ENERGY STORAGE VALUATION FUNDAMENTALS AND OVERVIEW OF MODELING TECHNIQUES AND TOOLS

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HAWAII PUBLIC UTILITIES COMMISSION ENERGY STORAGE SYSTEMS WORKSHOPS
SESSION 4: ENERGY STORAGE VALUATION MODELING
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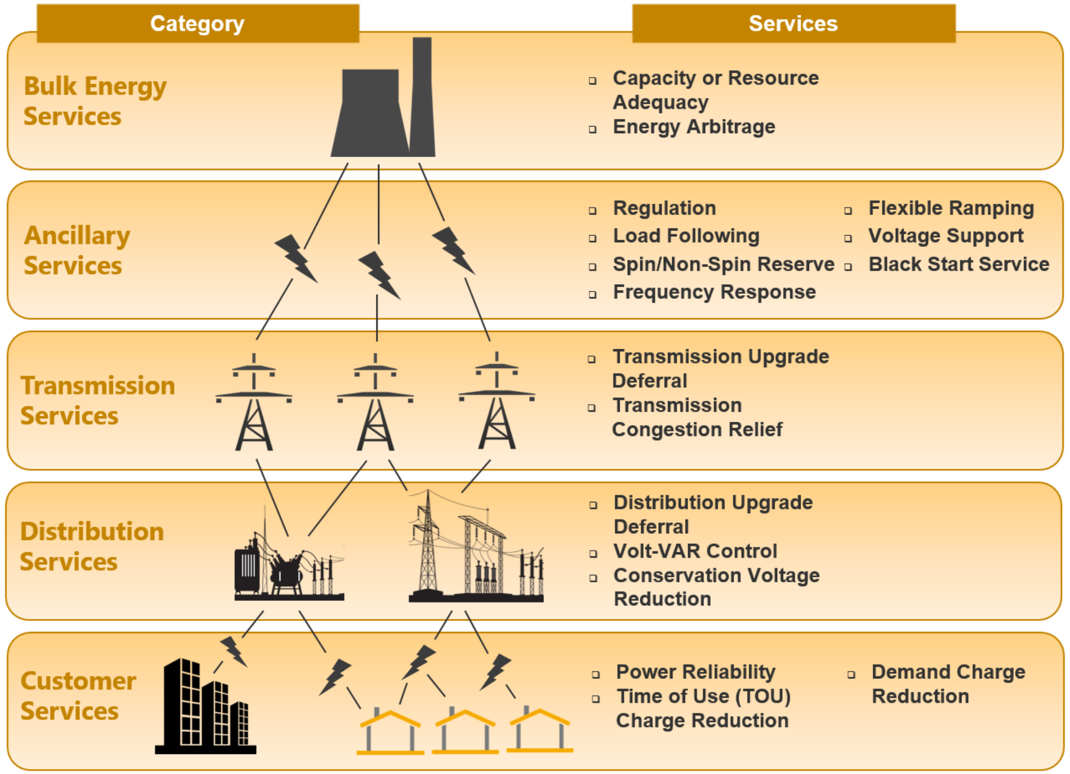
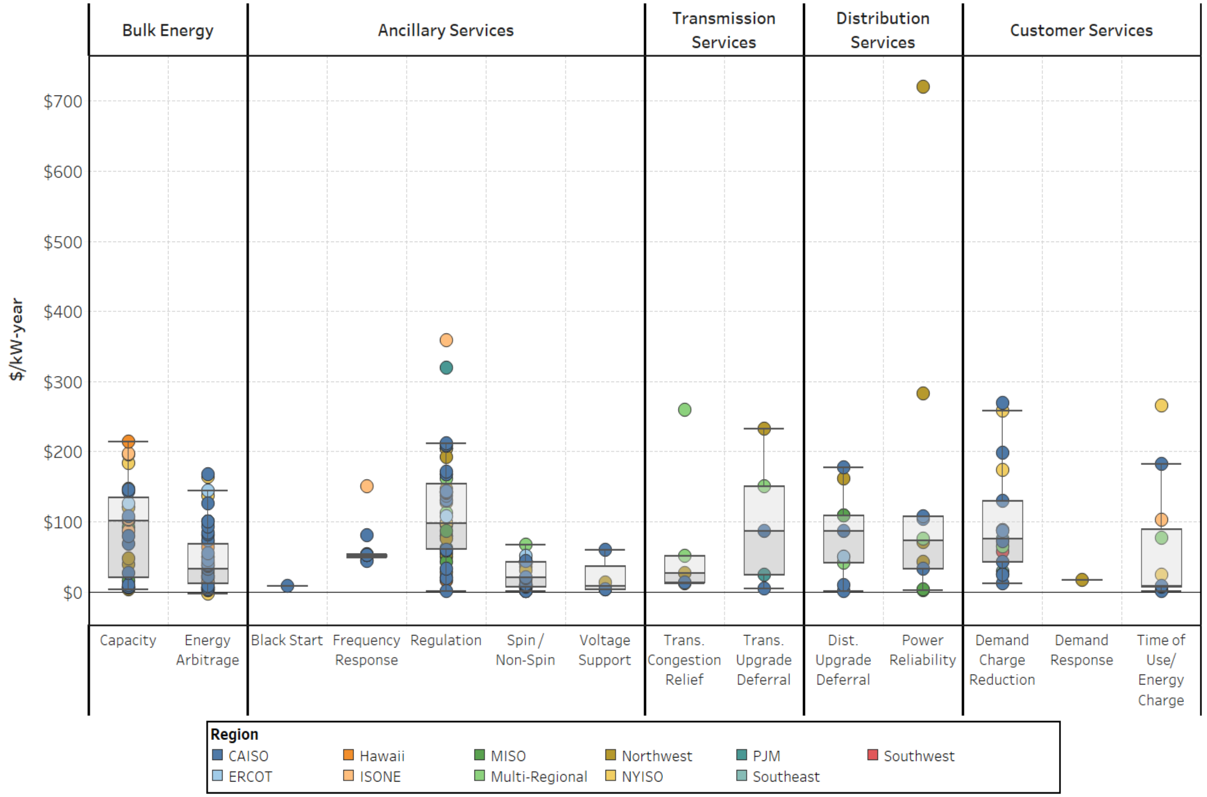
VALUATION TAXONOMY AND META-ANALYSIS RESULTS

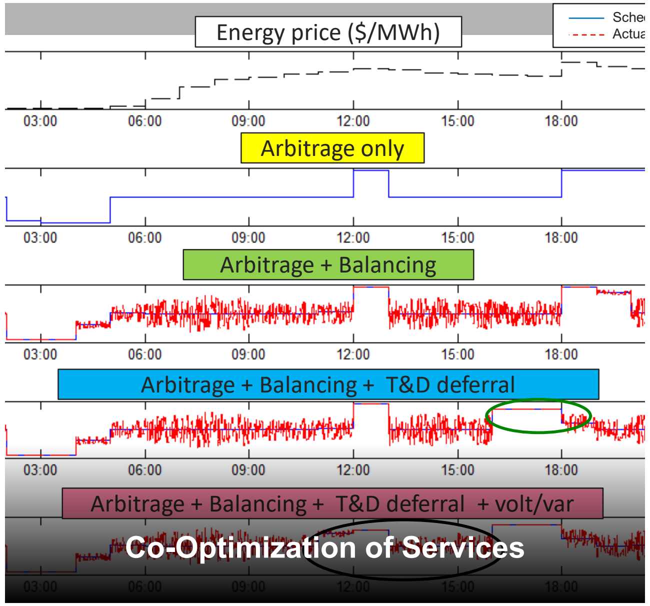




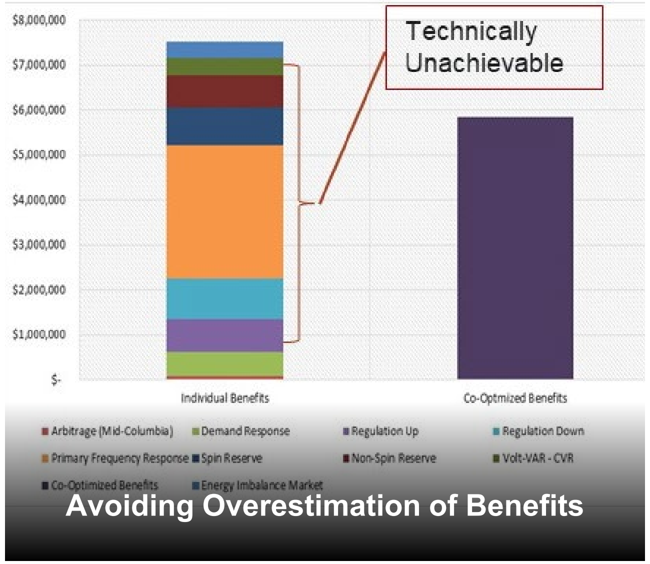
Source: Balducci, Patrick, Mongird, Kendall, and Weimar, Mark. Understanding the Value of Energy Storage for Power System Reliability and Resilience Applications. Germany: N. p., 2021. Web. https://doi.org/10.1007/s40518-021-00183-7.

CHALLENGES TO ACCURATELY ESTIMATING ECONOMIC BENEFITS

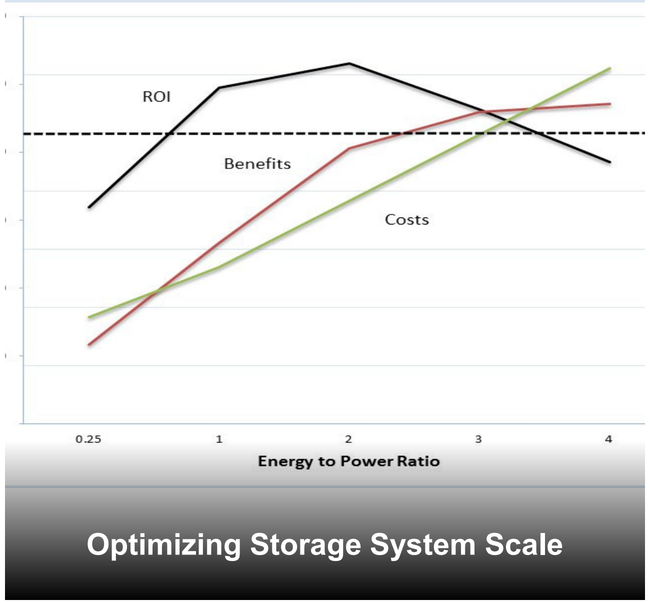
- Multidimensional competition for energy – not all services can be provided simultaneously and there exists intertemporal competition for energy
- Economic results are sensitive to sizing of energy storage system in terms of power and energy capacities
- Markets are complex and common practices of assuming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



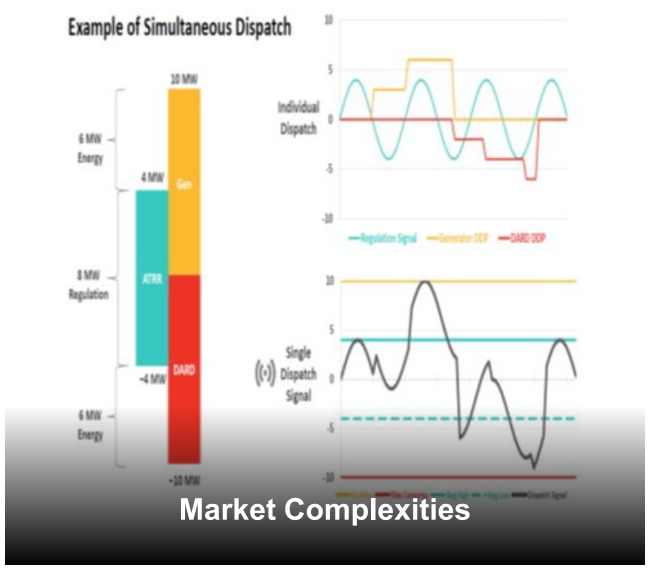
Co-Optimization of Services



Avoiding Overestimation of Benefits



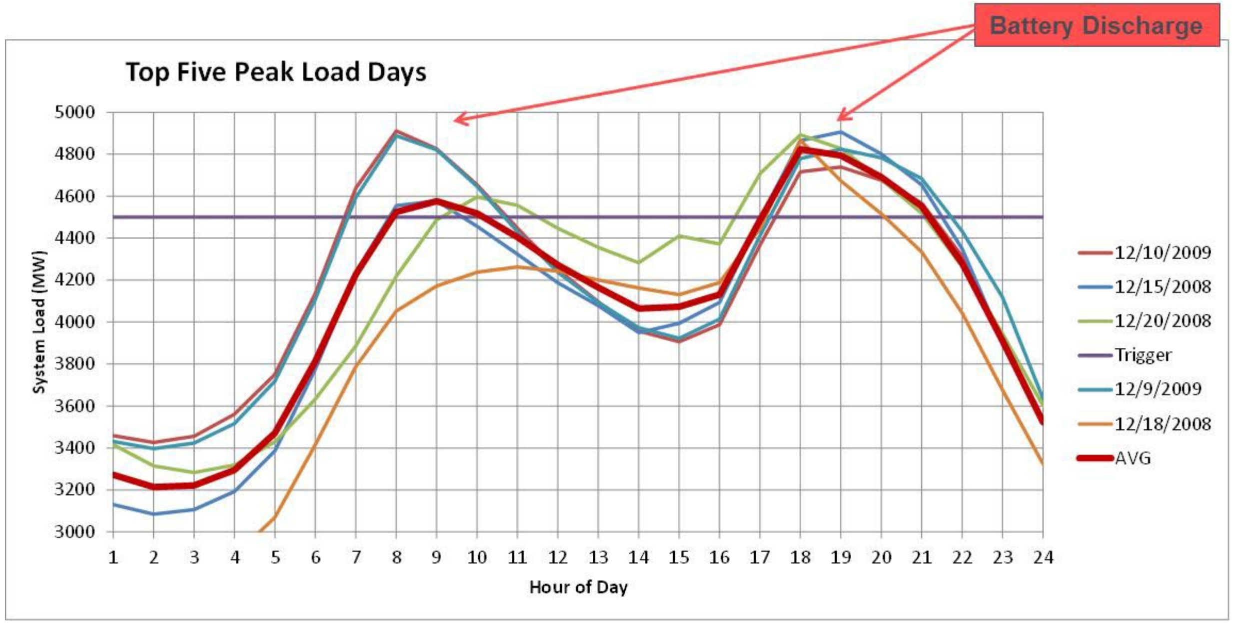
Optimizing Storage System Scale



Market Complexities

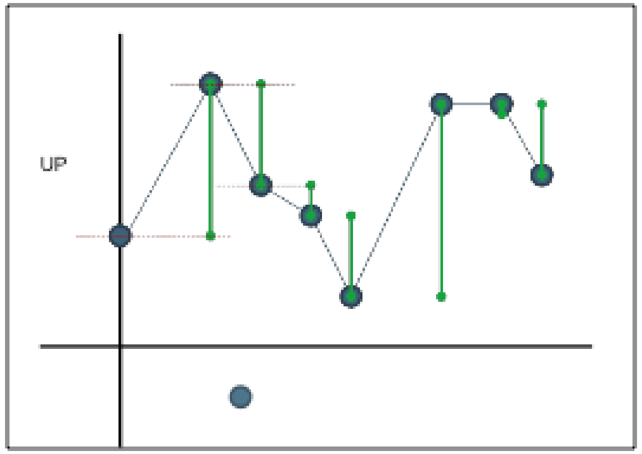
USE CASE EXAMPLE 1: CAPACITY / RESOURCE ADEQUACY

- Capacity markets have been established in regions throughout the United States with value based on forward auction results and demonstrated asset performance
- For regulated utilities, capacity value based on the incremental cost of next best alternative investment (e.g., peaking combustion turbine) with adjustments for:
  - energy and flexibility benefits of the alternative asset, and
  - the incremental capacity equivalent of energy storage.



USE CASE EXAMPLE 2 - FREQUENCY REGULATION

- Second-by-second adjustment in output power to maintain grid frequency
- Follow automatic generation control (AGC) signal
- Value defined by market prices or avoiding costs of operating generators



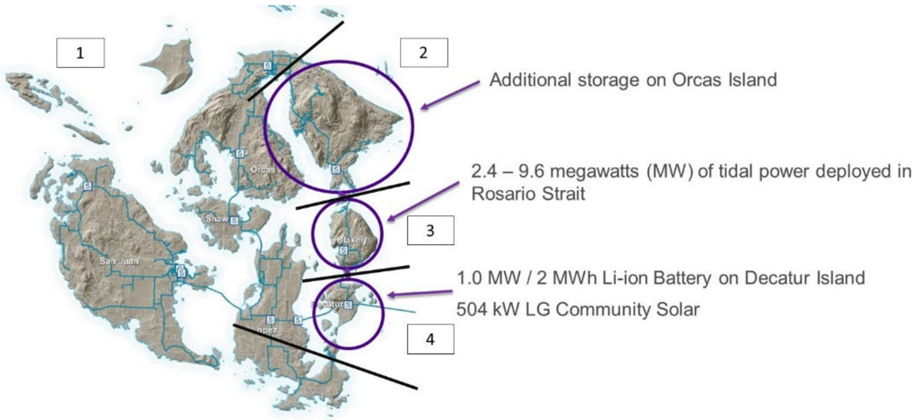
Mileage definition is the sum of all green bars in 15 min. intervals

Capacity Payment = Regulation Capacity Clearing Price
Service Payment = Mileage (AGC Signal Basis)
Performance = Regulation Service Performance Score

Key Lesson: Performance of battery storage in providing frequency regulation is exceptionally high. Market prices can be driven downward as a result, undermining the profit potential to storage operators in the process. Also, ancillary services markets are very shallow, limiting revenue potential.

USE CASE EXAMPLE 3: OUTAGE MITIGATION

- Outage data
  - Outage data obtained from utility
  - Average annual number of outages determined
  - Outage start time and duration
- Customer and load information
  - Number of customers affected by outages
  - Customer outages sorted into customer classes
  - Load determined using 15-minute SCADA information
- Scenarios
  - Perfect foreknowledge
  - No foreknowledge



Orcas Power and Light Tidal, Solar plus Storage

	Cost per Outage ($2008)*		
Duration	Residential	Small C + I	Large C + I
Momentary	$2	$210	$7,331
Less than 1 hr	$4	$738	$16,347
2-4 hours	$7	$3,236	$40,297
8-12 hours	$12	$3,996	$46,227

Source: Sullivan, M., Mercurio, M., and J. Schellenberg. 2009. "Estimated Value of Service Reliability for Electric Utility Customers in the United States." Prepared for U.S. Department of Energy by Lawrence Berkeley National Laboratory. Berkeley, CA.

Interruption Cost Estimates

USE CASE EXAMPLE 4: TRANSMISSION AND DISTRIBUTION DEFERRAL

Key Lesson: T&D deferral values are highly site- and condition-specific.

- Energy storage used to defer investment; impact of deferment measured in present value (PV) terms
- Net present value of deferring a $1 million investment for one year estimated at $90,000 or $10,400 annually over economic life of battery

PV = FV / (1+i)^n

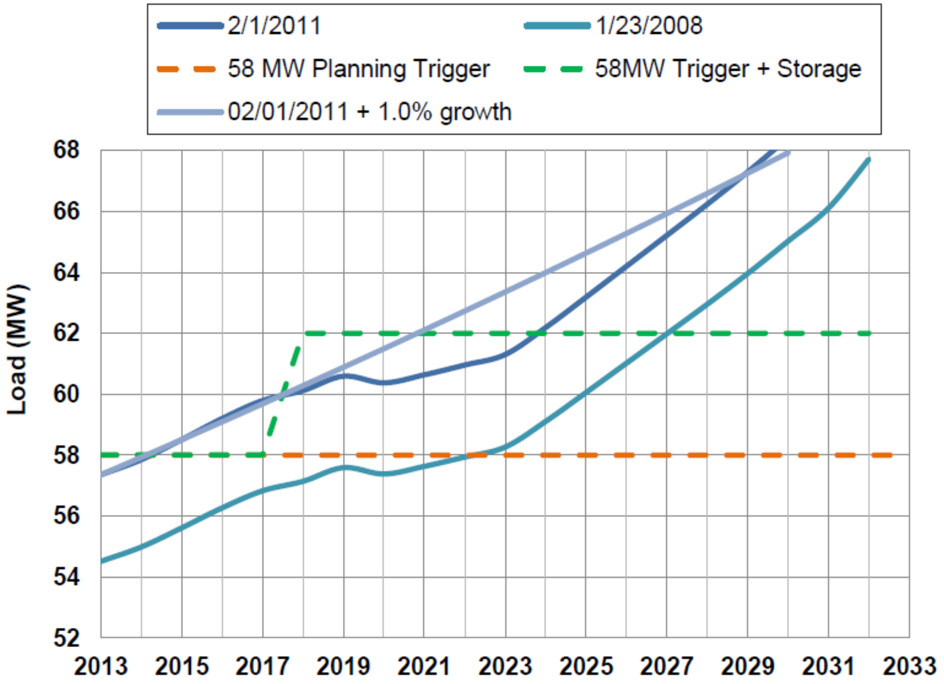
PV = Present value

FV = Future value

i = Cost of capital

n = Number of years

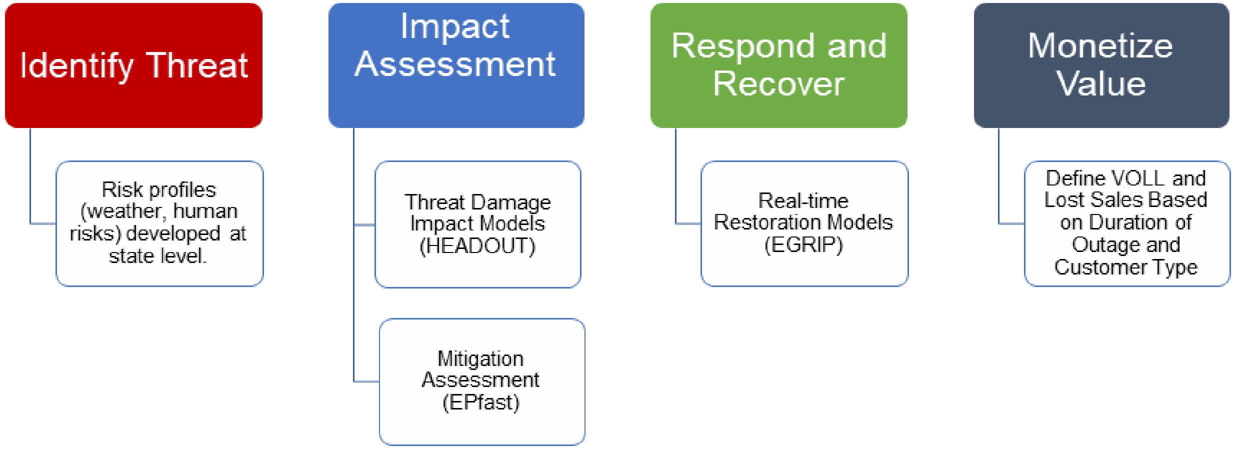
Assuming an 8% cost of capital (discount rate) and 3% cost inflation, distribution deferral of six years for a $10 million substation would be valued at $2.5 million based on calculation below:
*PV = $10 million*1.03^6 / (1+.08)^6 = $7.5 million.*



VALUING RESILIENCE

Key Lesson: Resilience is rarely valued and there is no consensus on the best approach.

- 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



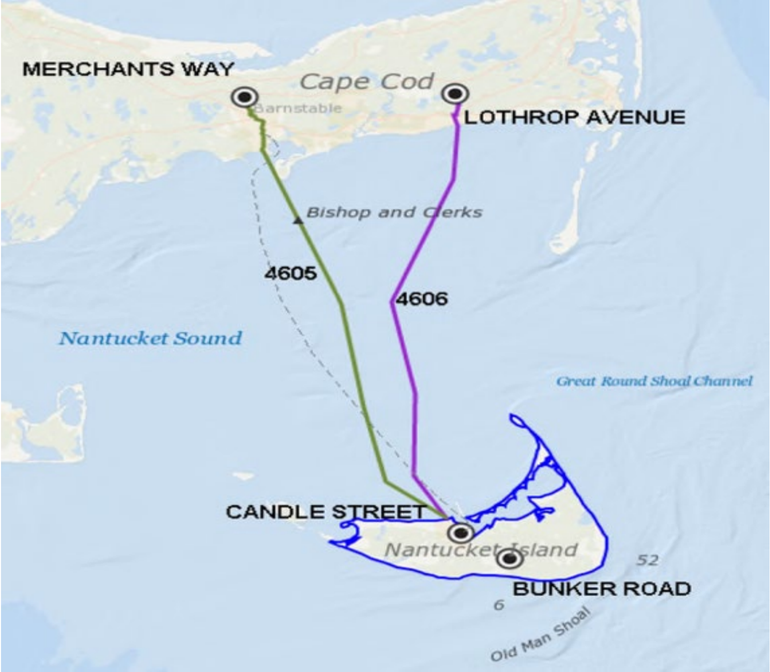
Argonne Suite of Tools for Resilience Modeling and Planning

- Resilience value can be embedded in other value streams, including transmission deferral, voltage sag compensation, and outage mitigation
- We propose using multi-hazard risk analysis that relies on expected value calculations based on probabilistic analysis – annual risk premium

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 replaced 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

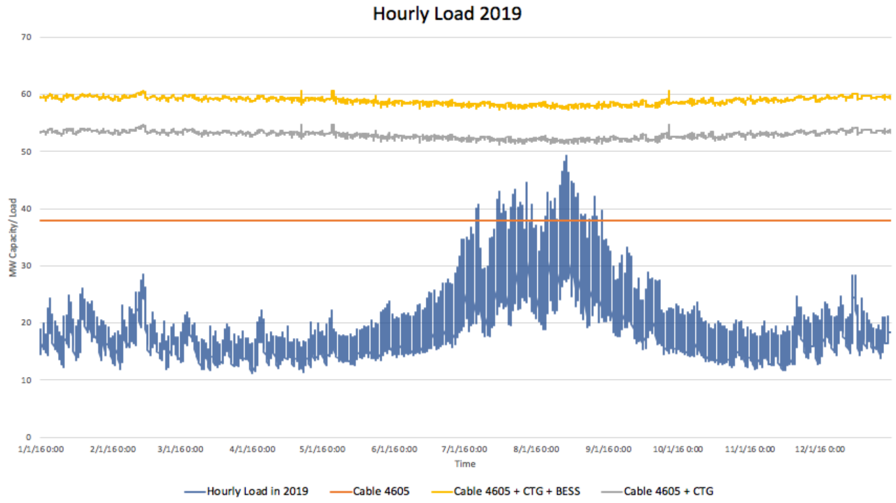


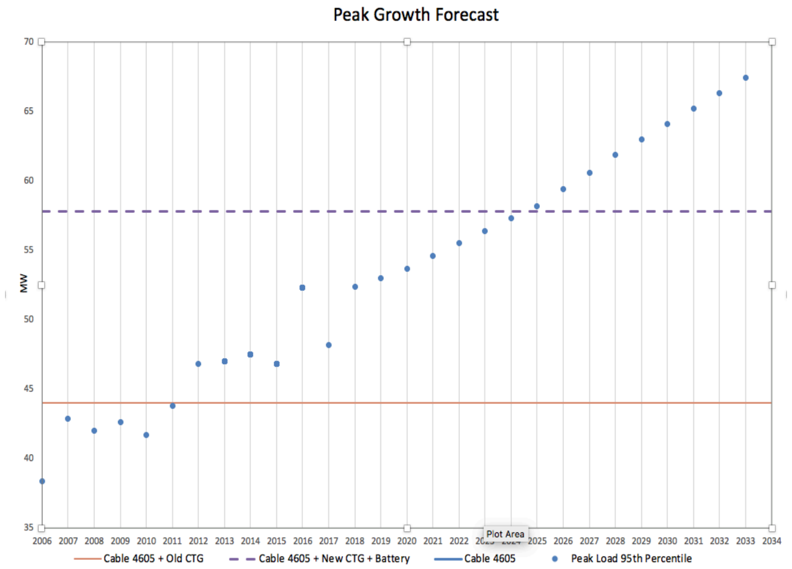
Nantucket Supply Cables

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

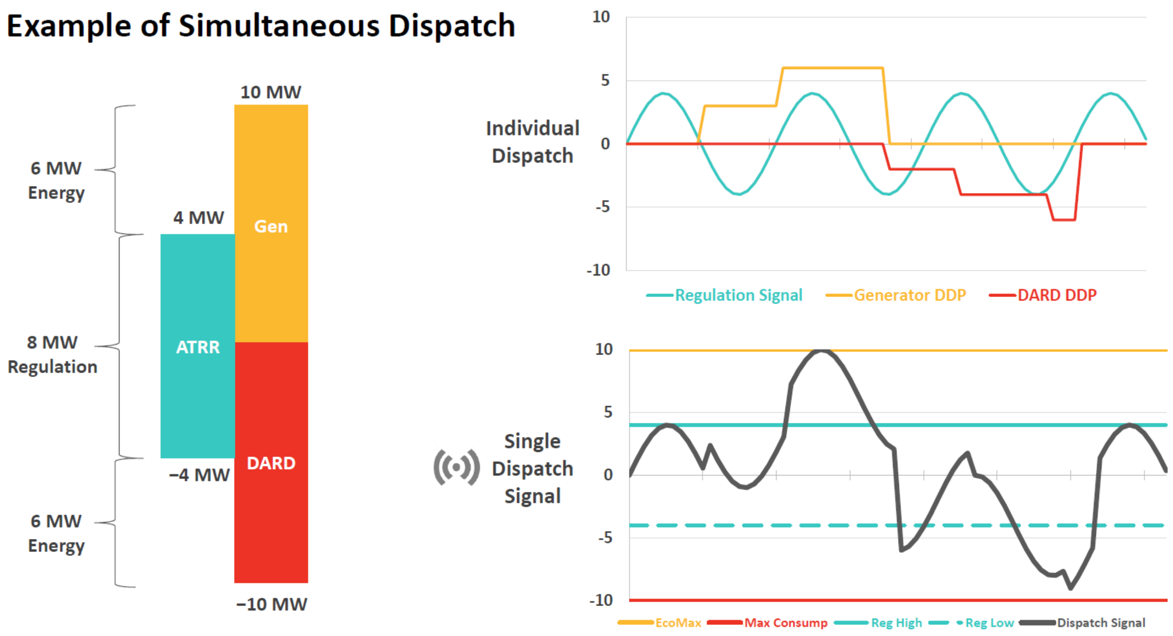
- The research team performed an extensive load analysis in order to define the n-1 contingency window and estimate the number of deferral years at 13
- Outage mitigation evaluated using historic outages and distribution system model
- Value of local operations ($122 million) exceeds the $93.3 million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





BENEFITS OF MARKET OPERATIONS

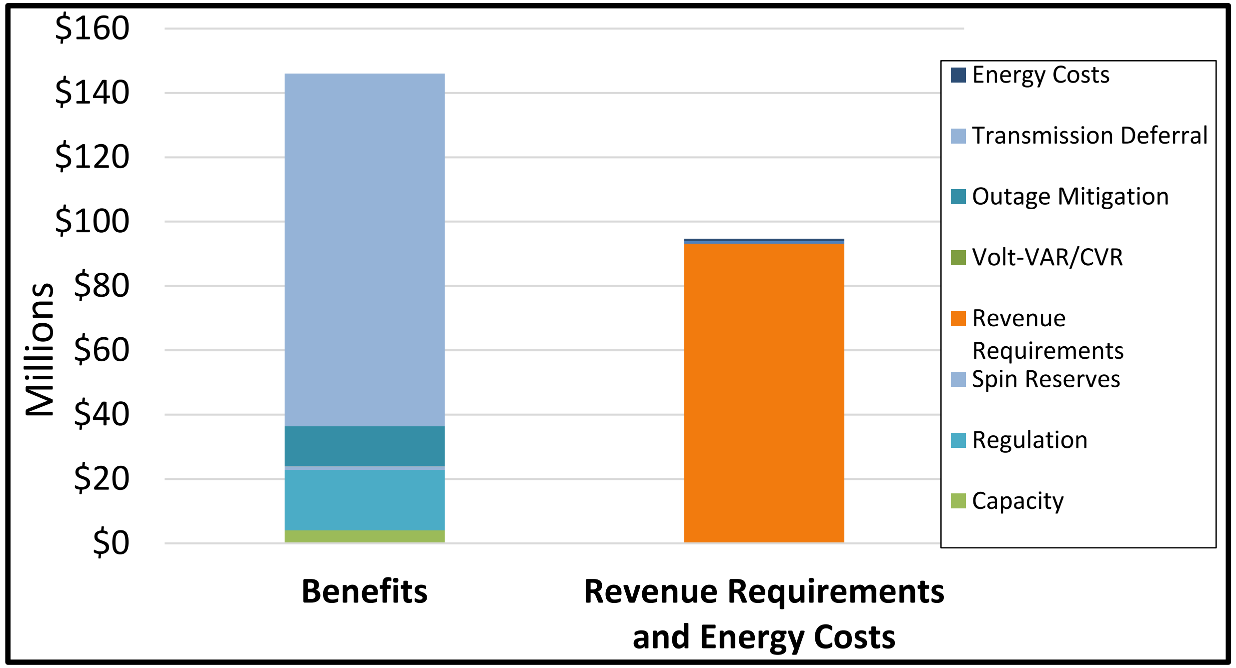
- Nantucket BESS modeled as a continuous storage facility
- BESS bid into markets using predicted prices – i.e., imperfect foresight
- Regulation follows energy neutral AGC signal with a performance score of 95%
- Market benefits estimated at $24.0 million over life of BESS
    - Regulation provides $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 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



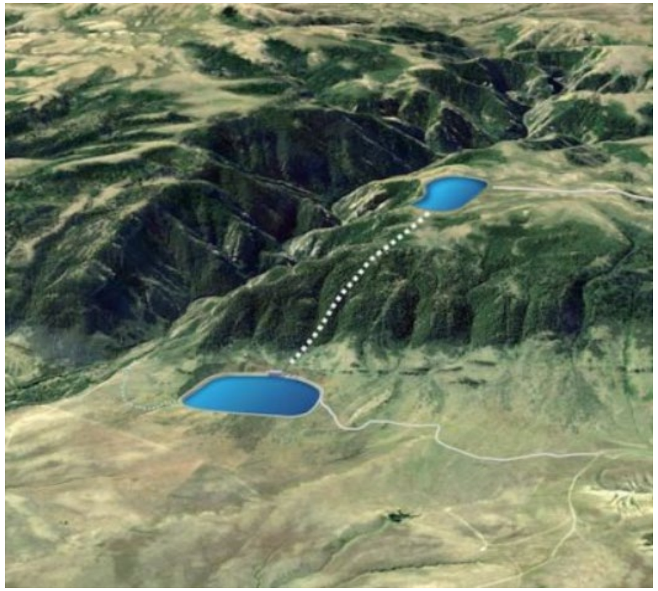
Benefits of Local and Market Operations (Base Case) vs. Revenue Requirements

PSH VALUATION GUIDEBOOK TEST REPORTS: COLLABORATION WITH TWO INDUSTRY PARTNERS

Absaroka Energy

Banner Mountain PSH

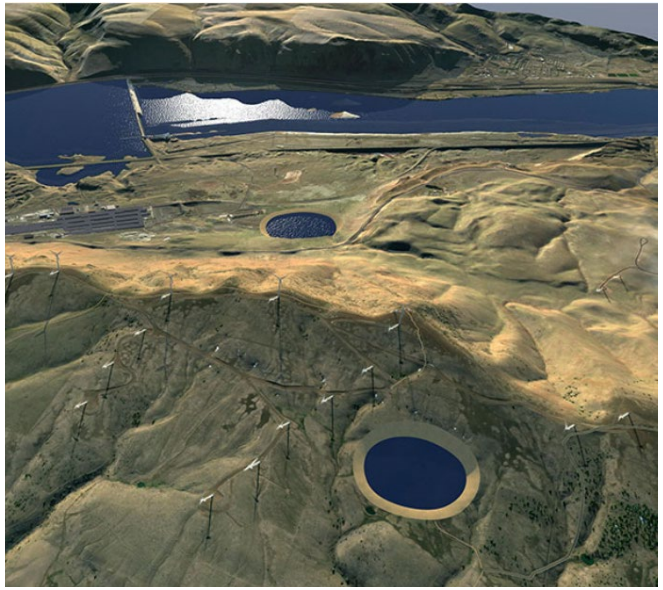
- 400 MW, quaternary technology
- Closed loop
- Site near Casper, WY



CIP & Rye Development

Goldendale Energy Storage Project

- 1,200 MW, adjustable speed technology
- Closed loop
- Site just north of OR/WA border



CIP = Copenhagen Infrastructure Partners

TECHNOECONOMIC STUDY COORDINATION AND MODELING FLOW

Capacity Expansion

ANL:

- Using AURORA
- Focus on 2028/2038
- Scenarios
  - Baseline
  - With PSH
  - With PSH and low battery costs
  - With high NG prices
  - With aggressive carbon reduction
- Generation builds passed on to NREL

Production Cost Modeling

NREL:

- Using PLEXOS
- Results provided to INL and PNNL
- Scenarios – Same as Capacity Expansion
  - Plus sensitivities
- Generator Status and generation provided to INL and PNNL for Power Flow Model
- LMPs and Congestion cost provided PNNL for transmission deferrals

Power Stability Analysis

INL:

- Using PSSE
- Analyzing power stability and voltage support

Transmission Analysis

PNNL:

- Using PSSE and GAMS
- Analyzing and valuing transmission deferrals and congestion relief

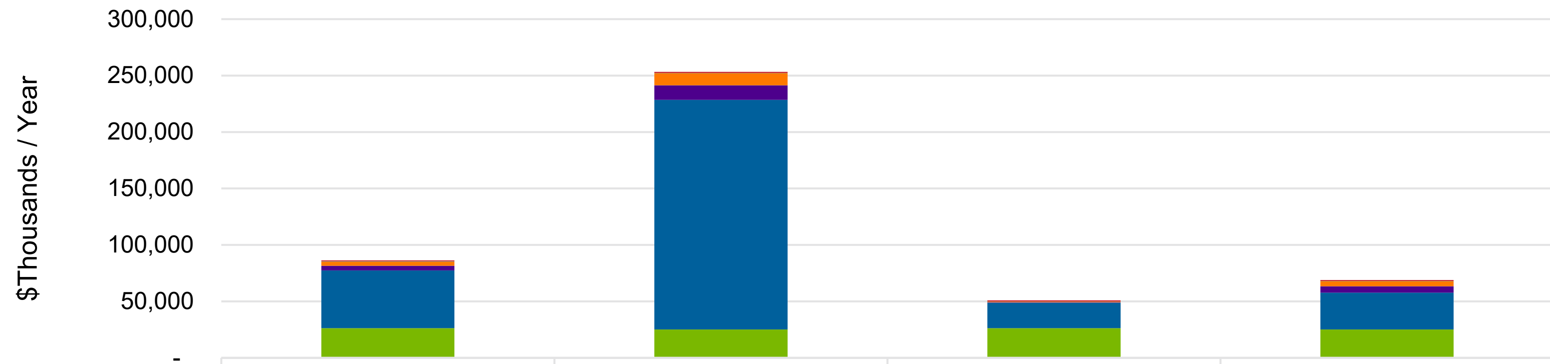
KEY FINANCIAL PARAMETERS

Key Financial Data Requirements	Goldendale	Banner Mountain
Project development period (years)	5	10
CBA period (years)	50	50
Plant economic life (years)	100	50
Total cost	$2.8 billion	$1.12 billion
Amount financed	70%	70%
Year of financial closure on loans (when funds are available and interest starts to accrue)	As required.	As required.
Repayment period (years)	30	30
Interest rate on debt financing (%)	3.25%	4%
Type of payment schedules	Even payments.	Even payments.
Weighted average cost of capital for sponsor - discount rate for owner-operator (%)	6.98%	6.98%
Federal tax rate (%)	21%	21%
State public utility tax rate (%)	3.8734%	0%
Recurring capital investment	$0	$100 million in Year 30
Annual O&M costs	$15 million	$6 million
Escalation rate for value of service and capital/O&M (%)	2%	2%
Insurance cost (annual as % of capital investment) (%)	0.10%	0.20%
Property tax and other cost rates (%)	.75%	0.01%
Expenditure pattern during construction period	8%, 31%, 31%, 25%, 5%	$0.5, $2, $2, $5, $5, $465, $180, $180, $180, $100.5 (Millions)
Non-depreciable investment costs	$75 million	$11.5 million

BANNER MOUNTAIN RESULTS FOR OWNER-OPERATOR ANALYSIS

- Annual estimated revenue ranges from $50.9 million (DA-baseline) or $127/kW-year to $253.3 million (RT-high renewables) or $633/kW-year
- Vast majority of revenue tied to capacity and energy (90% of base case)
- Unserved energy and other societal benefits excluded
- RT and high renewable cases drive benefits upward
- Transmission deferral, transmission congestion relief, and voltage support value eliminated

Owner/Operator Benefits



	RT - Baseline	RT - High Renewables	DA - Baseline	DA - High Renewables
Unserved Energy	-	-	-	-
Transmission Congestion Relief	-	-	-	-
Transmission Deferral	-	-	-	-
Voltage Regulation	-	-	-	-
Primary Frequency	960	960	960	960
Black Start	152	152	152	152
Frequency Regulation	3,761	10,750	600	4,501
Spin	4,124	13,014	481	5,606
Generation/Arbitrage	51,210	203,350	22,560	32,640
Capacity	26,184	25,100	26,184	25,100

Annual revenue to owner-operator for Banner Mountain PSH.

BANNER MOUNTAIN BCA RESULTS

System Analysis Results

Key Financial Data Requirements	RT Baseline	RT-High Renewables	DA-Baseline	DA-High Renewables
NPV (end-of-the-year-method)	$(184,661,570)	$290,733,699	$(505,794,685)	$(143,993,215)
NPV (mid-year method)	$(190,997,560)	$300,709,169	$(523,149,191)	$(148,933,819)
Benefit-cost Ratio	0.76	1.38	0.33	0.81
Internal Rate of Return	5.2%	9.4%	1.9%	5.6%
Discounted Payback Period (years)	N/A	23	N/A	N/A

Owner-Operator Results

Key Financial Data Requirements	RT Baseline	RT-High Renewables	DA-Baseline	DA-High Renewables
NPV (end-of-the-year-method)	$184,934,365	$2,588,855,940	$(337,287,745)	$(66,092,447)
NPV (mid-year method)	$191,279,715	$2,677,683,121	$(348,860,548)	$68,360,169)
Benefit-cost Ratio	1.24	4.41	0.56	0.91
Internal Rate of Return	8.6%	22.4%	3.7%	6.4%
Discounted Payback Period (years)	31	11	N/A	N/A

ENERGY STORAGE VALUATION TOOLS

Name of Tool	Developer	Summary	Online Access
Energy Storage Evaluation Tool (ESET)	Pacific Northwest National Laboratory	ESET relies on user input time-series values and energy signals by use case to determine the optimal schedule and value of storage. It can be used for utility-owned and behind-the-meter (BTM) storage and can optimally scale the BESS.	https://availabletechnologies.pnnl.gov/technology.asp?id=413
DER-VET	Electric Power Research Institute	DER-VET facilitates the understanding of where to place and install energy storage, the optimum size as well as controls options. DER-VET implements dispatch optimization with sensitivity analysis to assist in planning energy storage project development by enabling rapid analysis of scenarios with different storage sizes, costs, and value streams.	https://www.storagevet.com/
QuESt	Sandia National Laboratories	QuESt is an open source, Python-based application suite for energy storage simulation and analysis. It includes market-focused and BTM tools that include detailed market prices and retail tariff rates from across the US.	https://energy.sandia.gov/tag/quest/
REopt Lite	National Renewable Energy Laboratory	REopt Lite is a design and analysis tool that can be used to evaluate the economic viability of grid-connected photovoltaics (PV), wind, and energy storage for BTM installations. It identifies the system sizes and battery dispatch strategy to minimize energy costs. It also estimates how long a system can sustain critical load during a grid outage.	https://reopt.nrel.gov/

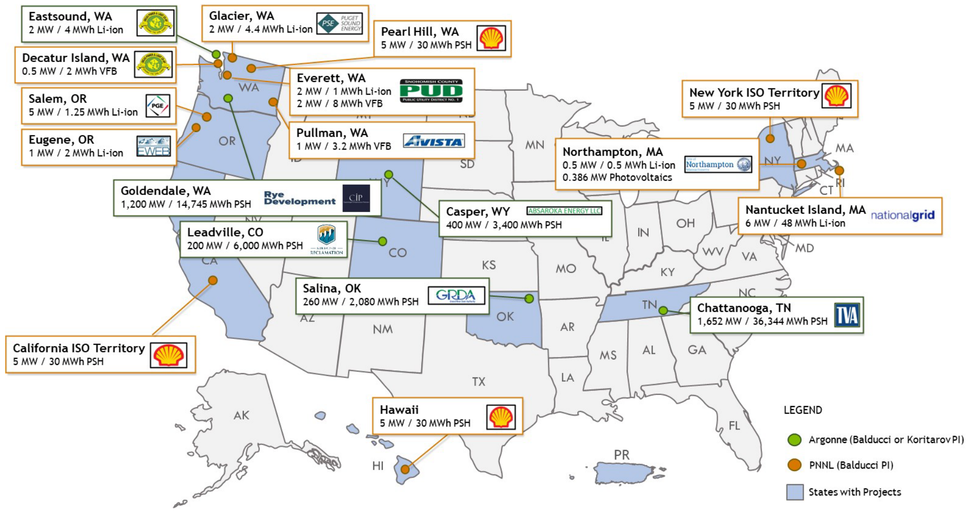
ENERGY STORAGE USE CASES

Category	Use Case	ESET	DER-VET	QuESt	REOpt Lite
Bulk Energy	Energy Arbitrage	✓	✓	✓	✓
	Capacity	✓	✓		
Ancillary Services	Frequency Regulation	✓	✓	✓	✓
	Spin / Non-Spin	✓	✓	✓	✓
Transmission	Upgrade Deferral	✓	✓		
	Congestion Relief		✓		
Distribution	Upgrade Deferral	✓	✓		
	Volt-VAR	✓	✓		
Customer Energy Management	Power Reliability	✓	✓		✓
	TOU Charge Management	✓	✓	✓	✓
	Demand Charge Management	✓	✓	✓	✓

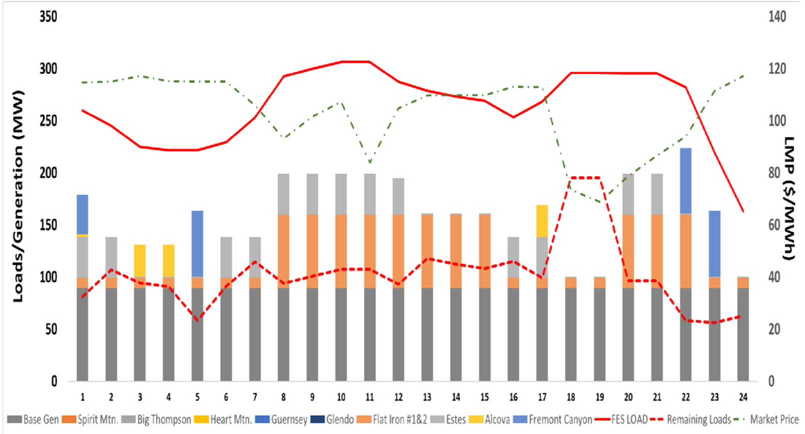
ENERGY STORAGE SCHEDULING TECHNIQUES

Use Case	ESET	DER-VET	QuESt	REOpt Lite
Optimization Across All Services	✓	✓	✓	✓
Optimization for Subset of Services	✓	✓		
Heuristic or Hierarchical Dispatch		✓	✓	✓
Imperfect Foresight	✓	✓		
Optimization Horizon	Rolling 24 hour	Flexible	One Year	One Year
Optimizes Customer and Utility Use Cases Concurrently	✓	✓		✓
User Defined Scheduling (No Optimization)	✓	✓		

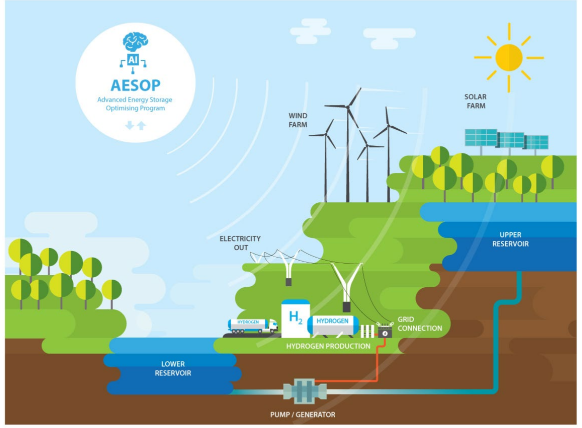
NOVEL ENERGY STORAGE DEPLOYMENTS



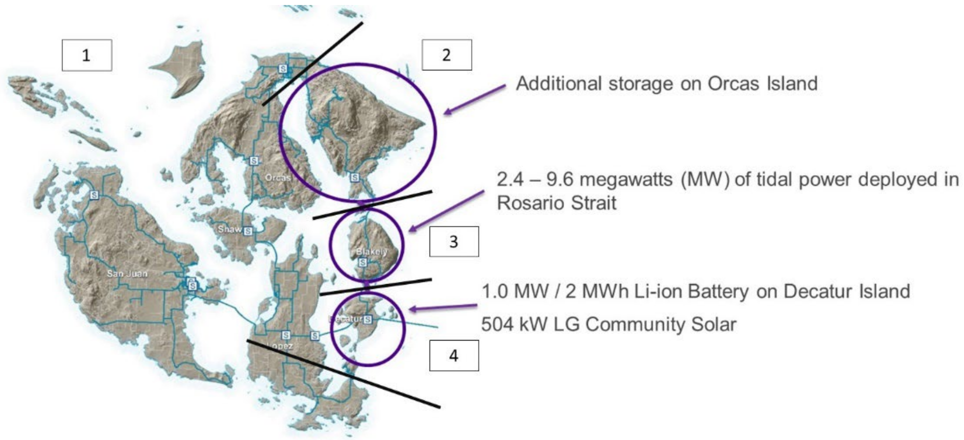
Recent Energy Storage Technoeconomic Assessments



Mt. Elbert Pumped Storage Hydro



Sunshine Hydro



Orcas Power and Light Tidal, Solar plus Storage

WHAT WE HAVE LEARNED – NUMEROUS FACTORS DETERMINE AN ENERGY STORAGE SYSTEM'S VALUE PROPOSITION

Siting/Sizing Energy Storage	Ability to aid in the siting of energy storage systems by capturing/measuring location-specific benefits
Broad Set of Use Cases	Measure benefits associated with bulk energy, transmission-level, ancillary service, distribution-level, and customer benefits at sub-hourly level
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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Kate Anderson, National Renewable Energy Laboratory

Di Wu, Pacific Northwest National Laboratory

U.S. DEPARTMENT OF ENERGY

Mission – to ensure a resilient, reliable, and flexible electricity system through research, partnerships, facilitation, modeling and analytics, and emergency preparedness.

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

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