk Energy Services	Capacity or Resource Adequacy Energy Arbitrage
Ancillary Services	Regulation Load Following Spin/Non-Spin Reserve Frequency Response Flexible Ramping Voltage Support Black Start Service
Transmission Services	Transmission Upgrade Deferral Transmission Congestion Relief
Distribution Services	Distribution Upgrade Deferral Volt-VAR Control Conservation Voltage Reduction
Customer Services	Power Reliability Time of Use (TOU) Charge Reduction Demand Charge Reduction



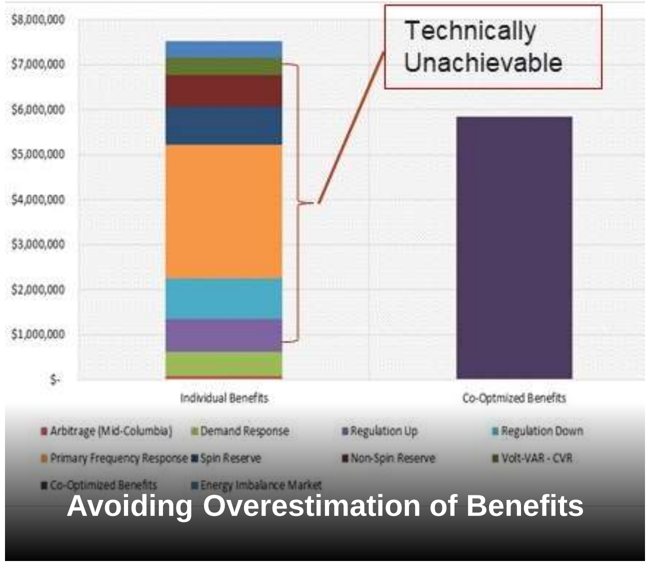
- A broad taxonomy and modeling approach for defining the value of storage is required to accurately assign value
- Economic value is highly dependent on siting and scaling of energy storage resources; many benefits accrue directly to customers

CHALLENGES TO ACCURATELY ESTIMATING ECONOMIC BENEFITS

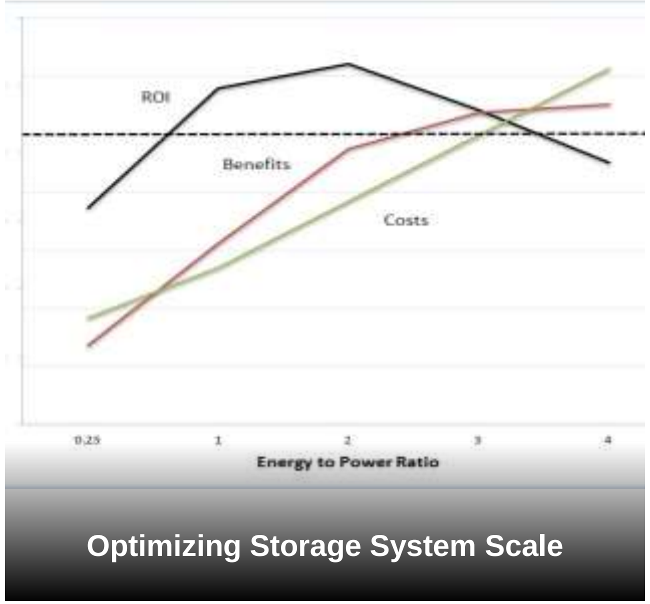
- Multidimensional competition for energy – not all services can be provided simultaneously and there exists intertemporal competition for energy
- Economic results are sensitive to sizing of energy storage system in terms of power and energy capacities
- Markets are complex and common practices of assuming perfect foresight into prices, price-taker position, and consistent performance lead to overestimation
- Battery performance is dynamic and there are challenges in capturing real-time value
- Battery degradation is an important consideration
- Storage valuation tools are required



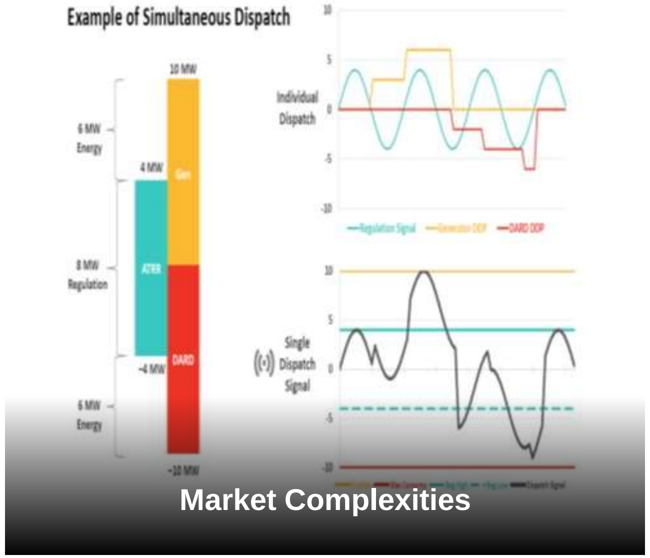
Co-Optimization of Services



Avoiding Overestimation of Benefits



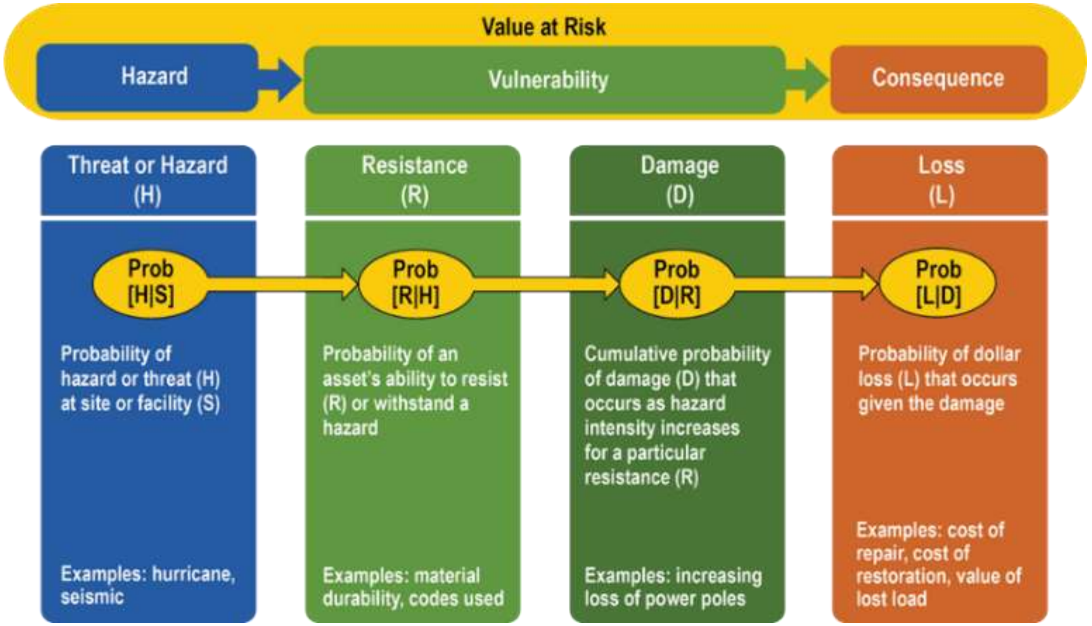
Optimizing Storage System Scale



Market Complexities

VALUING RESILIENCE

- Energy storage has demonstrated the capacity to enhance grid resilience
- Resilience benefits are poorly defined and generally ignored in energy storage valuation studies
- Resilience benefits are typically evaluated using customer damage functions and interruption cost studies, sometimes evaluated using willingness to pay studies (e.g., contingent valuation method) and input-output analysis
- Resilience value can be embedded in other value streams, including transmission deferral, voltage sag compensation, and outage mitigation



Pictorial Approach to Value Risk Assessment and Resilience Valuation

- Multi-hazard risk analysis that relies on expected value calculations based on probabilistic analysis, while addressing a broad range of hazards and values tied to lost economic productivity, infrastructure damage, and injuries/fatalities is required – annual risk premium approach
- More research is needed to properly value resilience

Source: Balducci, Patrick, Mongird, Kendall, and Weimar, Mark. Understanding the Value of Energy Storage for Power System Reliability and Resilience Applications. Germany: N. p., 2021. Web. https://doi.org/10.1007/s40518-021-00183-7.

NANTUCKET ISLAND ENERGY STORAGE SYSTEM

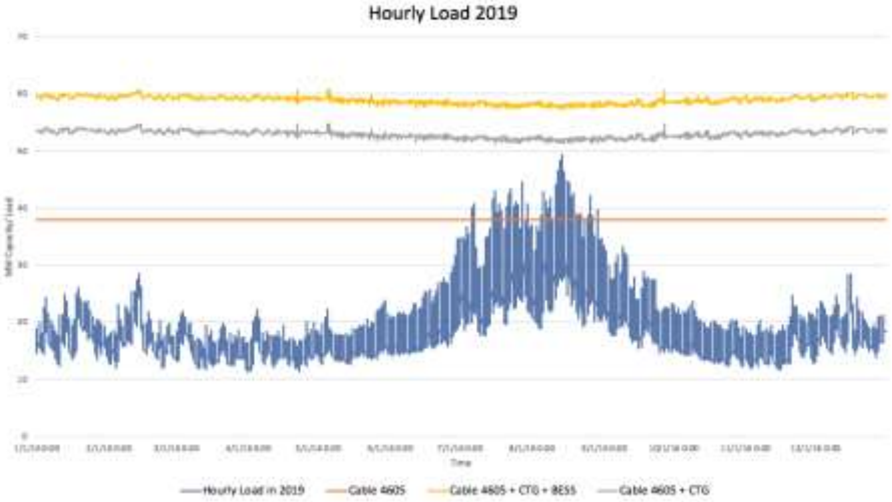
- Nantucket Island located off the coast of Massachusetts
    - Small resident population of 11,000; population swells to over 50,000 in summer
    - Nantucket's electricity supplied by two cables with a combined capacity of 71 MW and two small on-island combustion turbine generators (CTGs) with a combined capacity of 6 MW
    - Rather than deploying 3rd cable, National Grid is replacing two CTGs with a single, large (16 MW) combustion turbine generator (CTG) and a 6 MW / 48 MWh Tesla Li-ion battery energy storage system (BESS.)
- Use cases evaluated
    - Non-market operations
        - ✓ Transmission deferral
        - ✓ Outage mitigation
        - ✓ Conservation voltage reduction
        - ✓ Volt-VAR optimization
    - Market operations
        - ✓ Forward capacity market
        - ✓ Arbitrage
        - ✓ Regulation
        - ✓ Spinning reserves

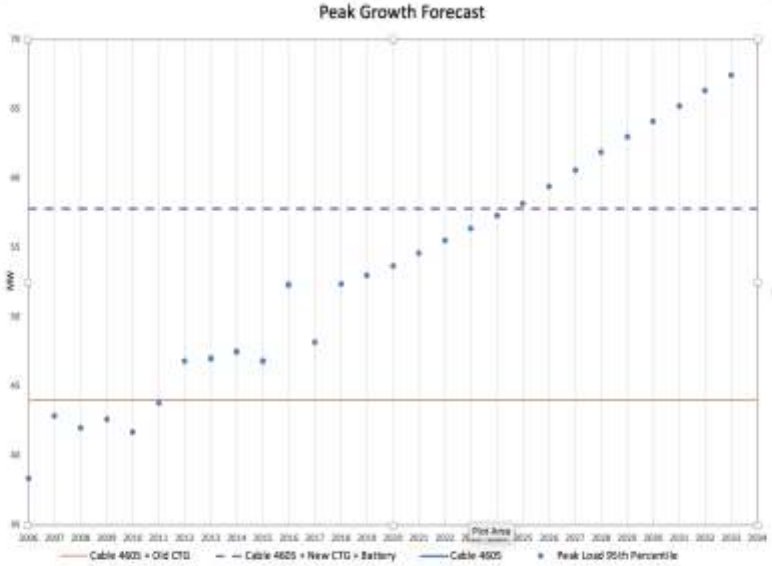
Nantucket Supply Cables

Source: Balducci, Patrick J., Alam, Md Jan E., McDermott, Thomas E., Fotedar, Vanshika, Ma, Xu, Wu, Di, Bhatti, Bilal Ahmad, Mongird, Kendall, Bhattarai, Bishnu P., Crawford, Aladsair J., and Ganguli, Sumitrra. Nantucket Island Energy Storage System Assessment. United States: N. p., 2019. Web. doi:10.2172/1564262.

BENEFITS OF LOCAL OPERATIONS

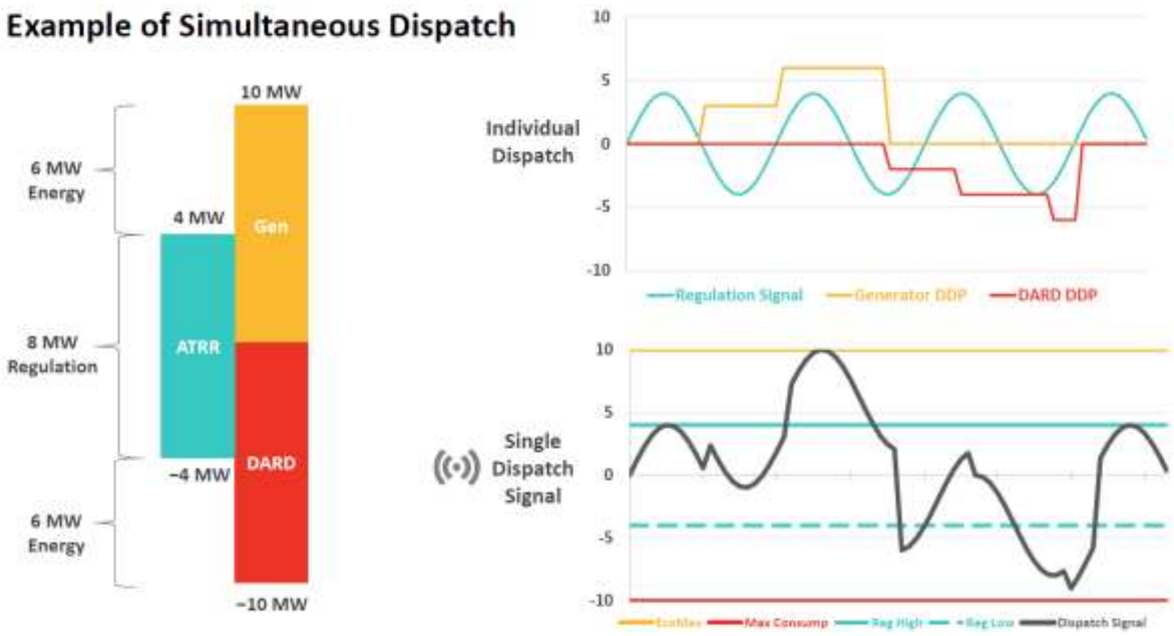
- The research team performed an extensive load analysis in order to define the n-1 contingency window and estimate the number of deferral years at 13
- Outage mitigation evaluated using historic outages and distribution system model
- Value of local operations ($122 million) exceeds the $93.3 million in revenue requirements for the systems, yielding an ROI ratio of 1.30





BENEFITS OF MARKET OPERATIONS

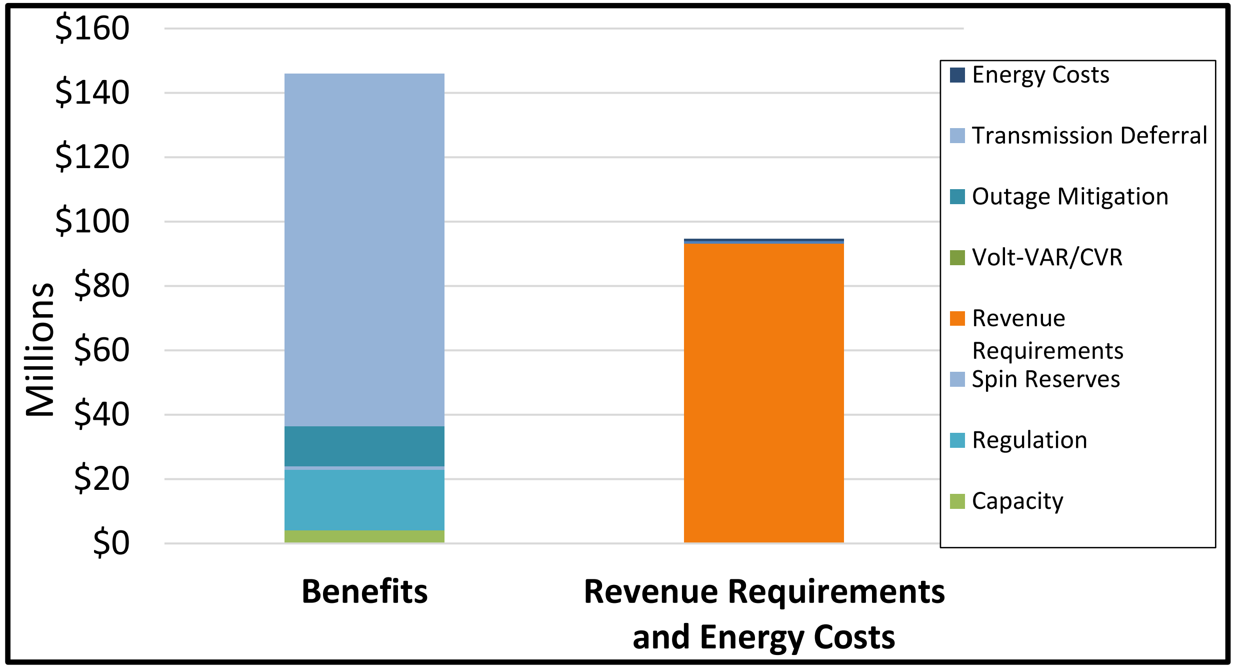
- Nantucket BESS modeled as a continuous storage facility
- BESS bid into markets using predicted prices – i.e., imperfect foresight
- Regulation follows energy neutral AGC signal with a performance score of 95%
- Market benefits estimated at $24.0 million over life of BESS
  - Regulation provides $18.8 million (78%) of market benefits
  - Capacity - $4.1 million (17%)
  - Spin reserves - $1.2 million (5%)



Simultaneous Dispatch of Continuous Storage Facility

NANTUCKET ISLAND CONCLUSIONS

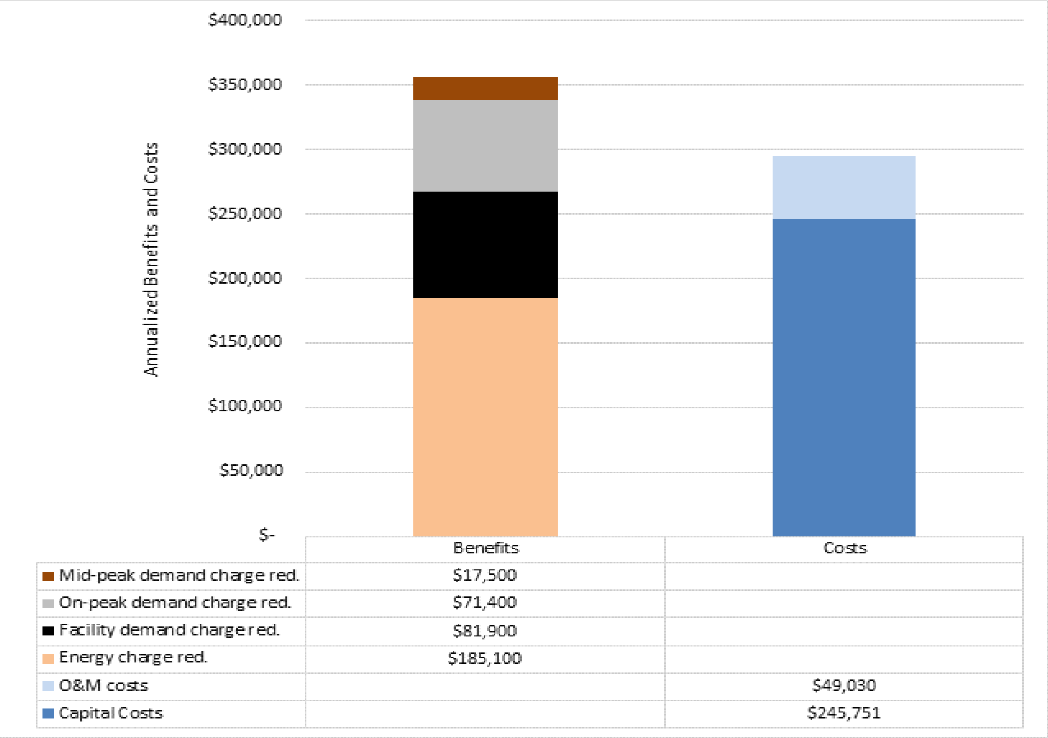
- Total 20-year present value benefits of BESS and CTG operations at $145.9 million exceed revenue requirements and energy costs at $93.9 million with an ROI ratio of 1.55
- Benefits largely driven by the transmission deferral use case, $109 million (75%) in present value terms.
- Regulation services - $18.8 million, 13% of total benefits
- Regulation service dominates the application hours, 7,900 hours each year



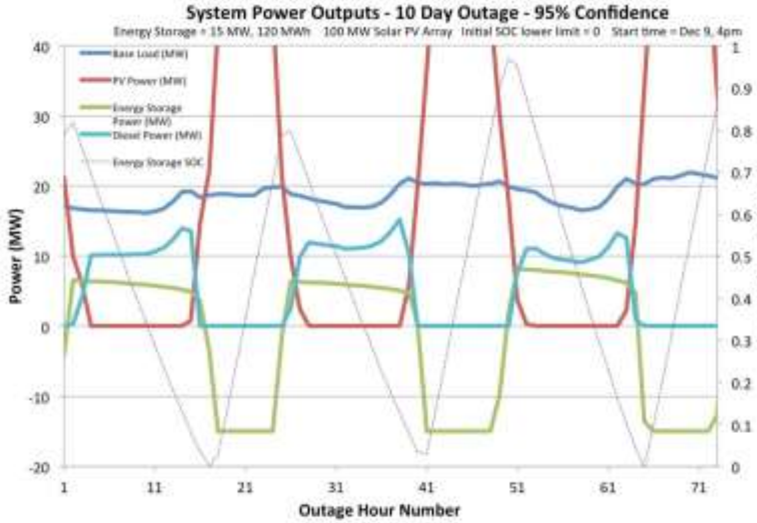
Benefits of Local and Market Operations (Base Case) vs. Revenue Requirements

JOINT FORCES TRAINING BASE LOS ALAMITOS

- JFTB Los Alamitos Microgrid Assessment
  - Resiliency goal – 90% survivability rate for a two-week outage
  - Energy assets – Photovoltaics, diesel gen sets, energy storage
  - Charge to analysts – Meet resiliency goal and maximize economic benefits given fixed budget



	Benefits	Costs
Mid-peak demand charge red.	$17,500	
On-peak demand charge red.	$71,400	
Facility demand charge red.	$81,900	
Energy charge red.	$185,100	
O&M costs		$49,030
Capital Costs		$245,751

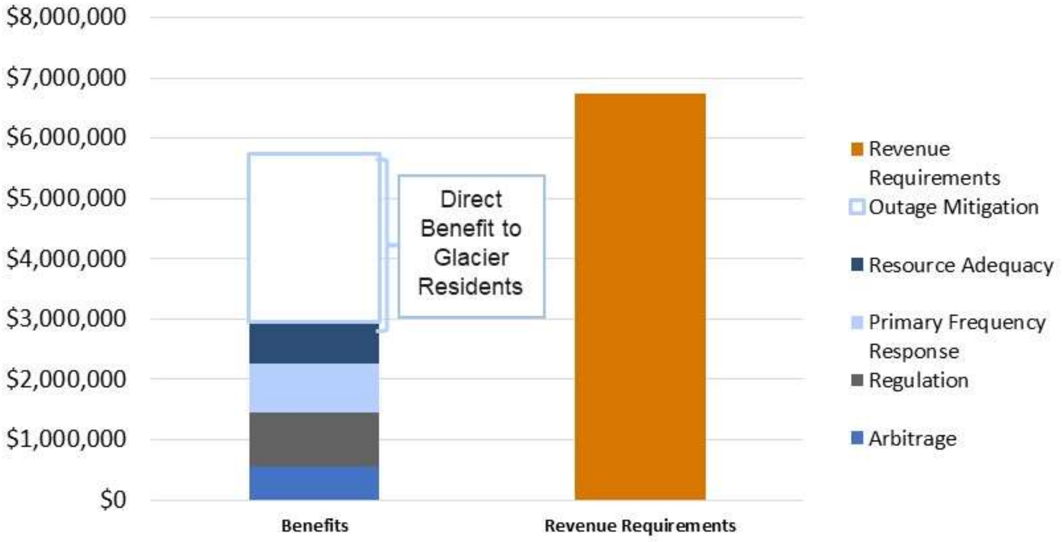


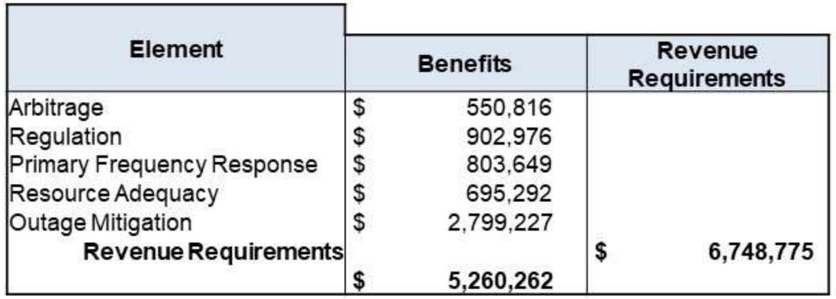
Optimal Microgrid Scale Required to Achieve *Energy Security* and *Operational Goals:*
Gen Set – 1,150 kW
Photovoltaics – 1,224 kW
Energy storage – 408 kW / 510 kWh

PUGET SOUND ENERGY GLACIER

- Outage Data
  - 27 hours of outages average annually
  - All outages (4 on average per year at approximately 6.5 hours each) can be mitigated with the BESS
  - PSE has islanded the downtown core of Glacier

- Customer information
  - Number and type of customers affected by outages determined (38 residential and 20 small commercial and industrial)
  - Annual benefit of roughly $310k to ratepayers



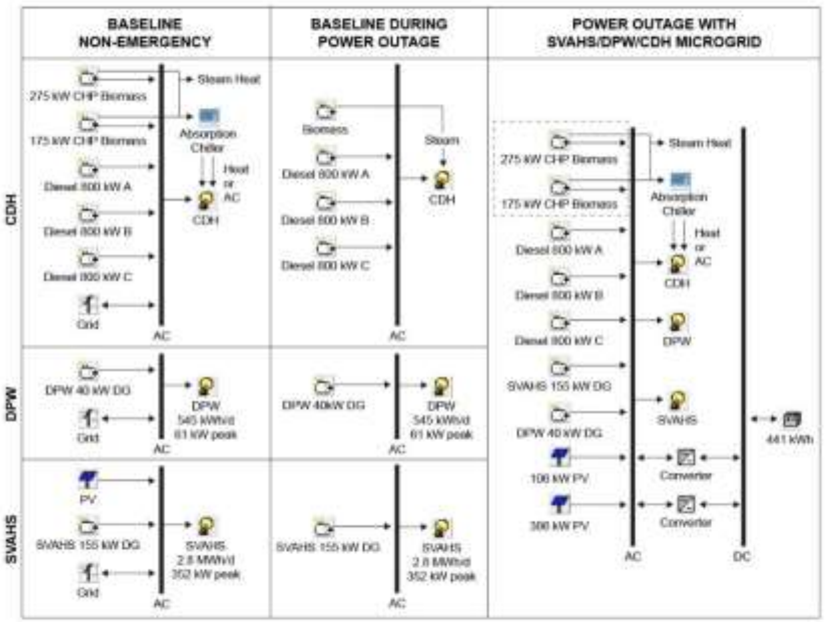


Element	Benefits	Revenue Requirements
Arbitrage	$ 550,816	
Regulation	$ 902,976	
Primary Frequency Response	$ 803,649	
Resource Adequacy	$ 695,292	
Outage Mitigation	$ 2,799,227	
Revenue Requirements		**$ 6,748,775**
	$ 5,260,262	

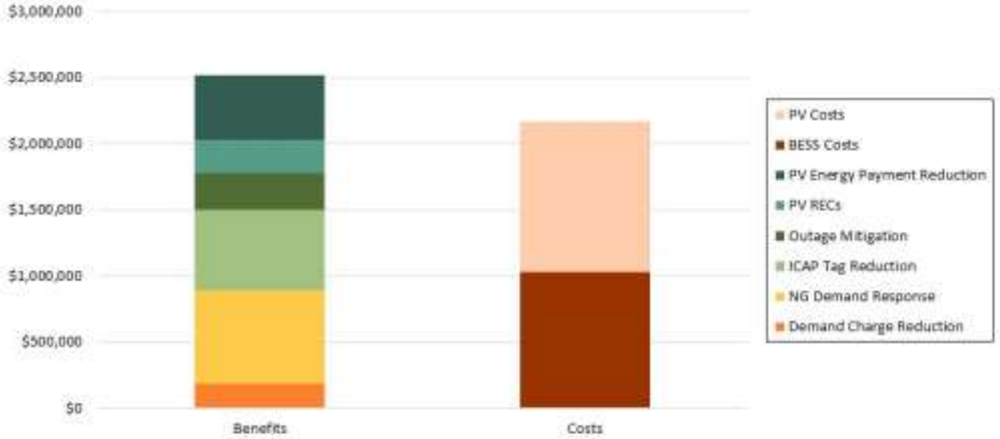
Source: Balducci, Patrick J., Mongird, Kendall, Alam, Jan E., Wu, Di, Fotedar, Vanshika, Viswanathan, Vilayanur V., Crawford, Aladsair J., Yuan, Yong, Labove, Garett, Richards, Shane, Shane, Xin, and Wallace, Kelly. Washington Clean Energy Fund Grid Modernization Projects: Economic Analysis (Final Report). United States: N. p., 2020. Web. doi:10.2172/1772558.

NORTHAMPTON MICROGRID

- Economic Benefits
  - BESS and the 386 kW solar array are estimated to generate a benefit-cost ratio of 1.16 with $0.3 million in net benefits.
- Resilience Benefits
  - When there is a full microgrid and full sharing between microgrid members, all facilities are able to withstand 100% of outages up to seven days in both summer and winter. If no microgrid exists, the survivability of Smith Vocational Area High School and the Department of Public Works during a seven-day outage assuming no DG failure drops to 41.24% and 88.95%, respectively.
  - When 14-day outages are considered, survivability drops significantly due to fuel shortages.



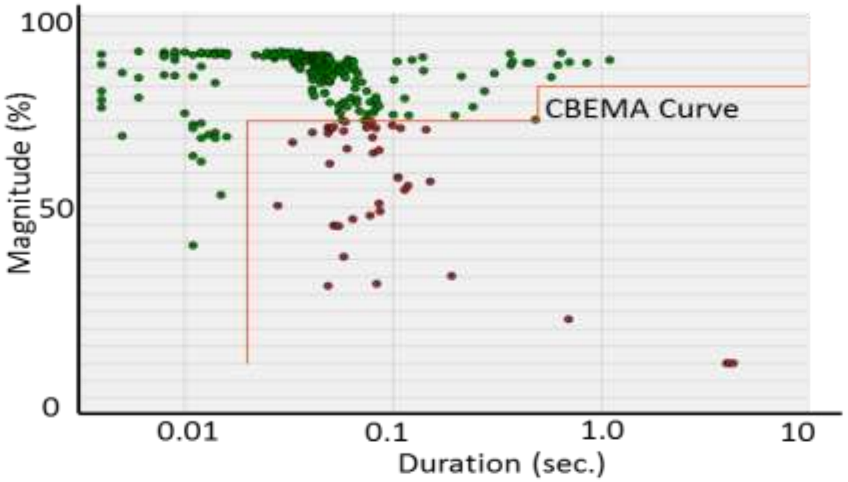
Existing and Planned Power Components of the Northampton Microgrid Project



Twenty-year Benefits and Costs for the Northampton Microgrid

Source: Balducci, Patrick, Mongird, Kendall, Wu, Di, Wang, Dexin, Fotedar, Vanshika, and Dahowski, Robert. An Evaluation of the Economic and Resilience Benefits of a Microgrid in Northampton, Massachusetts. Switzerland: N. p., 2020. Web. https://doi.org/10.3390/en13184802

TURNER ENERGY STORAGE PROJECT – VOLTAGE SAG COMPENSATION



- Sustained voltage sags lead to production disruptions
- PNNL evaluated voltage data from 2014-2017 provided by Schweitzer Engineering Labs
- Applying the Computer Business Equipment Manufacturers (CBEMA) defined power quality curve, over 40 voltage sag events (<70% in magnitude, >20 milliseconds in duration) identified
- On average, two events per year identified as capable of causing disruptions
- In addition, outages of over 5 minutes were experienced three times between 2011 and 2016
- Each outage causes a minimum of three hours of downtime at a cost of $150,000 per hour

Source: Balducci, Patrick J., Mongird, Kendall, Alam, Jan E., Wu, Di, Fotedar, Vanshika, Viswanathan, Vilayanur V., Crawford, Aladsair J., Yuan, Yong, Labove, Garett, Richards, Shane, Shane, Xin, and Wallace, Kelly. Washington Clean Energy Fund Grid Modernization Projects: Economic Analysis (Final Report). United States: N. p., 2020. Web. doi:10.2172/1772558.

CONCLUSIONS – KEY CONSIDERATIONS

Siting/Sizing Energy Storage	Siting/sizing of microgrid assets by capturing/measuring location-specific benefits is key prior to microgrid development
Broad Set of Use Cases	While most microgrid benefits are tied to demand charge reduction, time-of-use charge reduction and outage mitigation, additional benefits may accrue
Regional Variation	Differentiate benefits by region, market structures/rules
Utility Structure	Define benefits for different types of utility tariff structures
Battery Characteristics	Accurately characterize battery performance, including round trip efficiency rates across varying SOCs and battery degradation caused by cycling

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https://www.energy.gov/oe/activities/technology-development/energy-storage

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