MAKING THE ECONOMIC CASE FOR ENERGY STORAGE: WHAT WORKS AND WHAT DOESN'T

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COLORADO PUBLIC UTILITIES COMMISSION ENERGY STORAGE SYSTEMS WORKSHOP

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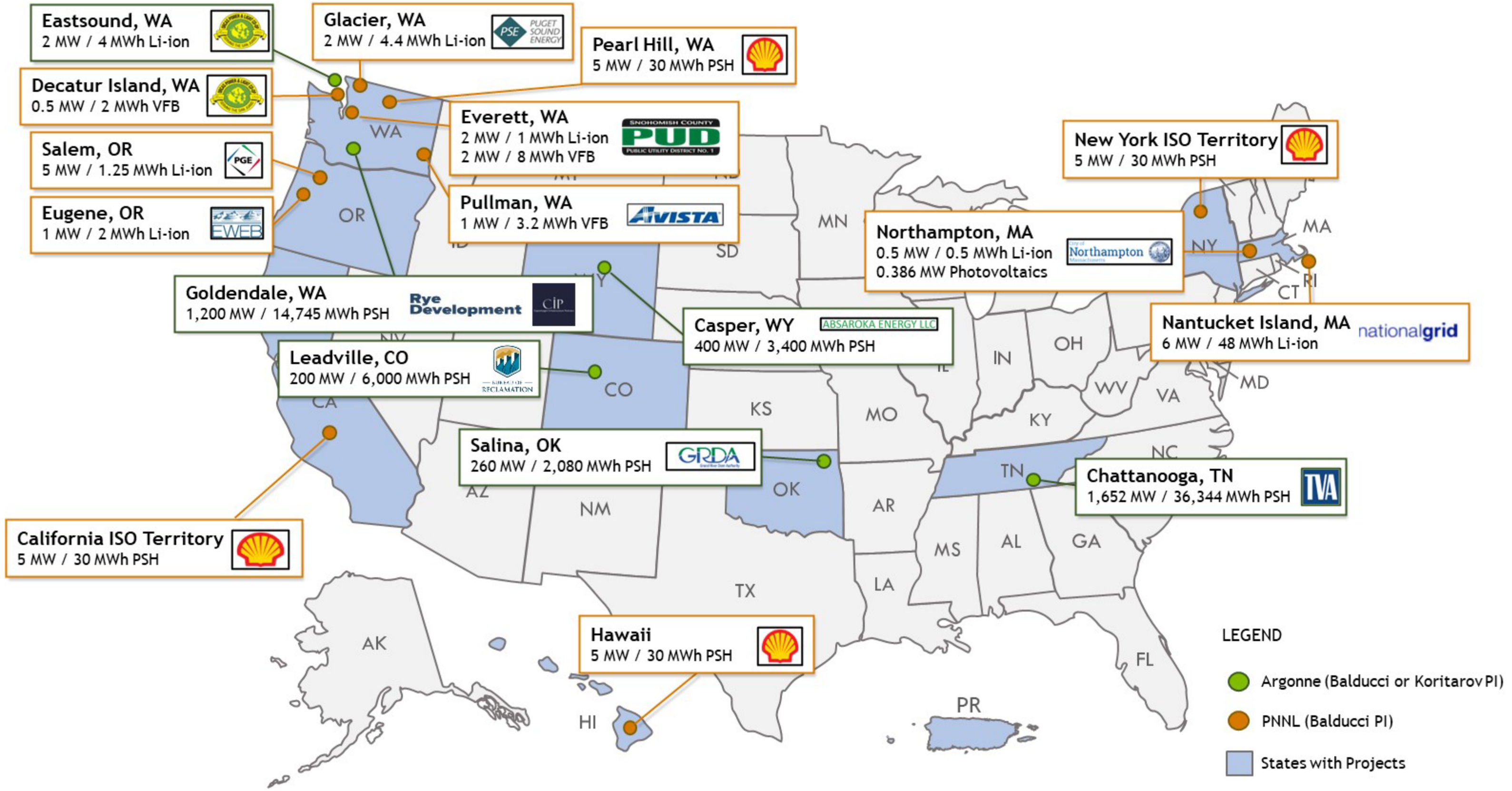
INTRODUCTION

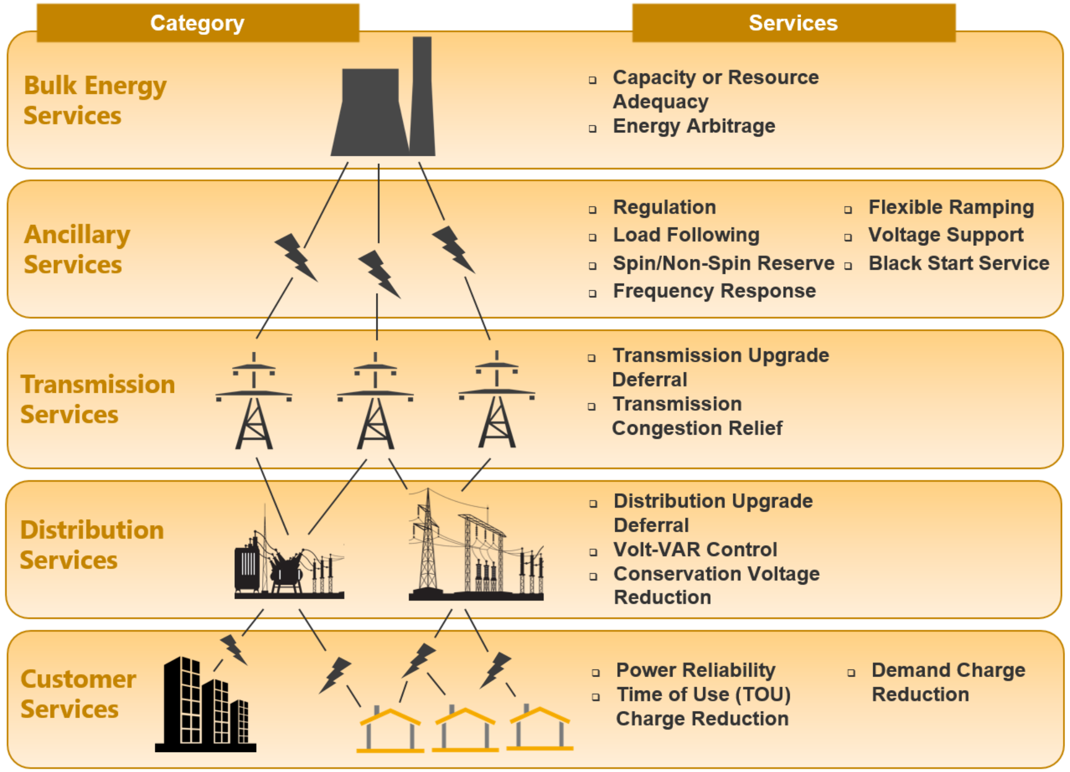
RECENT ENERGY STORAGE TECHNO-ECONOMIC ASSESSMENTS

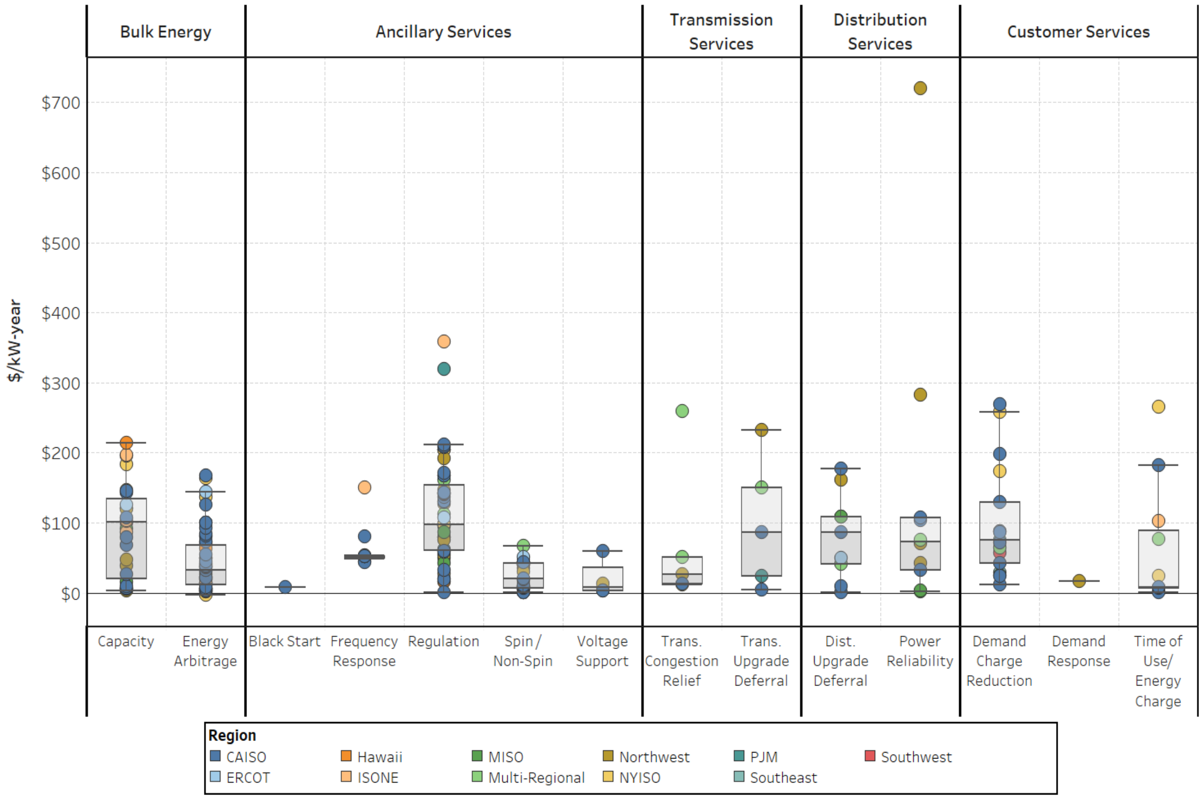


3,754 MW 62,763 MWh at 18 Sites

*Note that all projects highlighted in orange were led by Patrick Balducci during his tenure at Pacific Northwest National Laboratory.

VALUATION TAXONOMY AND META-ANALYSIS RESULTS

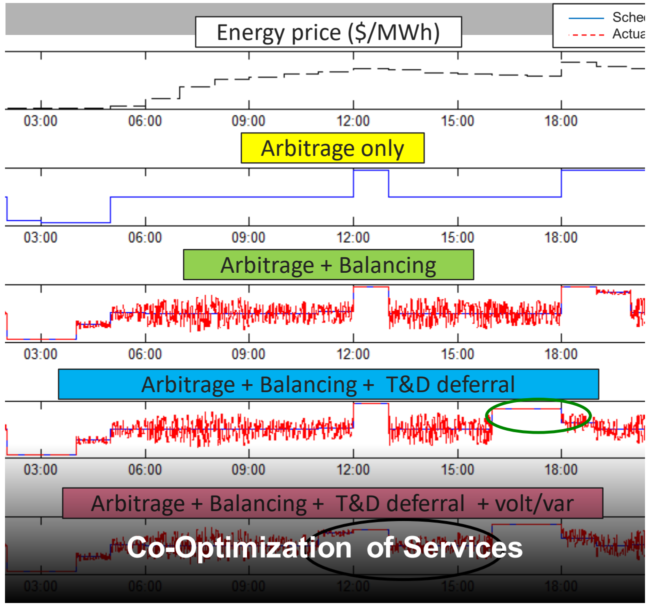




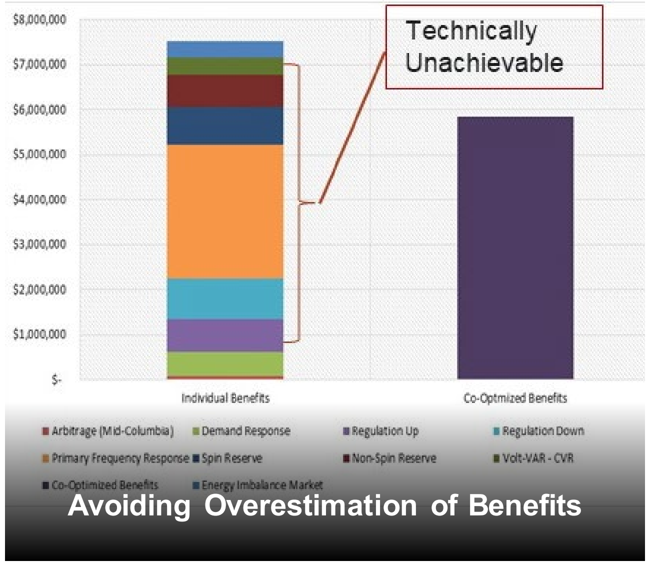
Source: Balducci, Patrick, Mongird, Kendall, and Weimar, Mark. Understanding the Value of Energy Storage for Power System Reliability and Resilience Applications. Germany: N. p., 2021. Web. https://doi.org/10.1007/s40518-021-00183-7.

CHALLENGES TO ACCURATELY ESTIMATING ECONOMIC BENEFITS

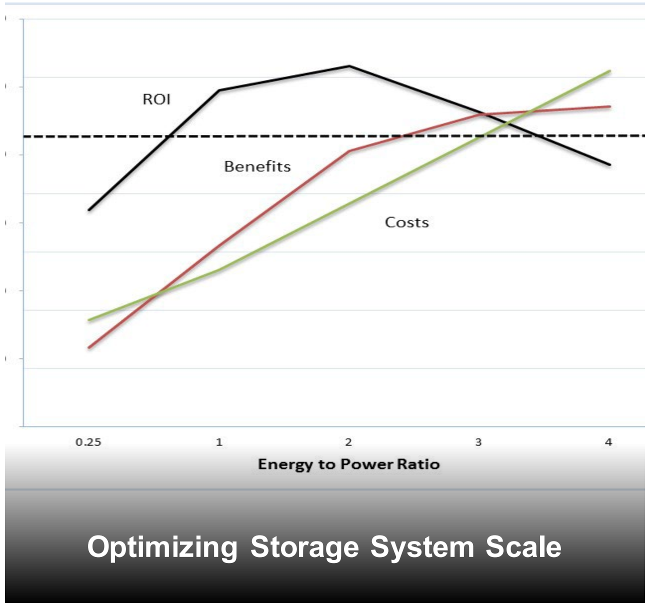
- Multidimensional competition for energy – not all services can be provided simultaneously and there exists intertemporal competition for energy
- Economic results are sensitive to sizing of energy storage system in terms of power and energy capacities
- Markets are complex and common practices of assuming 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
- Price-influencer models are required for large-scale storage



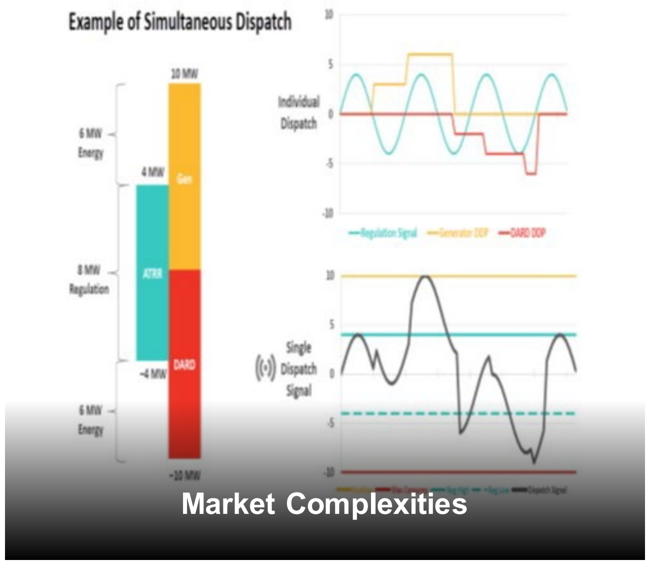
Co-Optimization of Services



Avoiding Overestimation of Benefits



Optimizing Storage System Scale



Market Complexities

SALEM SMART POWER CENTER AND NANTUCKET ISLAND MICROGRID

PORTLAND GENERAL ELECTRIC (PGE) SALEM SMART POWER CENTER (SSPC)

- Developed as an R&D project under the American Recovery and Reinvestment Act of 2009
- DOE provided half of the funding
- 5 megawatt (MW) – 1.25 megawatt-hour (MWh) lithium-ion battery system built and managed by PGE

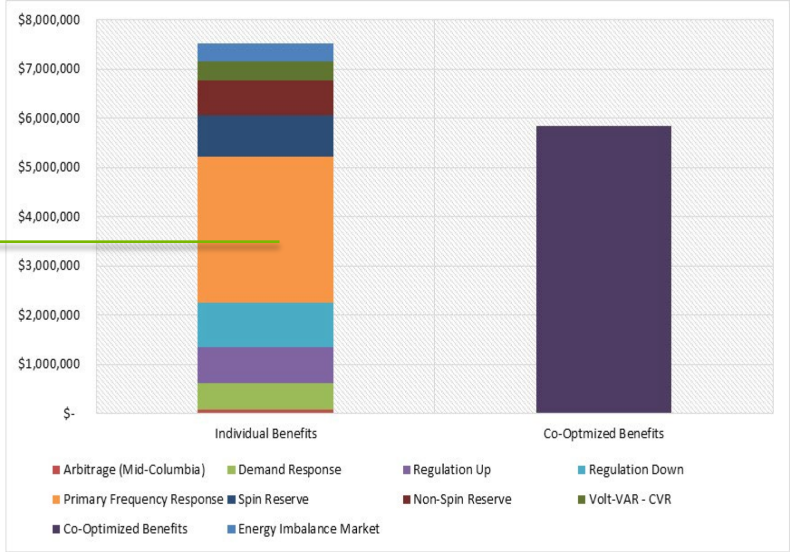
- Potential benefit streams:
  - Energy arbitrage
  - Participation in the Western Energy Imbalance Market (EIM)
  - Demand response
  - Regulation up and down
  - Primary frequency response
  - Spin/non-spin reserve
  - Volt-VAR control
  - Conservation voltage reduction

Western Energy Imbalance Market

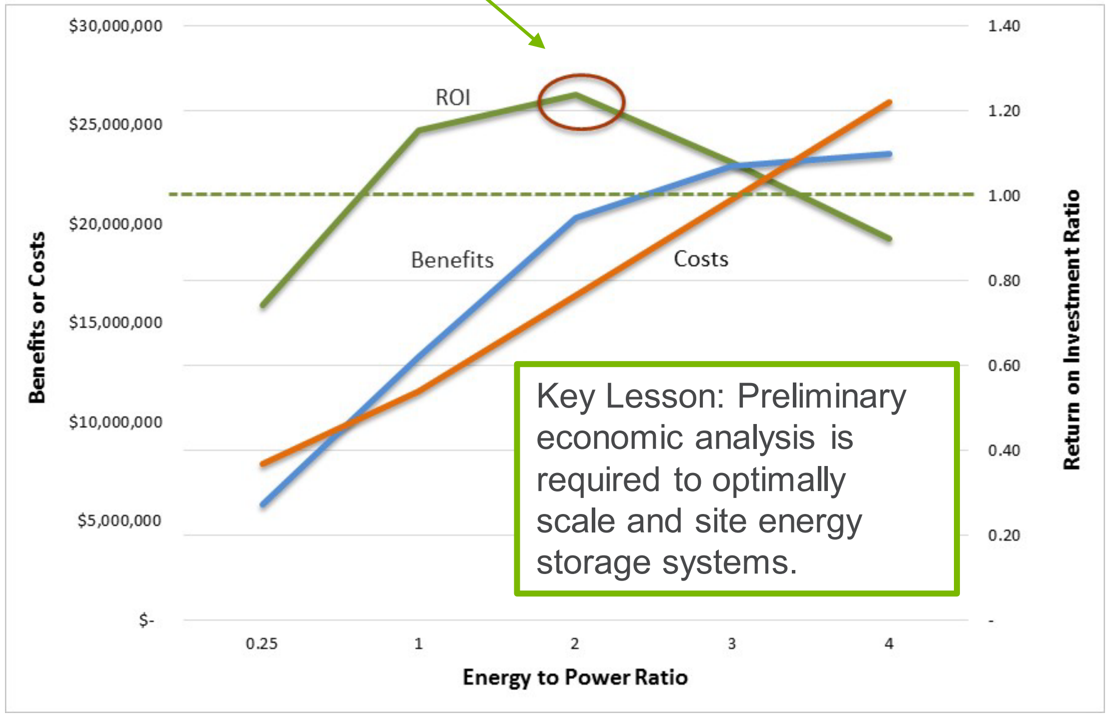
OPTIMAL SCALING OF THE SSPC

- Evaluated individually, 20-year PV benefits of SSPC operations exceeds $7.5 million. When co-optimized, value falls to $5.8 million
- At an energy to power ratio of 0.25, return on investment (ROI) falls below zero

Technically Unachievable



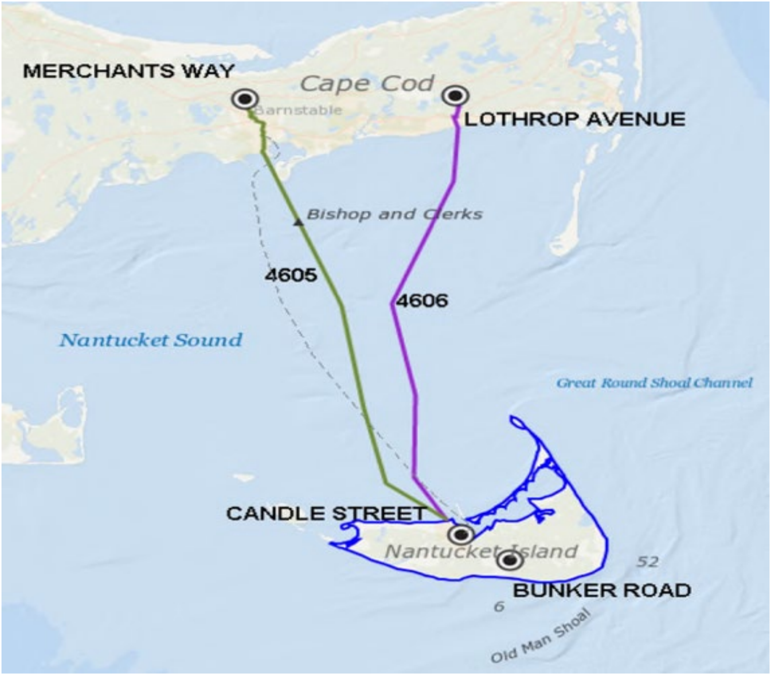
- By upsizing the energy storage capacity to 10 MWh, the ROI yields a positive result at 1.24



Key Lesson: Preliminary economic analysis is required to optimally scale and site energy storage systems.

NANTUCKET ISLAND ENERGY STORAGE SYSTEM

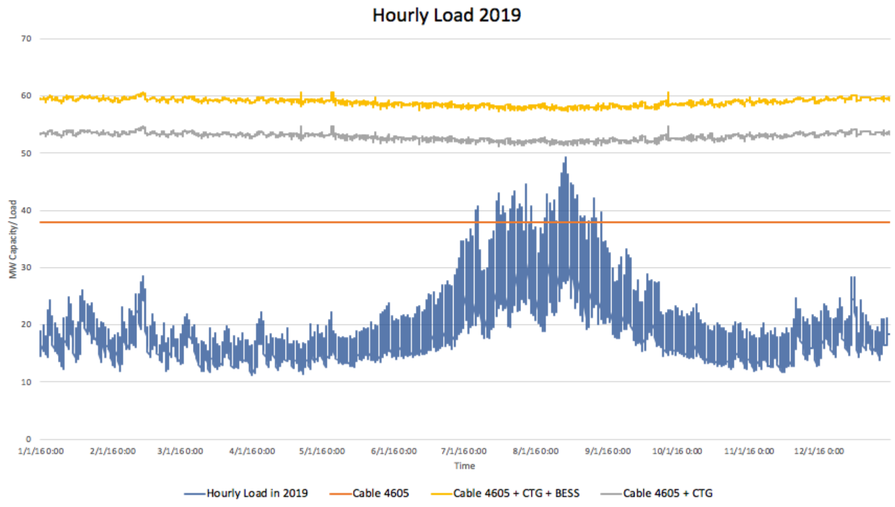
- Nantucket Island located off the coast of Massachusetts
  - Small resident population of 11,000; population swells to over 50,000 in summer
  - Nantucket's electricity supplied by two cables with a combined capacity of 71 MW and two small on-island combustion turbine generators (CTGs) with a combined capacity of 6 MW
  - Rather than deploying 3rd cable, National Grid is replacing two CTGs with a single, large (16 MW) CTG and a 6 MW / 48 MWh Tesla Li-ion 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

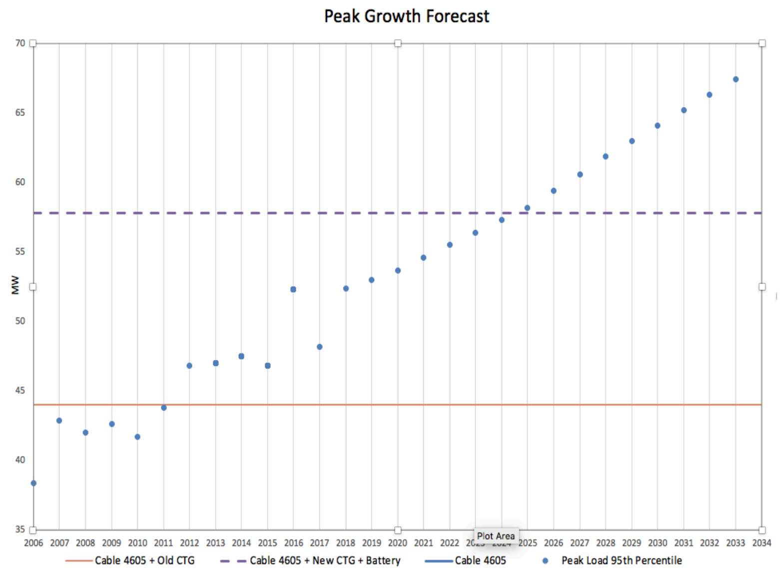


Nantucket Supply Cables

BENEFITS OF LOCAL OPERATIONS

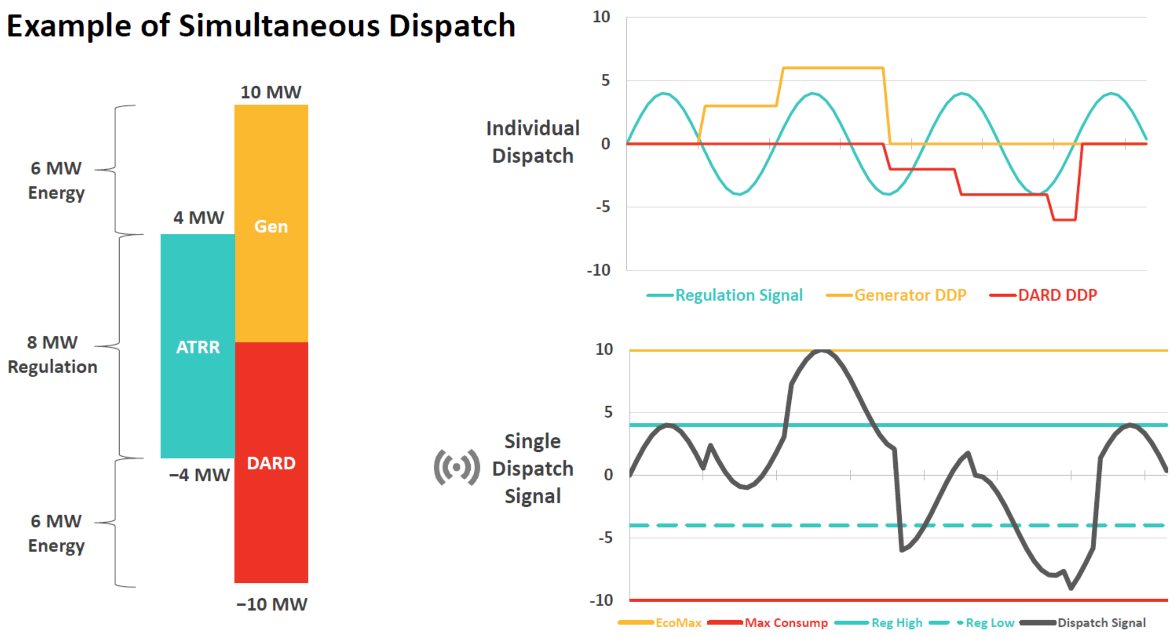
- The research team performed an extensive load analysis in order to define the n-1 contingency window and estimate the number of deferral years at 13
- Outage mitigation evaluated using historic outages and distribution system model
- Value of local operations ($122 million) exceeds the $93.3 million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

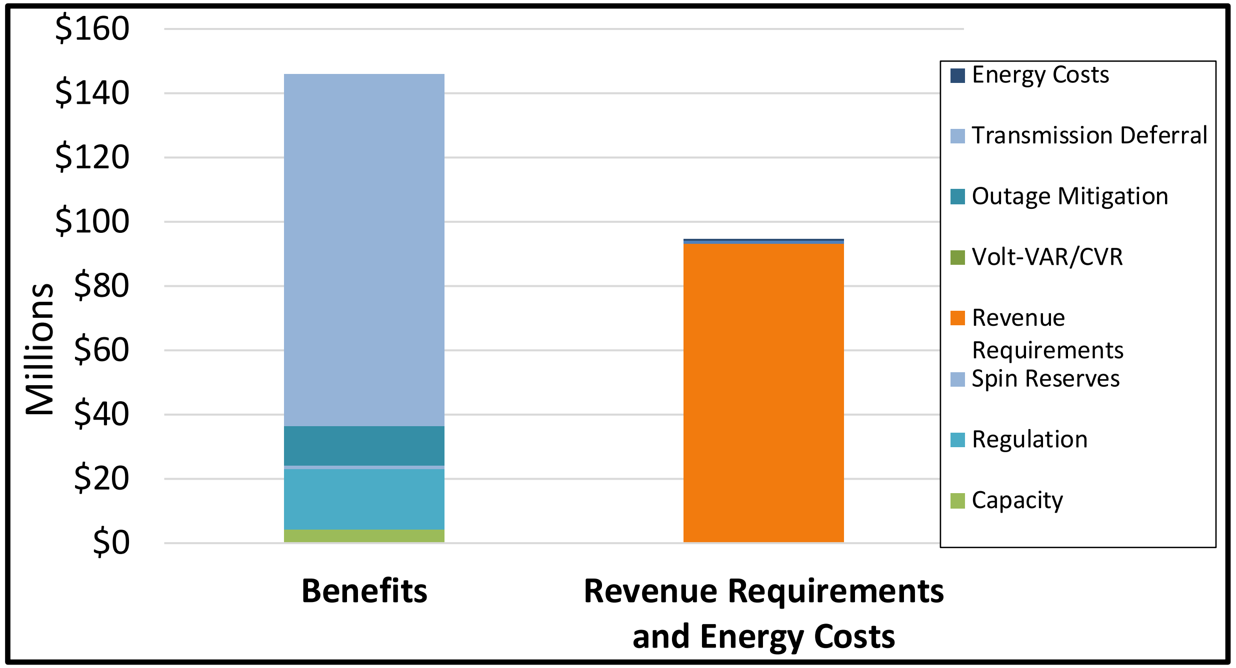


Simultaneous Dispatch of Continuous Storage Facility

U.S. DEPARTMENT OF ENERGY — Argonne National Laboratory is a U.S. Department of Energy laboratory managed by UChicago Argonne, LLC.

NANTUCKET ISLAND CONCLUSIONS

- Total 20-year pv 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 PV terms.
- Regulation services - $18.8 million, 13% of total benefits
- Regulation service dominates the application hours, 7,900 hours each year

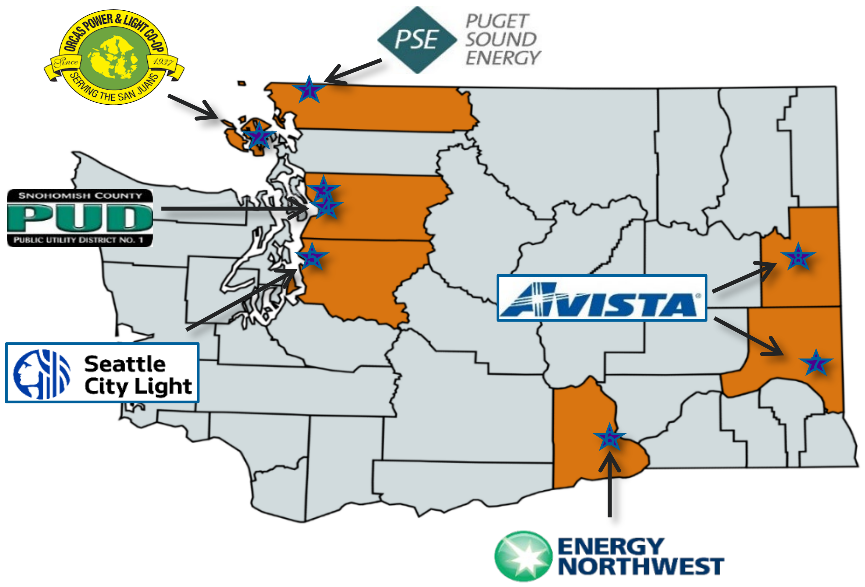


Benefits of Local and Market Operations (Base Case) vs. Revenue Requirements

Source: Balducci, Patrick J., Alam, 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.

WASHINGTON CLEAN ENERGY FUND

WASHINGTON CLEAN ENERGY FUND (CEF) GRID MODERNIZATION PROGRAM



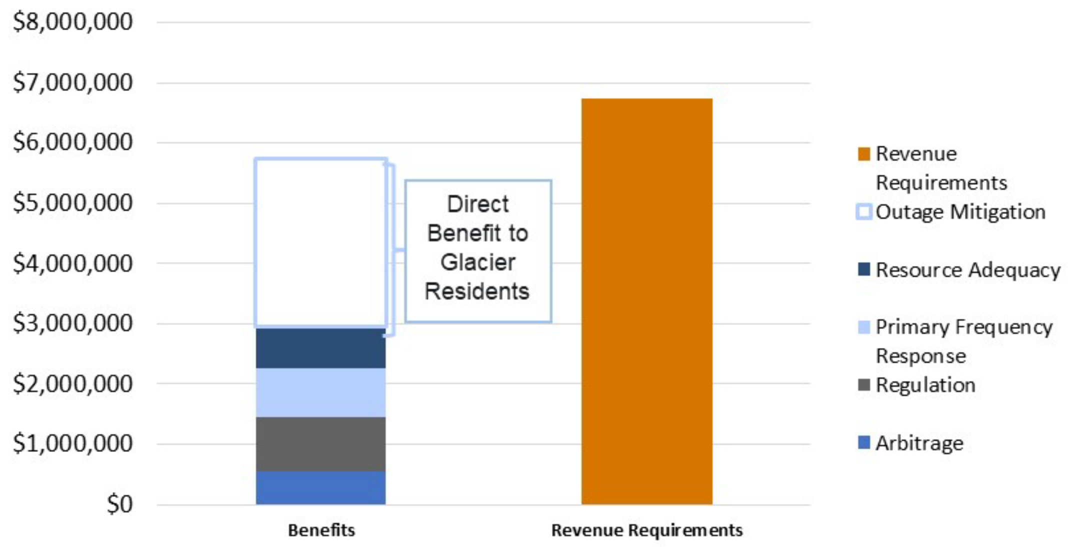
1. Puget Sound Energy Glacier Energy Storage Project
2. Orcas Power & Light Co-Op Community Solar and Energy Storage Project
3. Snohomish Public Utility District MESA 1 & MESA 2 Energy Storage Project
4. Snohomish Public Utility District MESA 3 Energy Storage Project
5. Seattle City Light Microgrid
6. Energy Northwest Battery and Solar Training Facility
7. Avista Turner Energy Storage Project
8. Avista Shared Energy Economy Model Project

Key features:

- Create the ability for a battery to “island” a remote community prone to frequent outages
- Combine battery storage, microgrid and solar technologies to leverage batteries in cars to store and use renewable energy
- Create a solar powered microgrid
- Combine battery storage and community solar to extend the life of an underwater electricity supply cable
- Create a battery and solar competency training facility in the Tri-Cities, WA
- Design a modeling approach for co-optimizing and stacking distributed energy resource (DER) benefits
- Develop a model for accurately predicting energy storage system performance

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, WA
- 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



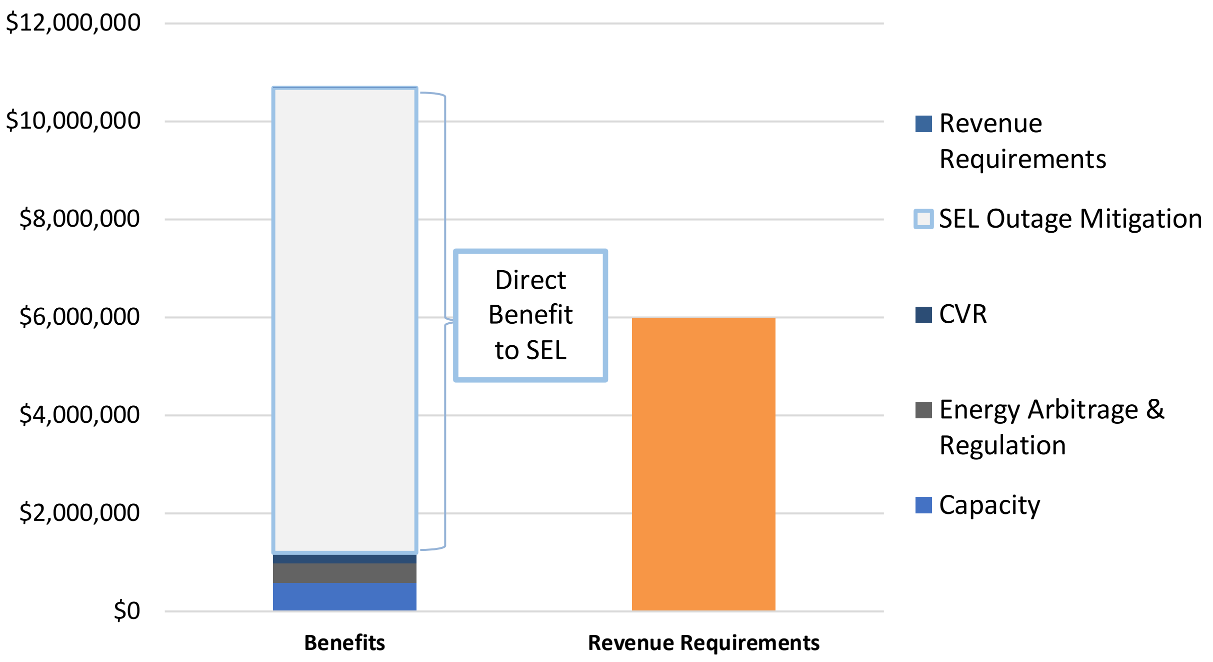
Element	Benefits	Revenue Requirements
Arbitrage	$ 550,816	
Regulation	$ 902,976	
Primary Frequency Response	$ 803,649	
Resource Adequacy	$ 695,292	
Outage Mitigation	$ 2,799,227	
Revenue Requirements		**$ 6,748,775**
	$ 5,260,262	

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.

RESULTS – AVISTA BENEFITS AND COSTS

Utility Perspective:

- Outage mitigation not included as a benefit
- $3.2 million CEF grant reduces project cost
- Highest benefit derived from capacity with just under $600k in 20-year PV benefits
- Total 20-year benefit value of ESS operations at $1.2 million in present value (PV) terms, while revenue requirements are $5.98 million
- Benefit-cost ratio of 0.20



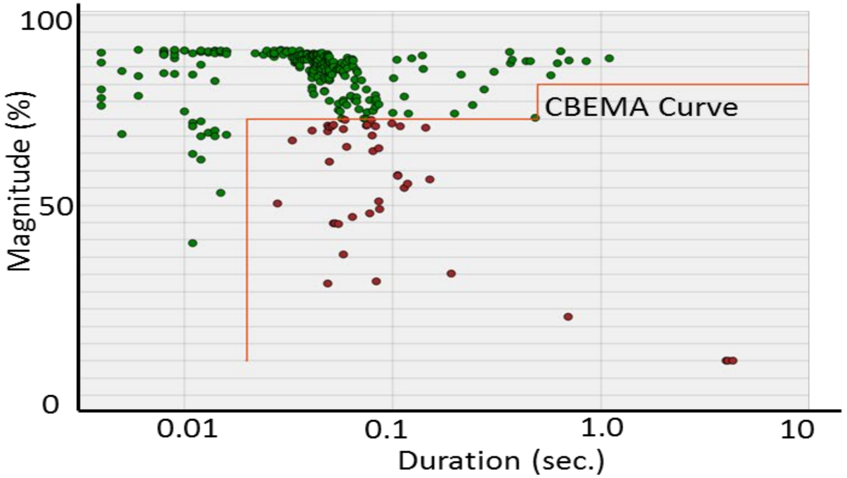
Outage Mitigation Included:

- Including SEL outage mitigation as a benefit increases total 20-year PV benefits by nearly $9.5 million
- BCR increases to 1.78 with this benefit included*

Element	Benefits	Revenue Requirements
Capacity	$ 599,762	
Energy Arbitrage & Regulation	$ 381,473	
CVR	$ 220,935	
SEL Outage Mitigation	$ 9,487,911	
Revenue Requirements		**$ 5,982,768**
	$ 10,690,081	

While the Avista Turner ESS demonstrated the capacity for significant value, it later became non-operational and was removed from the facility. The results presented here, therefore, represent the potential benefits that could have been derived had the battery operated as tested and remained in place for its entire usable life.

TURNER ENERGY STORAGE PROJECT – VOLTAGE SAG COMPENSATION

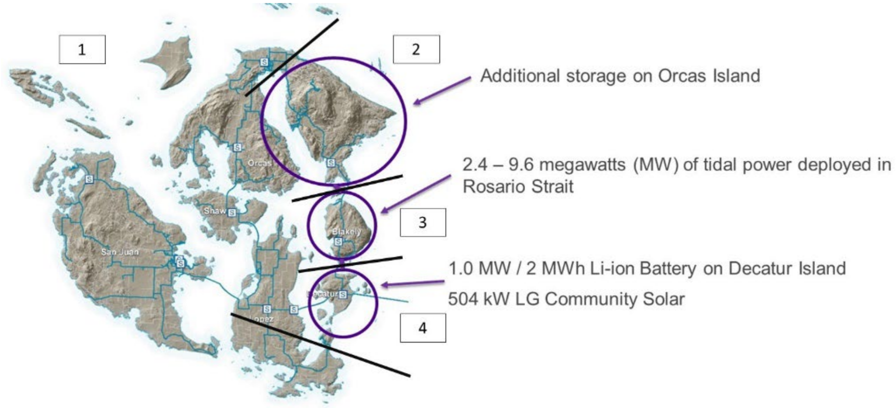


- Sustained voltage sags lead to production disruptions
- Pacific NW National Laboratory (PNNL) evaluated voltage data from 2014-2017 provided by Schweitzer Engineering Labs
- Applying the Computer Business Equipment Manufacturers (CBEMA) defined power quality curve, over 40 voltage sag events (<70% 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.

OPALCO MICROGRID STUDY PROJECT SYNOPSIS

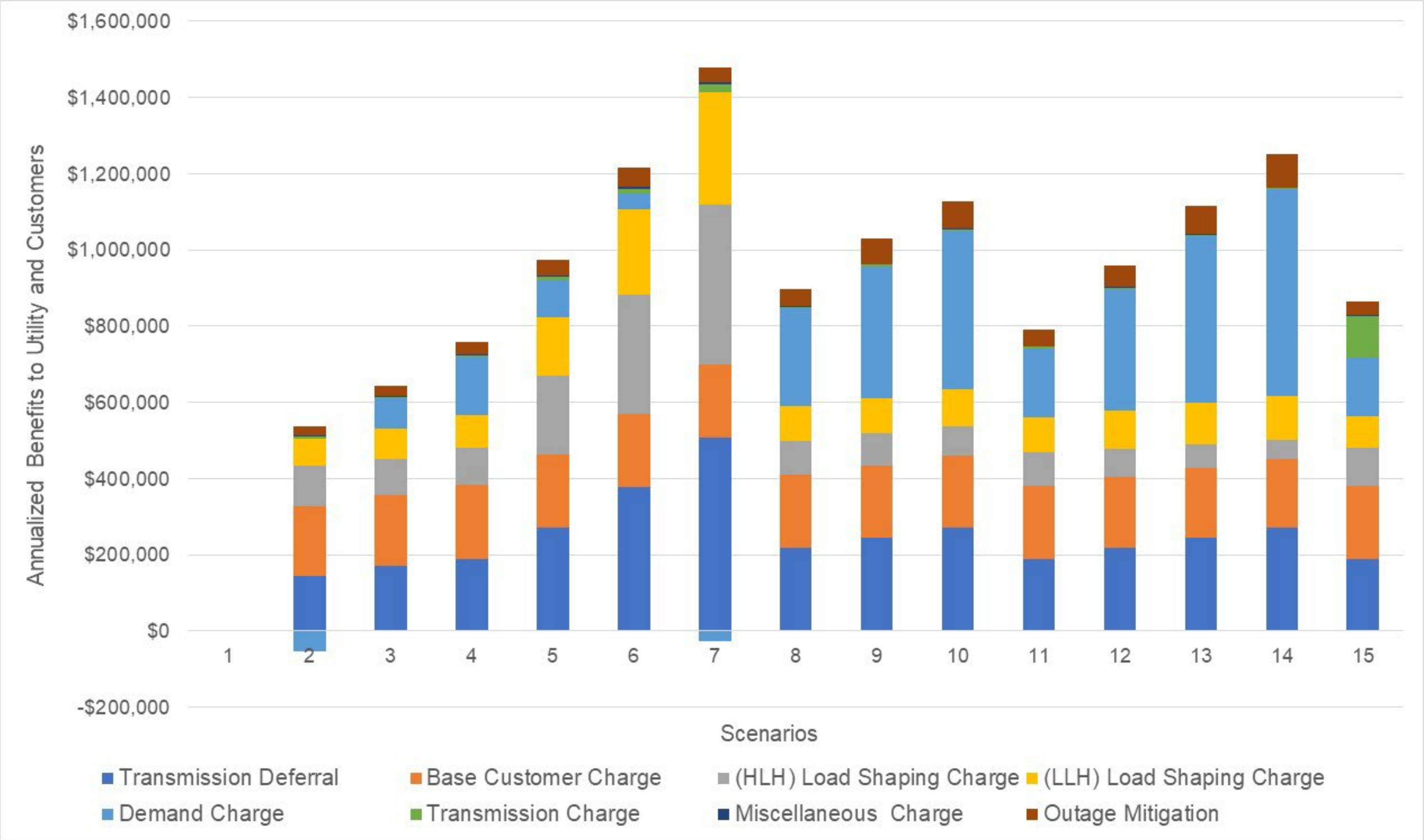
- To assess the technical and economic feasibility of tidal power in the Orcas Power and Light Co-op (OPALCO) network, Argonne National Laboratory (Argonne) employed an optimization model to evaluate several economic benefits associated with:
  - 2.4-9.6 megawatts (MW) of tidal power deployed in Rosario Strait
  - 1.0 MW / 2 MWh Li-ion BESS on Decatur Island
  - Additional battery storage on Orcas Island
  - 504 kW LG Community Solar (photovoltaic or PV) Array from Puget Sound Solar
- Scenarios
  - Tidal power in isolation,
  - Tidal power plus local storage, and
  - Tidal power plus PV and coordinated use of the Decatur Island BESS.



Outage Mitigation Zones and Assets

- Benefit Streams
  - Transmission deferral
  - Load shaping charge
  - Demand charge
  - Fixed customer charge
  - Transmission charge
  - Outage mitigation

OPALCO RESULTS



Source: Balducci, P., J. Kwon, V. Nwadiaru, R. Guerry, T. Neal, and B. Polagye. Rosario Strait Tidal Energy plus Energy Storage – Preliminary Economic Assessment. 2024. Available at https://publications.anl.gov/anlpubs/2024/01/186713.pdf.

Scenario
1. no DERs
2. Tidal power in isolation
3 . Tidal power plus local storage on Orcas Island
4. Add in Decatur solar and the Decatur BESS to Scenario 3
5. Use Scenario 4; 2X tidal power
6. Use Scenario 4; 3X tidal power
7. Use Scenario 4; 4X tidal power
8. Use Scenario 4; 2x Orcas ES Cap
9. Use Scenario 4; 3x Orcas ES Cap
10. Use Scenario 4; 4x Orcas ES Cap
11. Use Scenario 4; 1x Orcas ES Cap, 4 hr
12. Use Scenario 4; 2x Orcas ES Cap, 4 hr
13. Use Scenario 4; 3x Orcas ES Cap, 4 hr
14. Use Scenario 4; 4x Orcas ES Cap, 4 hr
15. Use Scenario 4 but no assets are DSRs

- Scenarios yield $480k to $1.5 million annually
  - Demand and transmission charge reductions of up to $542k and $111k, respectively, largely driven by BESS operations
  - Transmission deferral ($143k-$507k), fixed customer charges ($183-$194k), and load shaping charges ($167-$715k), largely driven by tidal energy production

WHAT WE HAVE LEARNED – NUMEROUS FACTORS DETERMINE AN ENERGY STORAGE SYSTEM'S VALUE PROPOSITION AND ABILITY TO PREDICT IT

Siting/Sizing Energy Storage	Ability to aid in the siting of energy storage systems by capturing/measuring location-specific benefits
Key Modeling Challenges	There are several key challenges associated with grid modeling, including price-taker vs. price-influencer modeling, perfect vs. imperfect foreknowledge of prices, and future climate conditions
Regional Variation	Differentiate benefits by region and market structures/rules
Utility Structure	Define benefits for different types of utilities (e.g., co-ops, utilities in organized markets, and vertically integrated investor-owned utilities operating in regulated markets)
Battery Characteristics	Accurately characterize battery performance, including round trip efficiency rates across varying SOCs and battery degradation caused by cycling

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