ENERGY STORAGE ECONOMICS MODELING FOR VALUE STACKING

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WISCONSIN PUBLIC SERVICE COMMISSION/US. DEPARTMENT OF ENERGY ENERGY STORAGE WEBINAR SERIES: ENERGY STORAGE ECONOMICS

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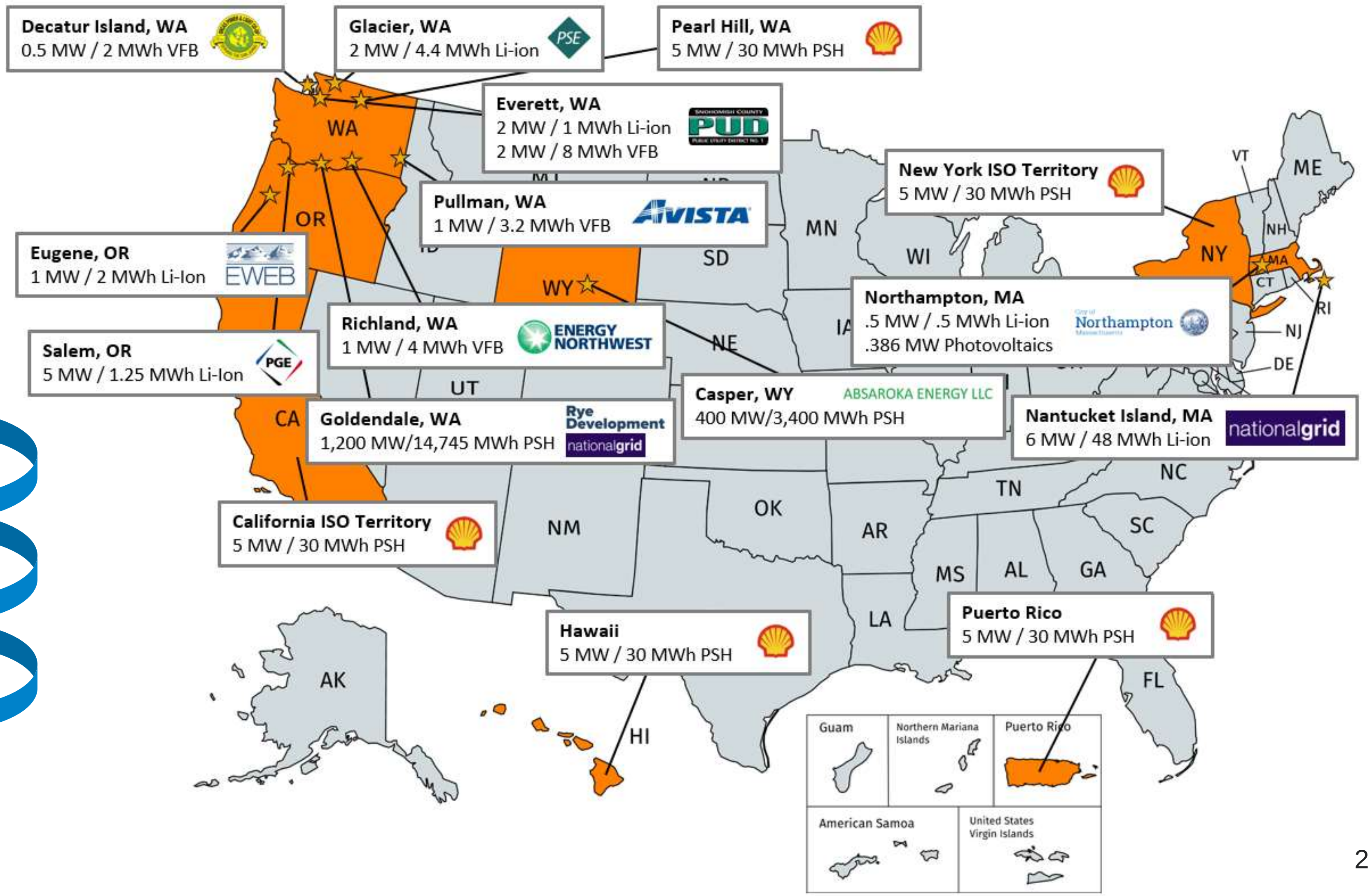
RECENT ENERGY STORAGE ASSESSMENTS

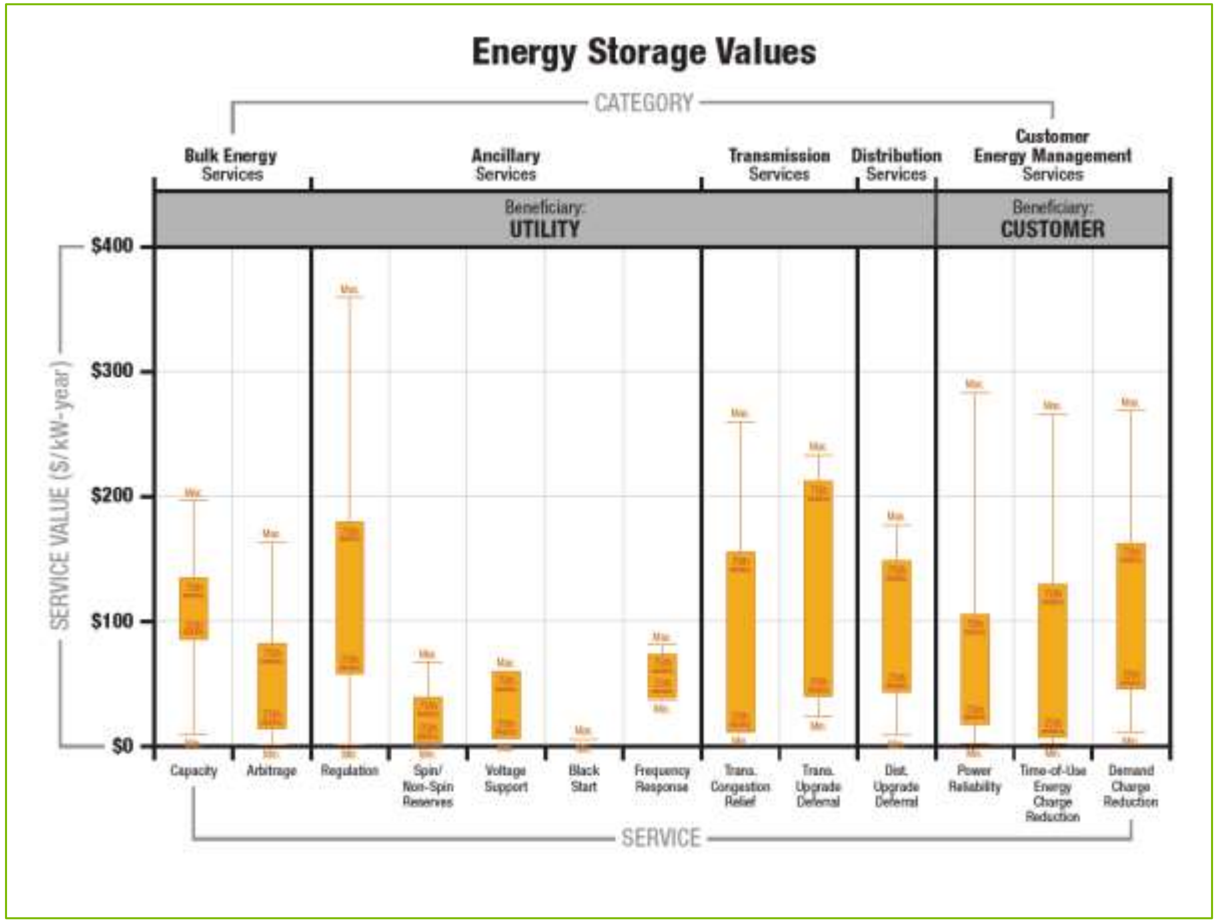
1,626 MW 18,248 MWh at 16 Sites

Analytics Task-flow

1. Preliminary Economic Analysis and Identification of Use Cases
2. Baseline Testing to Evaluate Ratings etc.
3. Use Case Testing and Analysis
4. Final Techno-Economic Analysis



ENERGY STORAGE HOLDS TREMENDOUS VALUE

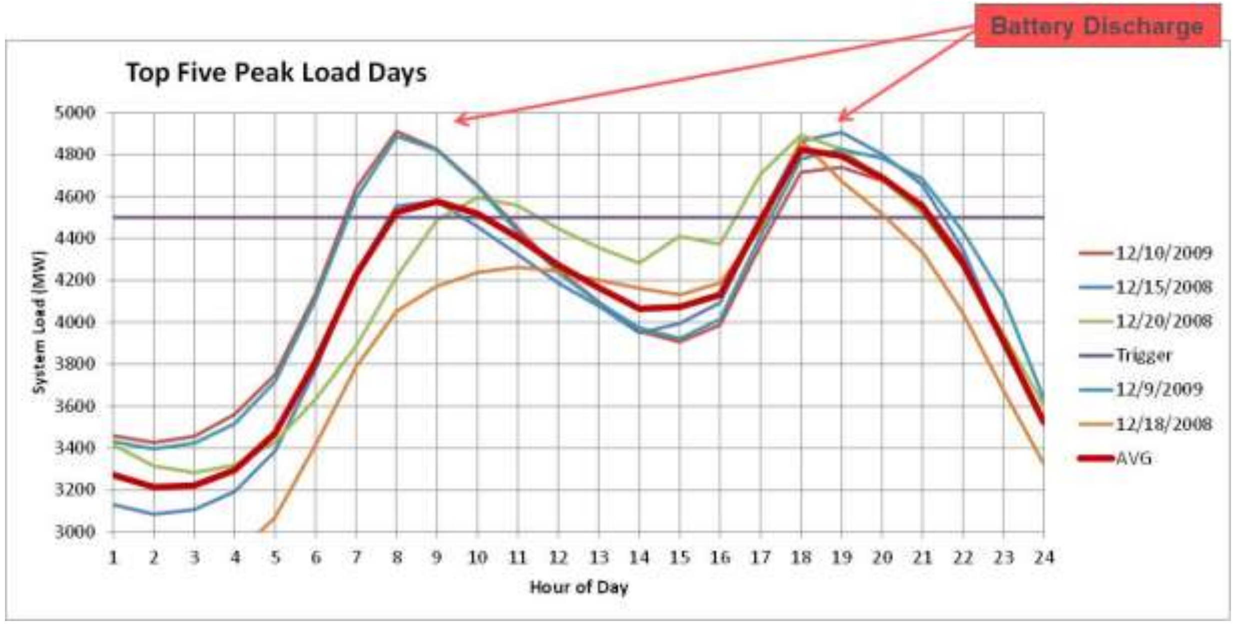


Key Lesson: The value of distributed energy resources (DERs) accrues at multiple levels of the electric grid, and there are no existing tools with all the required features to fully capture these values.

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.

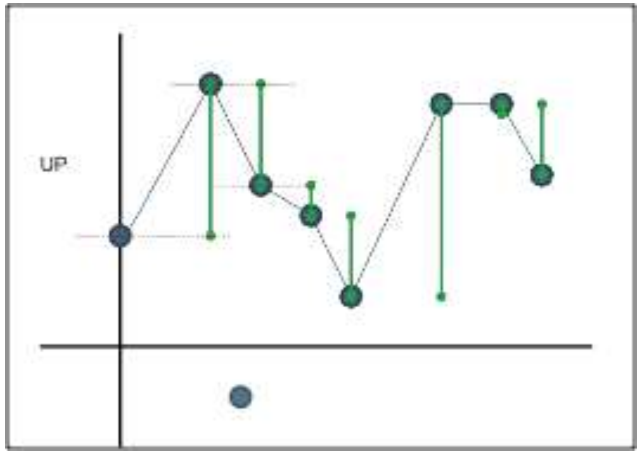
USE CASE EXAMPLE 1: CAPACITY / RESOURCE ADEQUACY

- 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
  - the incremental capacity equivalent of energy storage, and
  - line losses.



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



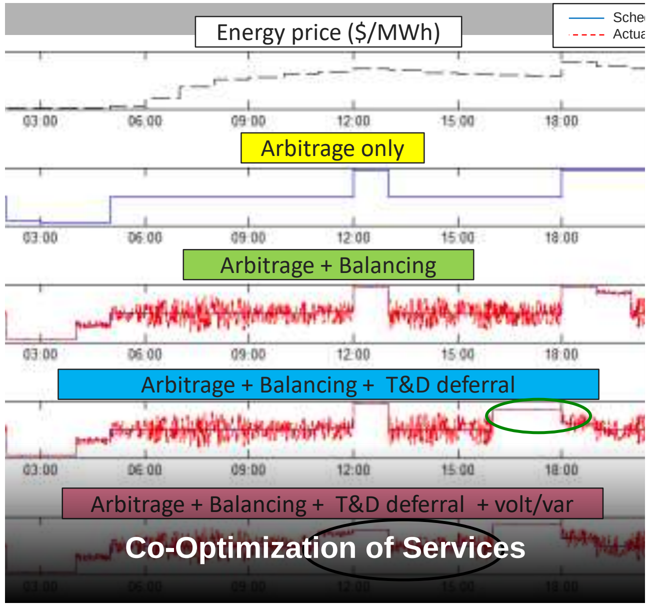
Mileage definition is the sum of all green bars in 15 min. intervals

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

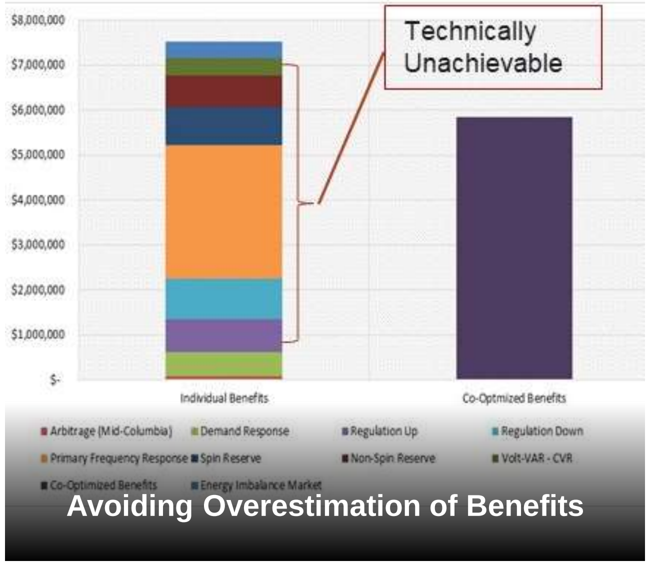
Key Lesson: Performance of battery storage in providing frequency regulation is exceptionally high and markets are shallow. Market prices can be driven downward as a result, undermining the profit potential to storage operators in the process.

CHALLENGES TO ACCURATELY ESTIMATING ECONOMIC BENEFITS

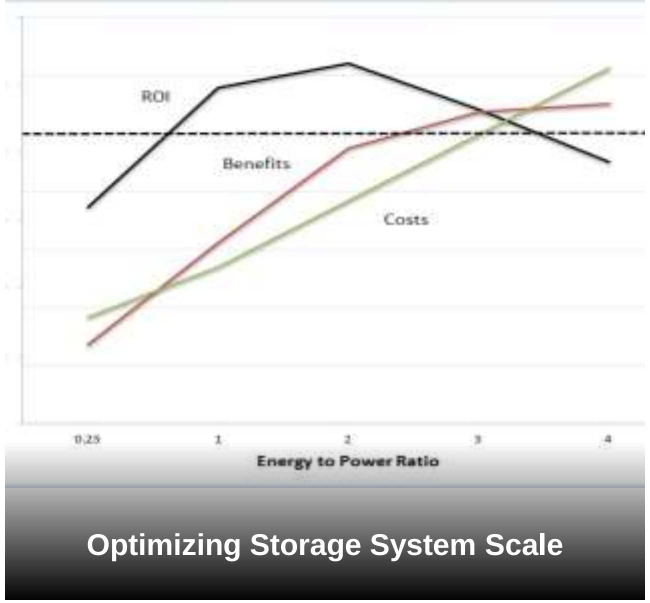
- Multidimensional competition for energy – not all services can be provided simultaneously and there exists intertemporal competition for energy
- Economic results are sensitive to sizing of energy storage system in terms of power and energy capacities
- Markets are complex and common practices of assuming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



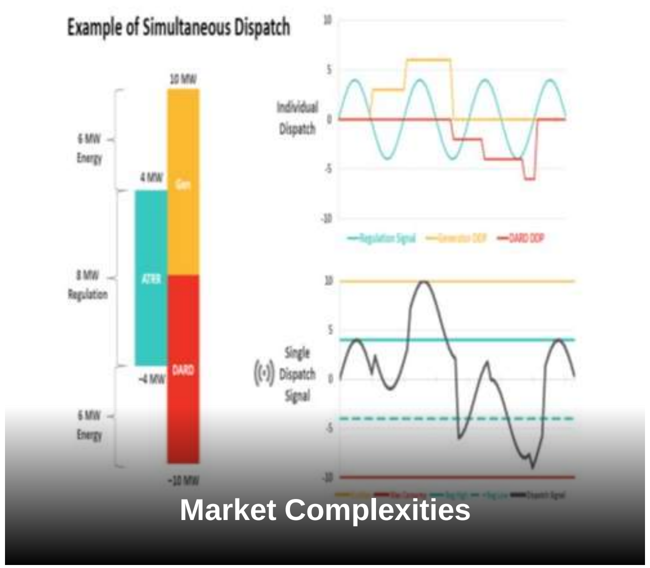
Co-Optimization of Services



Avoiding Overestimation of Benefits



Optimizing Storage System Scale



Market Complexities

ENERGY STORAGE VALUATION MODEL ATTRIBUTES

Ideal Model Attributes	Typical Model Attributes
Optimize across a broad set of use cases, with all use cases considered concurrently	Optimize across a limited number of use cases
Thorough representation of internal device state	Ignore electrical system and market effects
Estimation of electrical system effects	Use of simplistic representations of internal state
Estimation of market impacts	Assumes perfect foreknowledge of prices, loads, and outages
Accounting for uncertainties in battery energy storage system (BESS) operation	Price taker model
Ability to define optimal capacity / placement	
Freely available and easily usable	

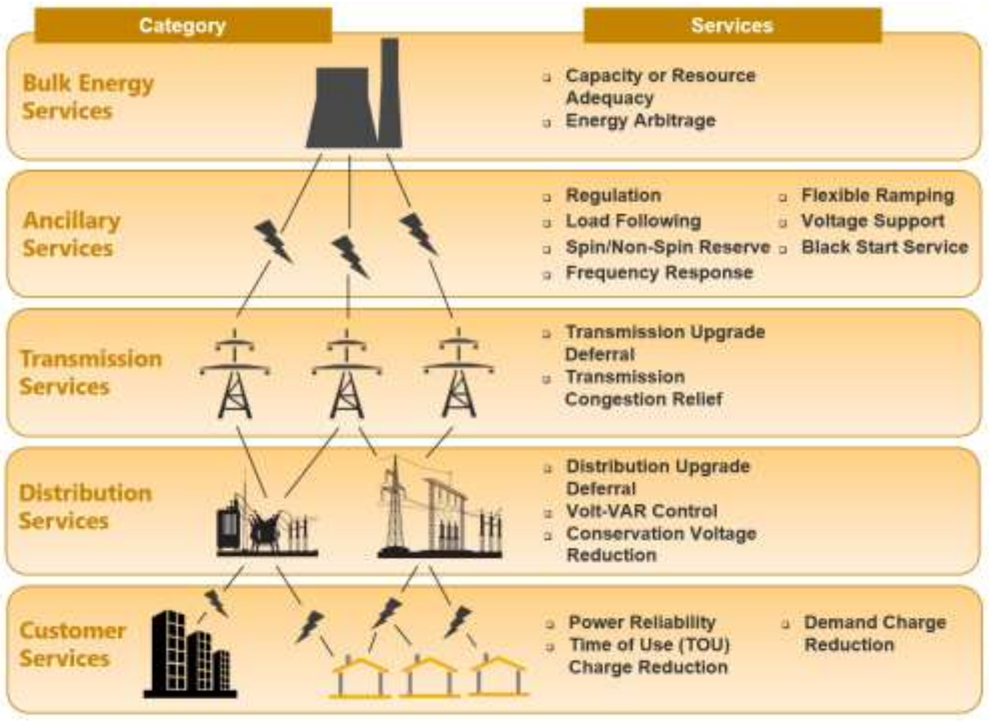
ENERGY STORAGE VALUATION TOOLS

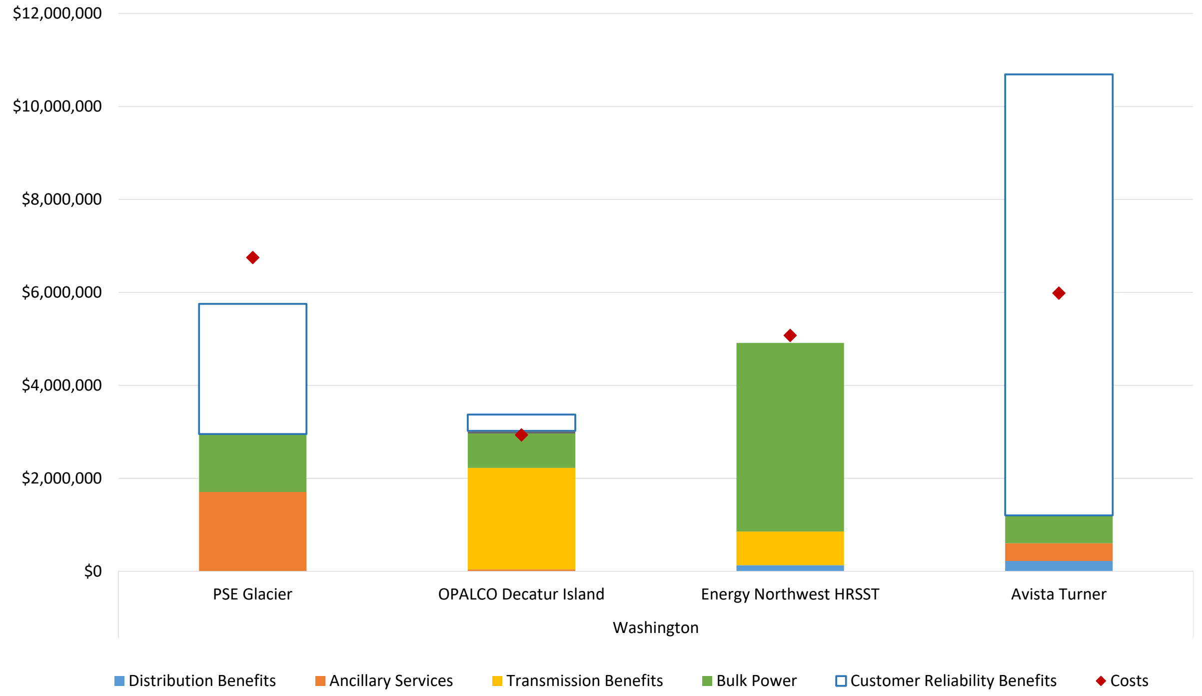
Name of Tool	Developer	Summary	Online Access
Battery Storage Evaluation Tool (BSET)	Pacific Northwest National Laboratory	BSET relies on user input time-series values and energy signals by use case to determine the optimal schedule and value of storage. It can be used for utility-owned and behind-the-meter (BTM) storage and can optimally scale the BESS.	https://availabletechnologies.pnnl.gov/technology.asp?id=413
StorageVET	Electric Power Research Institute	StorageVET® 2.1 facilitates the understanding of where to place and install energy storage, the optimum size as well as controls options. StorageVET 2.1 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	BSET	StorageVET	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	✓	✓	✓	✓

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





- 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

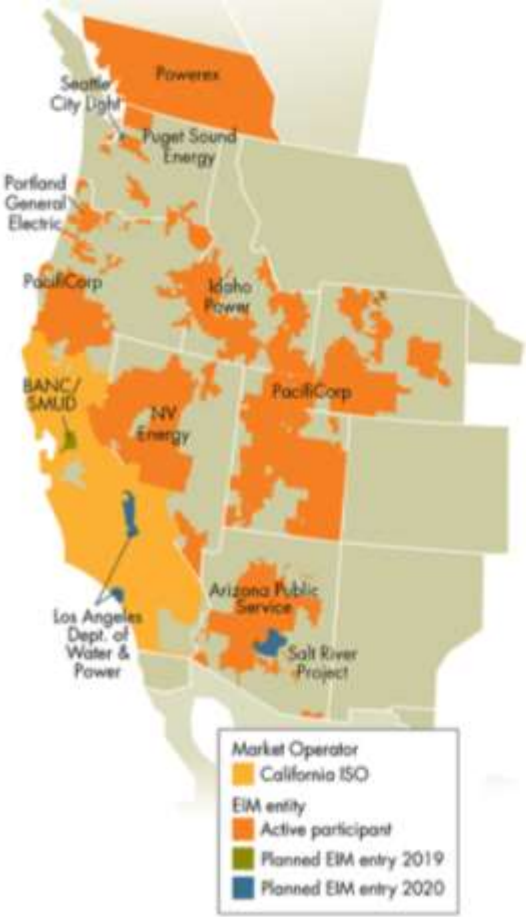
ENERGY STORAGE SCHEDULING TECHNIQUES

Use Case	BSET	StorageVET	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)	✓	✓		

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

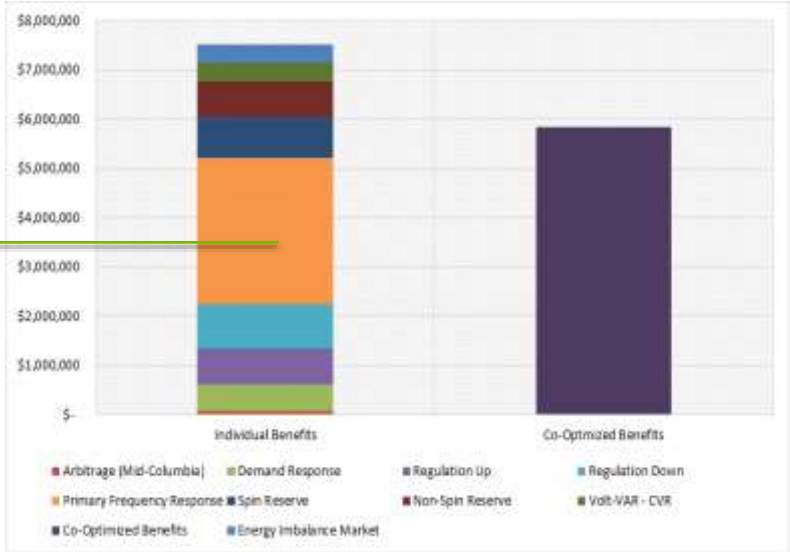


Western Energy Imbalance Market

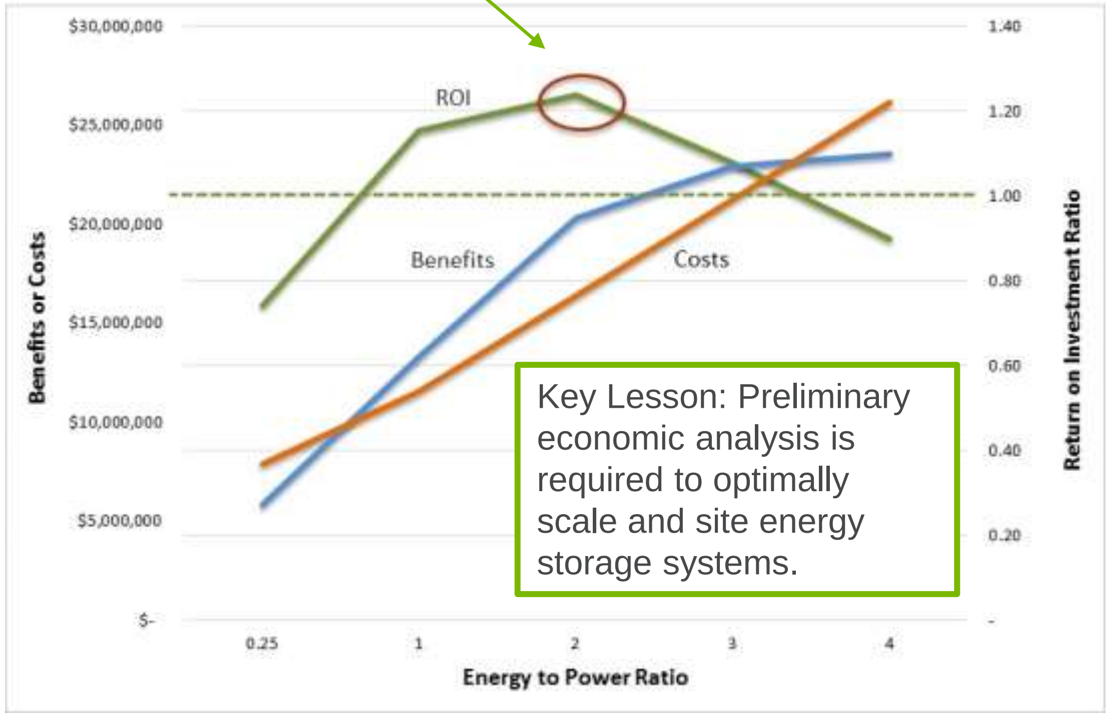
OPTIMAL SCALING OF THE SSPC

- Evaluated individually, 20-year present value 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) ratio falls below 1.0

Technically Unachievable



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



ENERGY STORAGE SYSTEM MODELING

Use Case	BSET	StorageVET	QuESt	REOpt Lite
Specification-based (Power and Energy Limits)	✓	✓	✓	✓
Optimal Storage Power and Energy Rating Capability	✓	✓		✓
Dynamic Battery Performance Model (Variable Round-trip Efficiency Based on Changes in State of Charge, Power Output Level, Operation Mode)	✓			
Lifetime and Degradation Effects	✓	✓		

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

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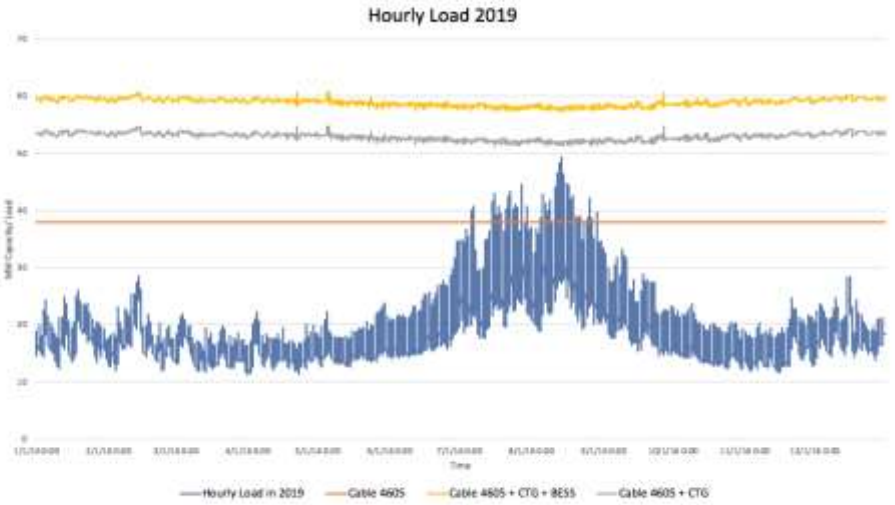
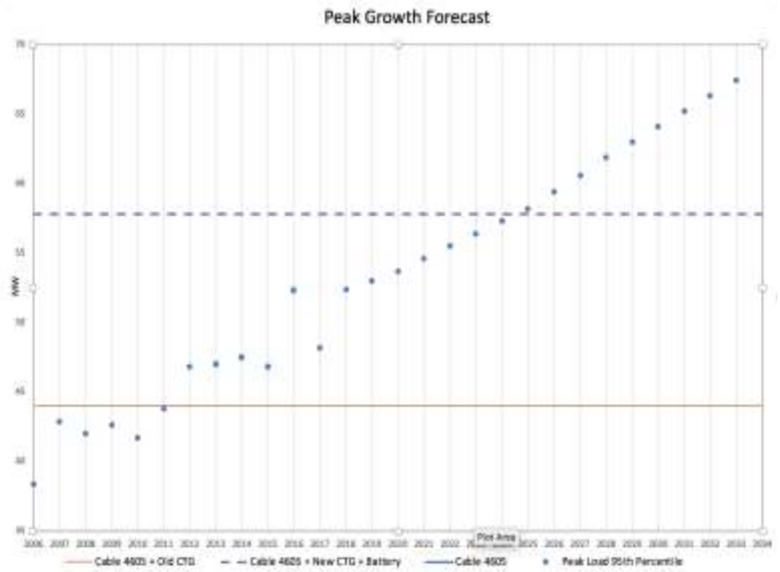
BENEFITS OF LOCAL OPERATIONS

- 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





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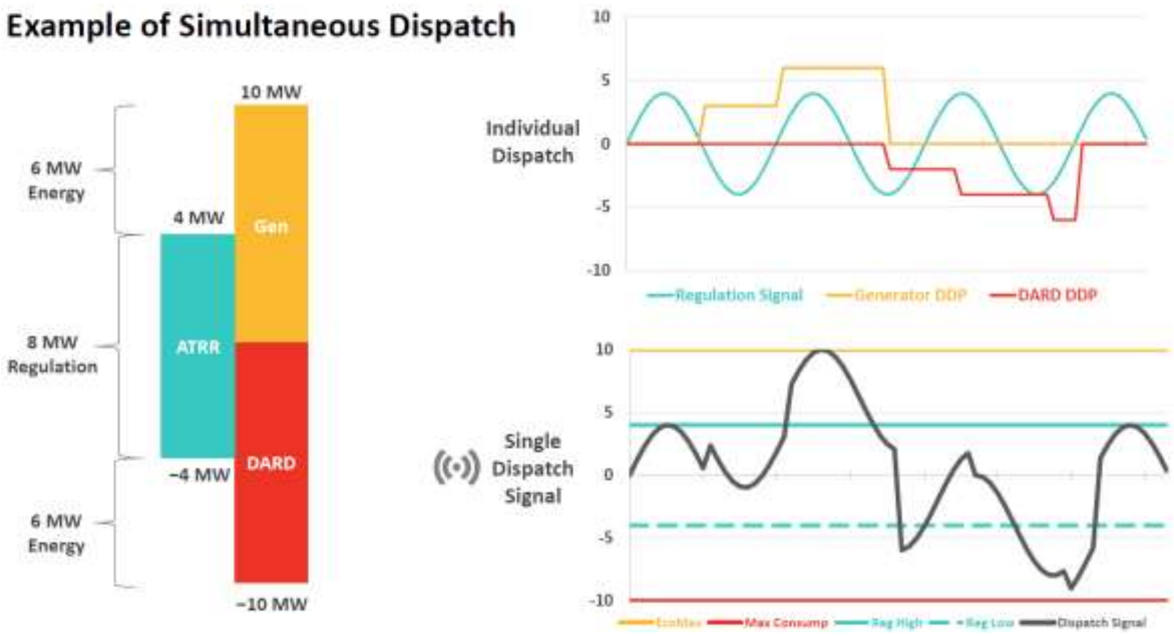
BENEFITS OF MARKET OPERATIONS

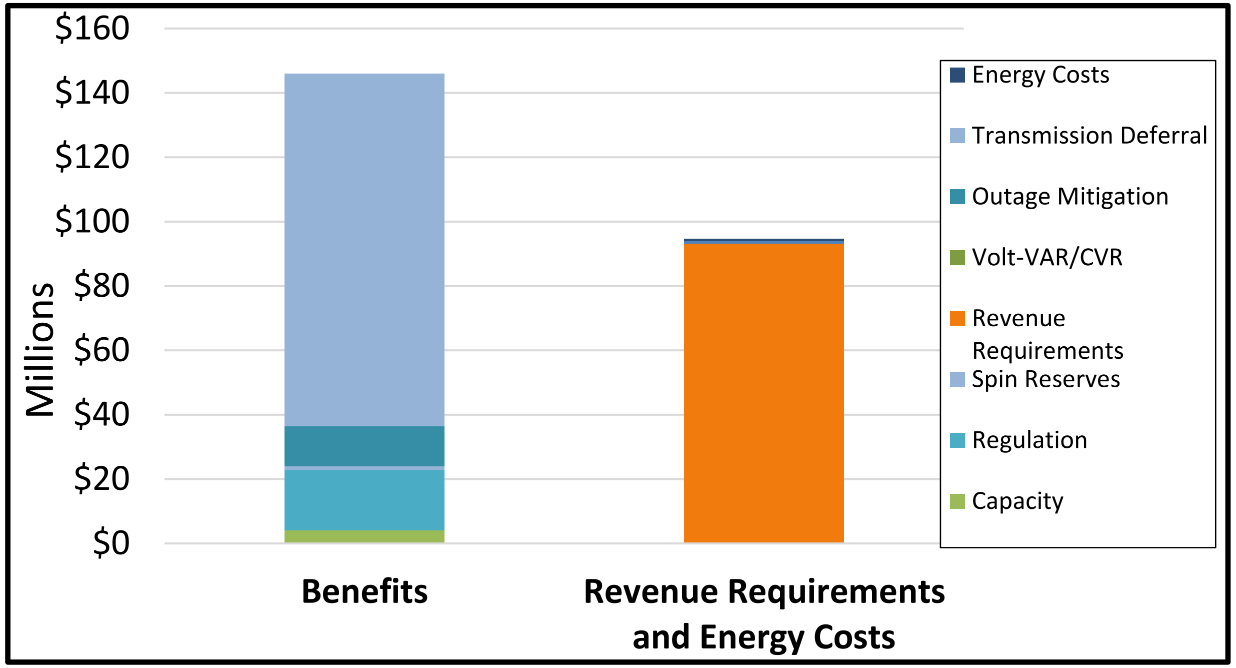
- Nantucket BESS modeled as a continuous storage facility
- BESS bid into markets using predicted prices – i.e., imperfect foresight
- Regulation follows energy neutral AGC signal with a performance score of 95%
- Market benefits estimated at $24.0 million over life of BESS
  - Regulation provides $18.8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

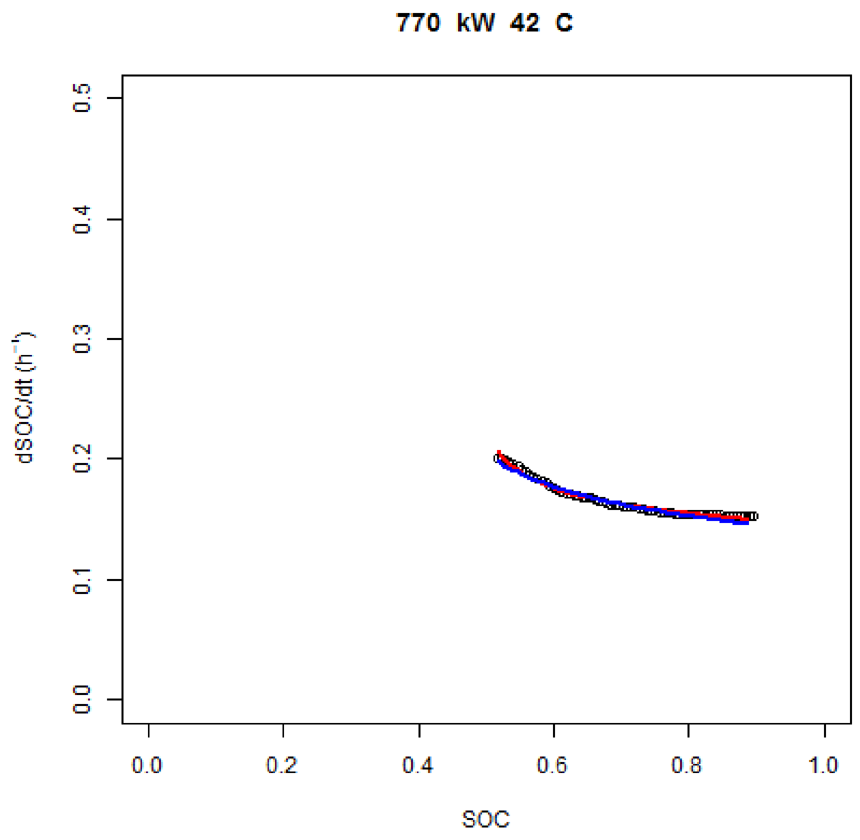
- Total 20-year present value benefits of BESS and CTG operations at $145.9 million exceed revenue requirements and energy costs at $93.9 million with an ROI ratio of 1.55
- Benefits largely driven by the transmission deferral use case, $109 million (75%) in present value terms.
- Regulation services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

IMPORTANCE OF OPERATIONAL KNOWLEDGE IN CAPTURING ENERGY STORAGE VALUE

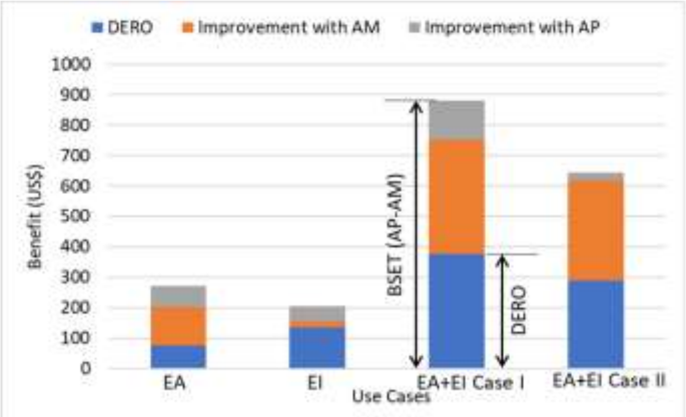
- Non-linear Performance Modeling
  - Model estimates state of charge (SOC) change during operation based on operating mode, power, SOC, and temperature
  - Model has been validated with data
  - Self-learning model applicable to any type of storage system
- Modeling State of Health
  - Optimizing the allocation of cycling budgets; expending cycling budgets through enhanced operational knowledge
  - Artificial intelligence / machine learning precise predictions require ~2 weeks of testing, a ~50X reduction in time
  - Degradation penalties to build in full system costs



DEVELOPMENT OF EFFECTIVE CONTROL SYSTEMS

- Field deployed commercially sourced optimizers – generally no dedicated process to keep track of the difference between ‘anticipated’ vs. ‘generated’ value – essentially an open loop process
- Reasons could be lack of adequate information/approach (logic, forecast error, lack of operational knowledge of energy storage system)
- Analytics to determine the reasons could close the loop and help improve the value generated

Illustrative results from a utility deployed ESS site



ESS Controller		Use Case Benefits (US$)			
		EA	EI	EA+EI (Case I)	EA+EI (Case II)
DERO	Without mathematical optimization considering financial information	75	134	377	290
BSET	Perfect ESS performance prediction	203	156	753	619
	Perfect price foresight and ESS performance prediction	272	204	881	643
Potential Improvement	With perfection in predicting ESS performance	128	22	376	329
	With perfection in forecasting price and predicting ESS performance	197	70	504	353

Potential Improvement

ANALYTICS CONCLUSIONS

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

MODEL CONCLUSIONS

- Each of the reviewed models lack certain features required to conduct a realistic valuation assessment (e.g., perfect foresight, no market effects, no cycling or degradation effects); achievable revenues take a “haircut” for each model shortcoming
- Each model offers distinct advantages and shortcomings
  - BSET (PNNL) models a broad range of benefits and has a detailed battery performance characterization but the publicly available version lacks several key components
  - QuESt does not include non-market values, assumes perfect foresight, user-specified model performance, and does not evaluate costs but has an embedded data management tool that includes market and retail tariff rates from across the US
  - REopt Lite is focused on BTM benefits but includes several features that allow for more detailed and flexible evaluations of microgrid assets
  - Storage VET evaluates a broad range of system benefits and offers a fairly complete set of options
- Each model is a “price-taker” model and should be used only for small (e.g., under 10 MW) energy storage investments if the analysis is not integrated with additional planning and operations tools

ACKNOWLEDGMENTS

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Kate Anderson, National Renewable Energy Laboratory

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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