Pacific Northwest
NATIONAL LABORATORY

Introduction to Energy Storage Valuation

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Outline

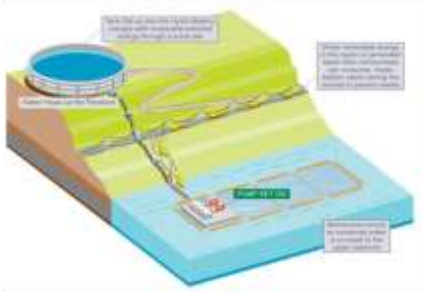
- Grid and End-user Services
- Storage Valuation Problems
- Energy Storage Assessment Projects
- Lessons Learned

Services Provided by Energy Storage

Stationary BESS

Hydrogen/P2G

Small Modular PSH



PEVs

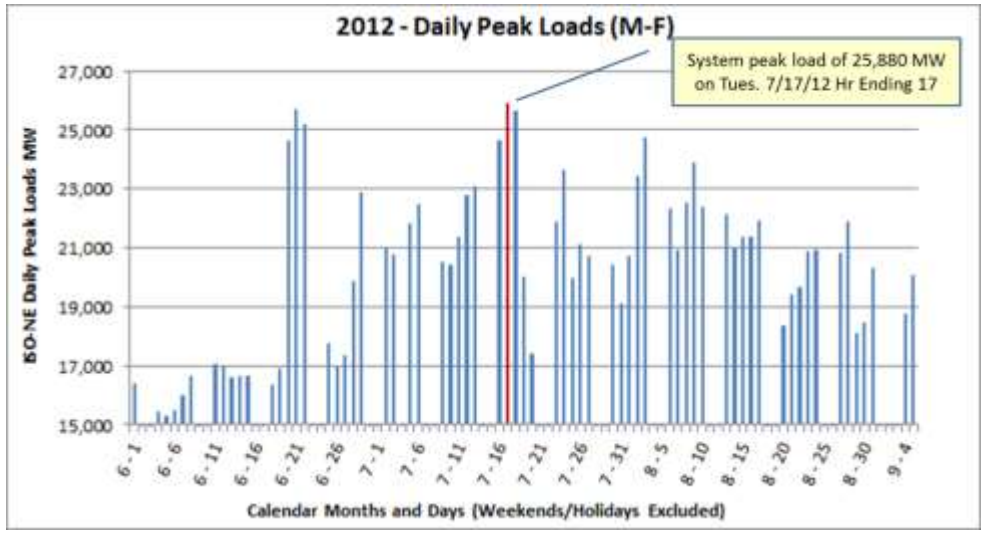
Thermal Storage in Buildings

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

Capacity and Resource Adequacy

Capacity markets and integrated resource planning ensure sufficient resources to meet the future demand

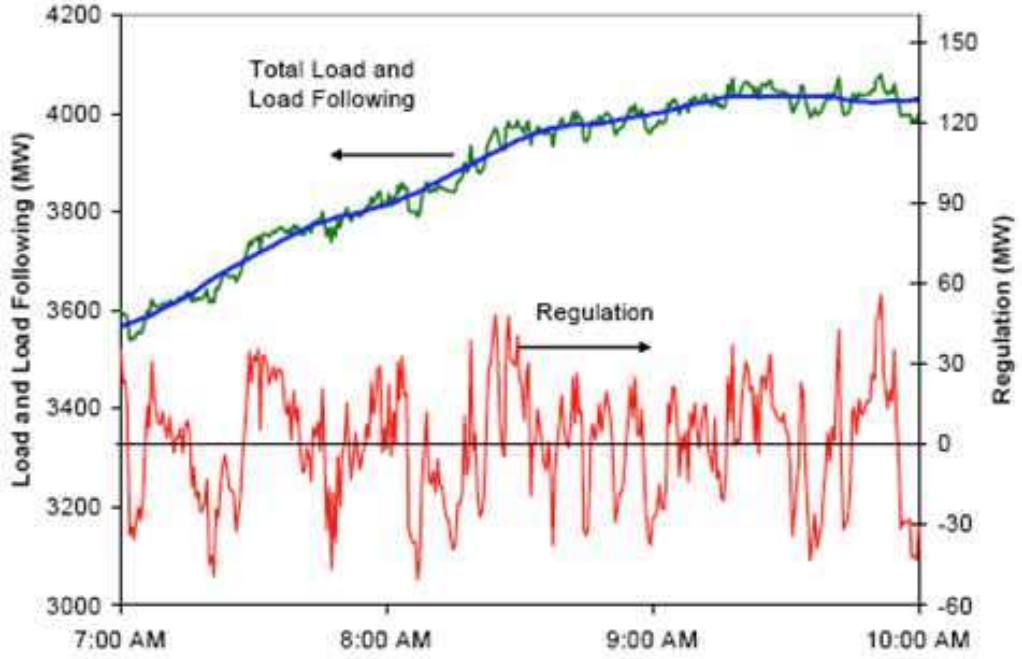
- Capacity markets:
  - Capacity payment is for participants offering supply capacity for ensuring resource adequacy.
  - Capacity charge is paid by load serving entities based on their coincident demand during system peak hours.



- Power purchase agreement: energy storage can be used to reduce capacity charge.
- Vertically integrated utilities: capacity value can be estimated based on the incremental cost of next best alternative investment (e.g., peaking combustion turbine) to meet the load.

Frequency Regulation

- Frequency regulation is an ancillary service required to continuously balance generation and load within a control area.
  - maintain system frequency
  - manage differences between actual and scheduled power flows between control areas
- Respond rapidly to system-operator requests for up and down movements by following automatic generation control signals
- Value defined by market prices or reduced costs of operating generators



Pay-for-performance terms:

- **Regulation capacity**
- **Regulation mileage**
- **Performance factor/score**

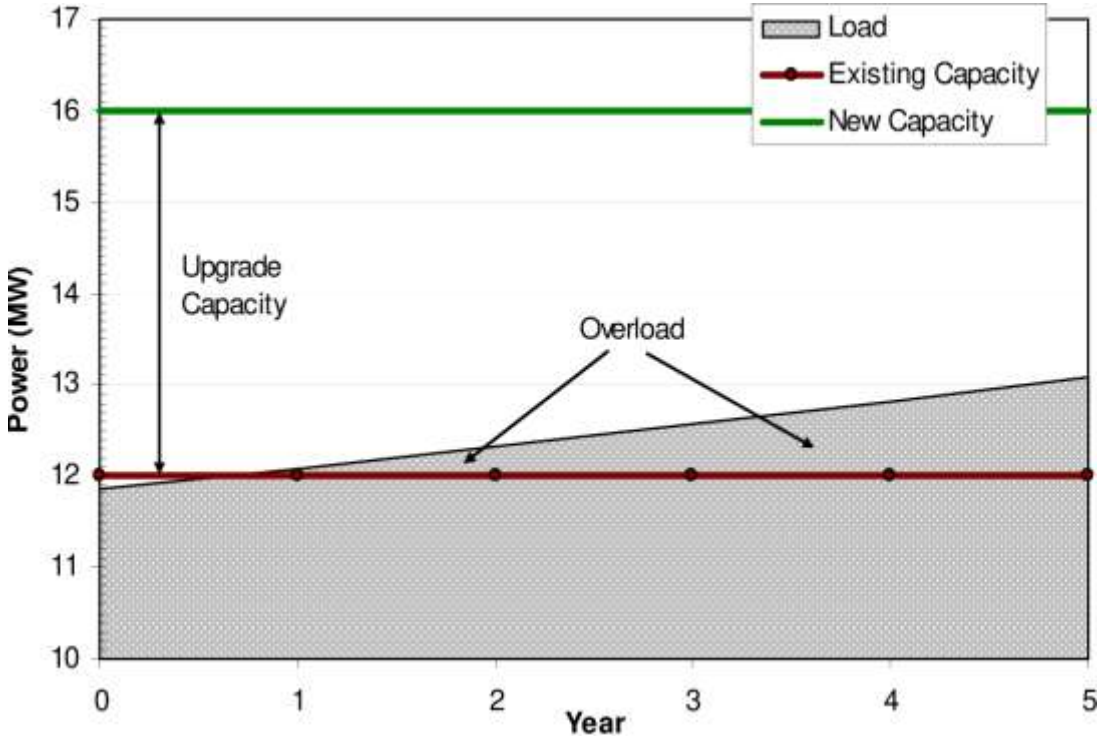
Transmission and Distribution Upgrade Deferral

Using local energy resources to reduce peak demand can help

- Defer or avoid the need to upgrade transmission and distribution (T&D) equipment
- Extend the life of existing T&D equipment

Key Indicators of opportunities for T&D deferral:

- Capacity constrained systems
- High T&D upgrade cost
- Low load factor



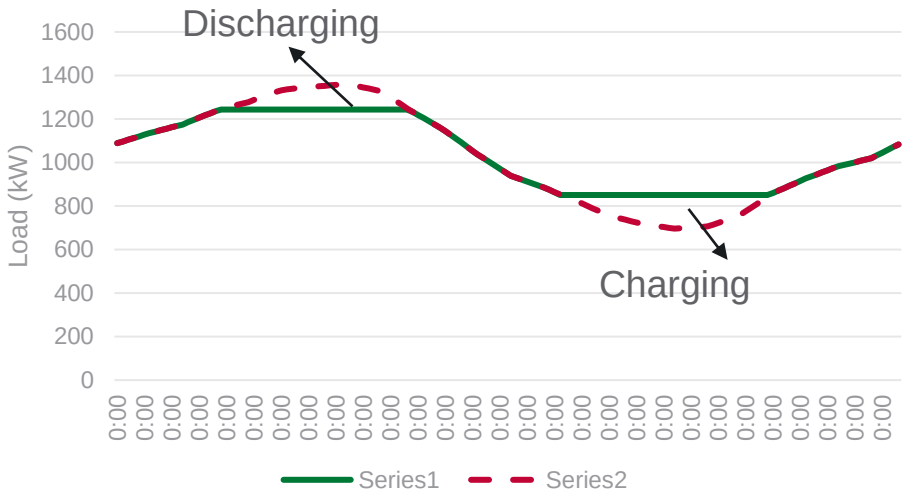
Net present value of deferring a $1 million investment for one year estimated at $65,000 assuming an 7% real discount rate.

Electricity Bill Management

- Energy charge is based on the amount and time when energy is consumed.
- Demand and transmission charges are typically based on the maximum rate of consumption ($/kW) over the billing period
  - Narrow spikes can significantly increase the electricity bill
  - Often results in significant economic benefits

An Example of TOU Tariff

		Summer	Winter
Energy ($/kWh)	On	0.145	-
	Mid	0.092	0.096
	Off	0.067	0.073
Demand ($/kW-month)	On	24.1	-
	Mid	6.95	-
	Facilities	13.7	



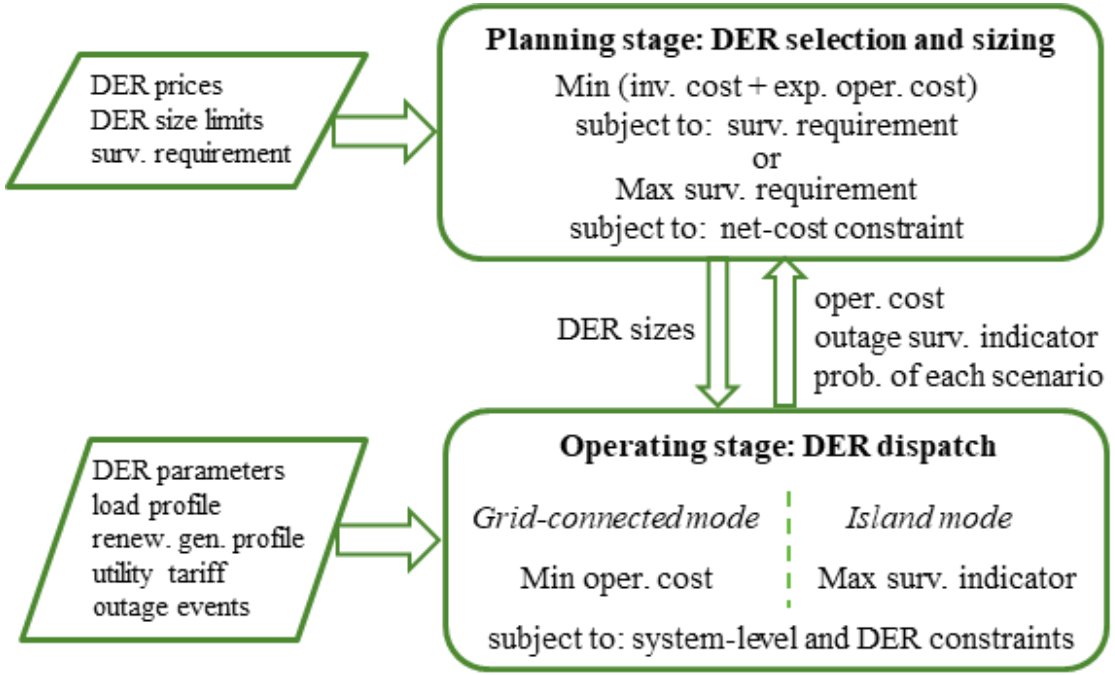
Resilience Improvement

Improve resilience through microgrids:

- Grid-connected and island modes
- Coordination of multiple resources
- Critical load vs non-critical load
- Intra-hour variability and uncertainty

Metrics:

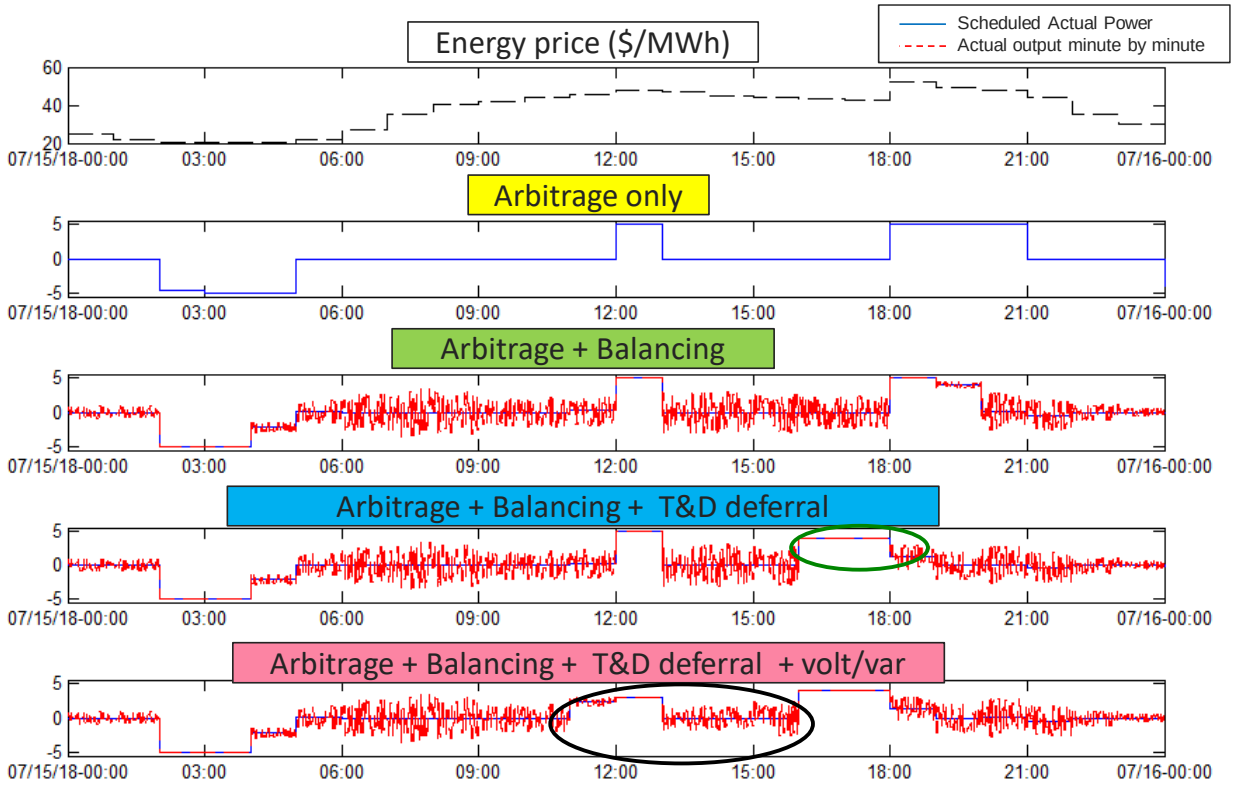
- Survivability against a random outage
- Total unserved energy or duration and magnitude of affected load during outages
- Cannot be fully captured by monetary value



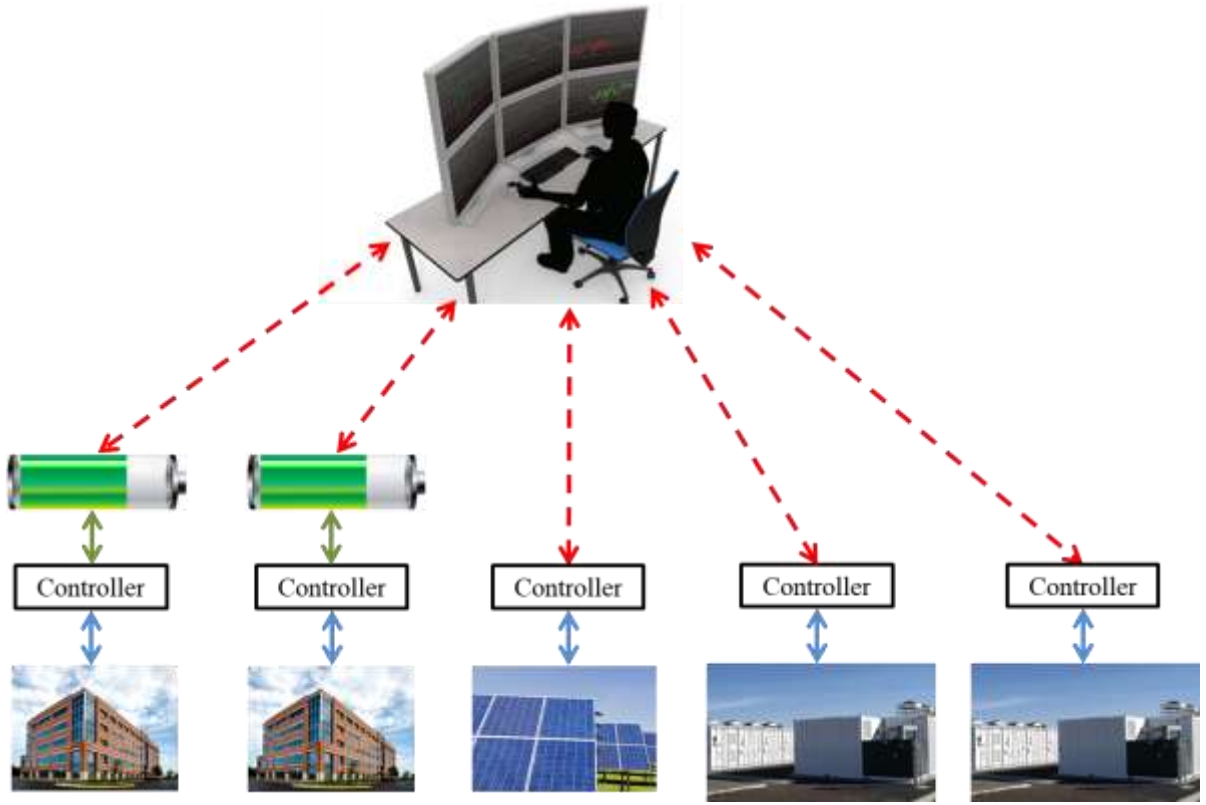
Two-stage stochastic sizing considering economic benefits and resilience requirement

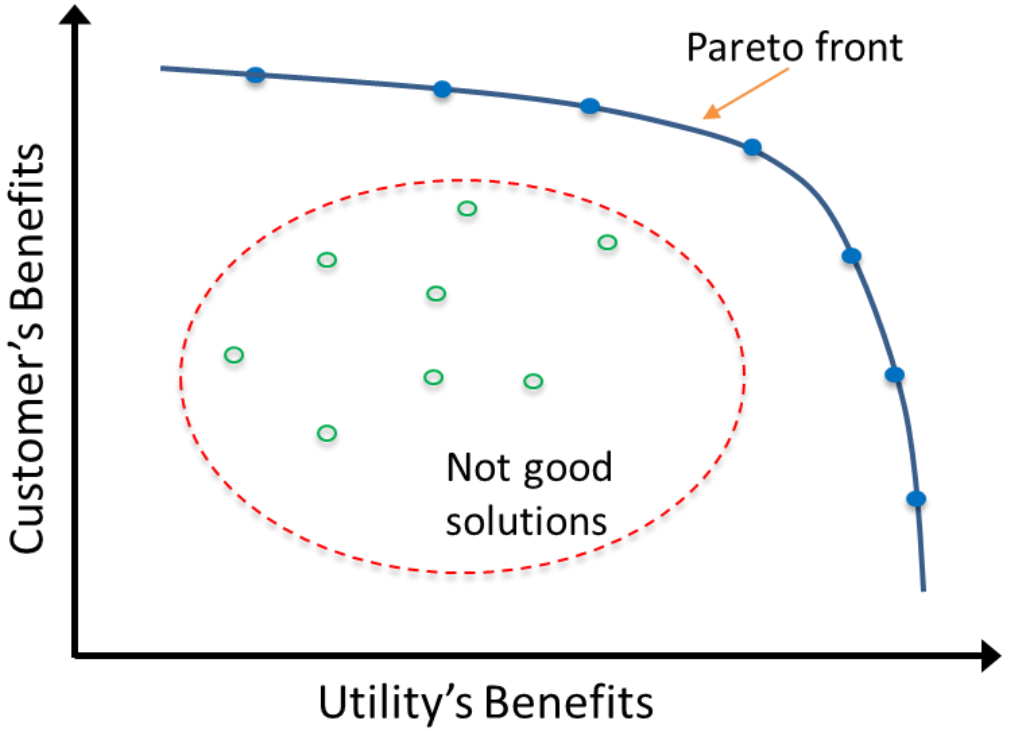
Bundling Services: How To Do It Optimally

- Co-optimization procedures are required to ensure no double counting of benefits
  - Different services compete for limited ESS capacity
  - By using energy in one hour, less is available in the next hour; more frequent operation in a year, reduced cycle life in future years
- Energy storage valuation and sizing tools are required to determine optimal sizes and define technically achievable benefits



Customer and Utility Benefit from Shared Energy Economy

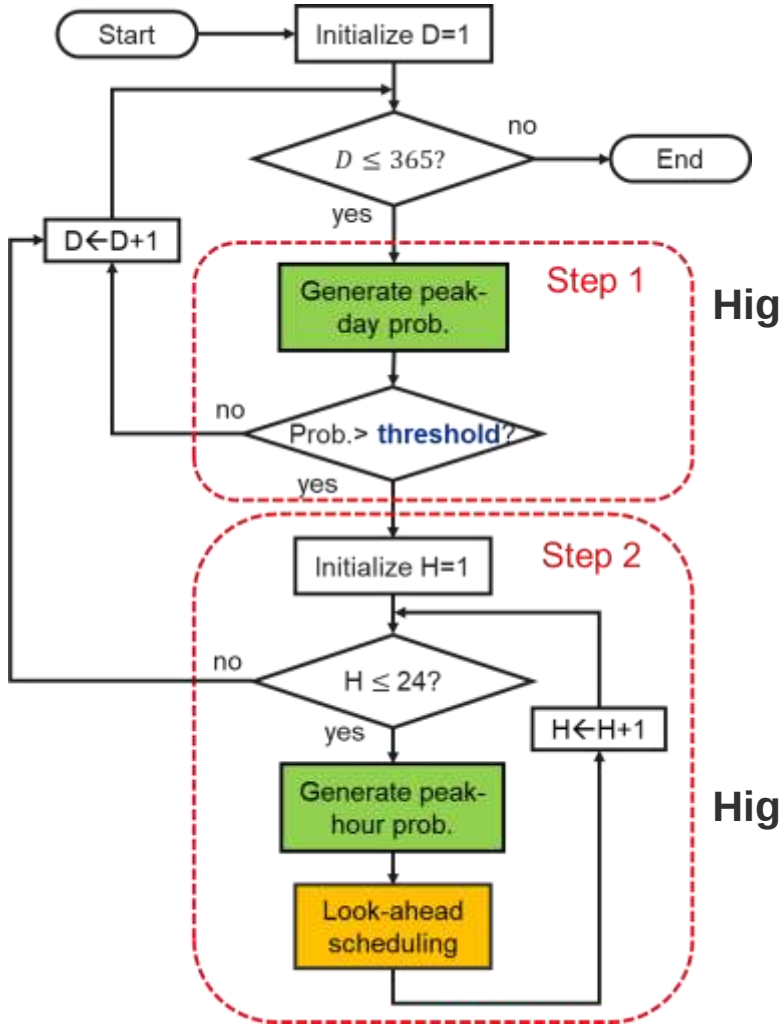




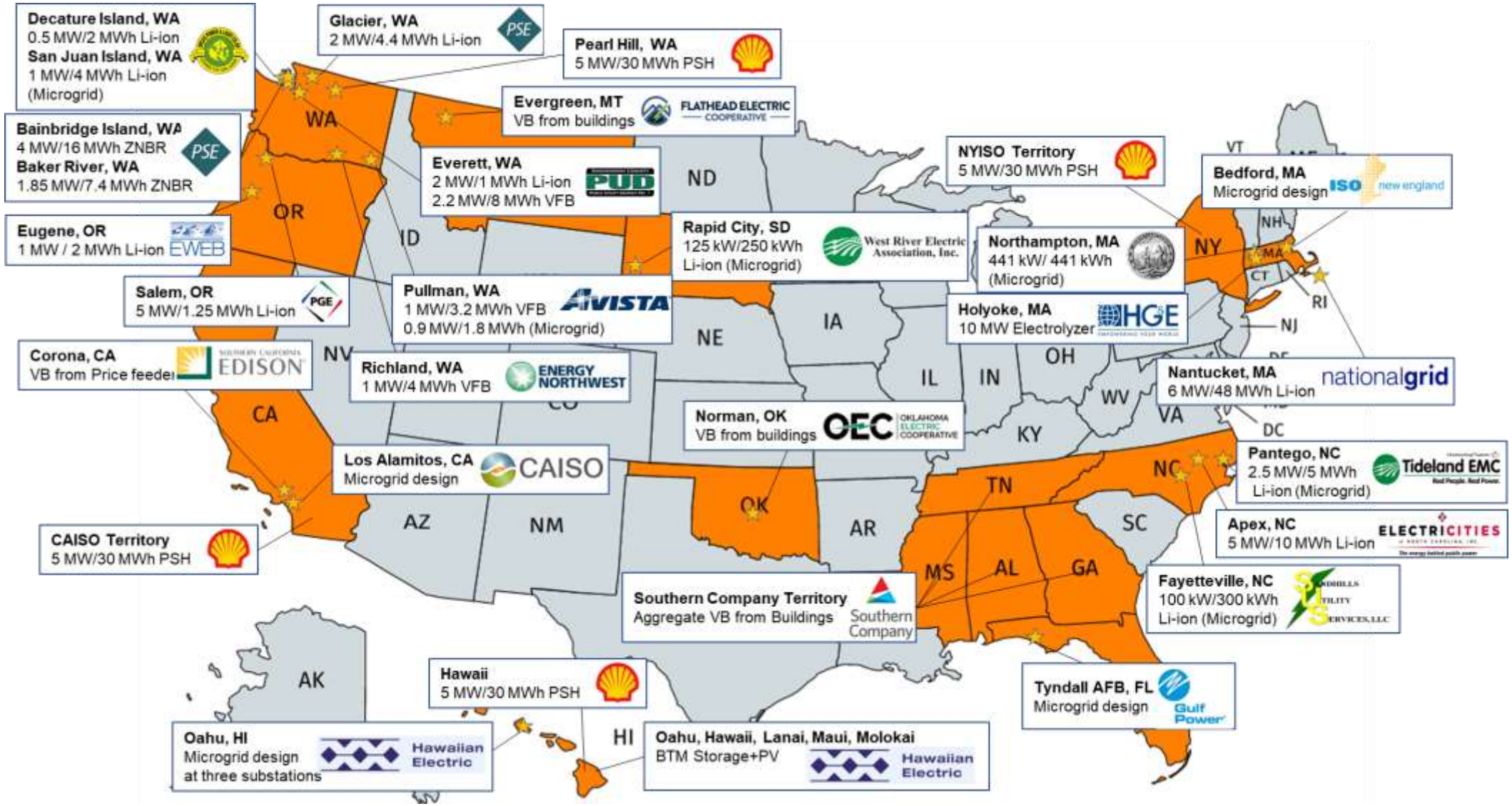
There does not exist a control strategy that can simultaneously maximize benefits for both parties

Dispatch Under Uncertainties and Optimal Sizing

- Seamlessly integrate load forecast and ESS dispatch to model and address uncertainties
- Effectively explore the trade-off between short-term benefits and battery life
- Optimize distribution of battery life to maximize the present value of benefits
- Optimize battery duration considering both uncertainty and battery degradation



PNNL Has Evaluated Energy Storage Systems at More Than 30 Sites

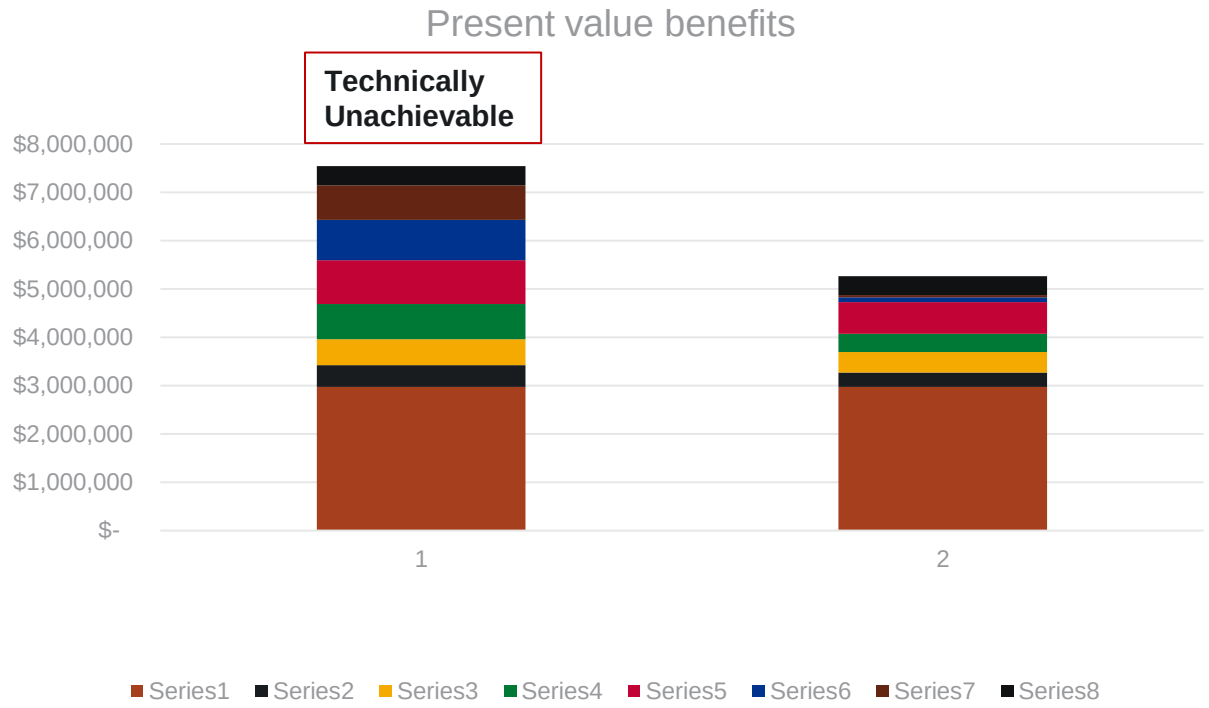


Salem Smart Power Center 5 MW/1.25 MWh Li-ion

Pacific Northwest Smart Grid Demonstration Project (Smart Grid Demo), launched in 2010 as a five-year $178 million program co-funded by DOE, focusing on R&D value demonstrations:

- Integration of renewables
- Stabilization of grid frequency during power sag
- Demonstration of transactive power, microgrid islanding, Volt-VAR control, and other advanced control methods

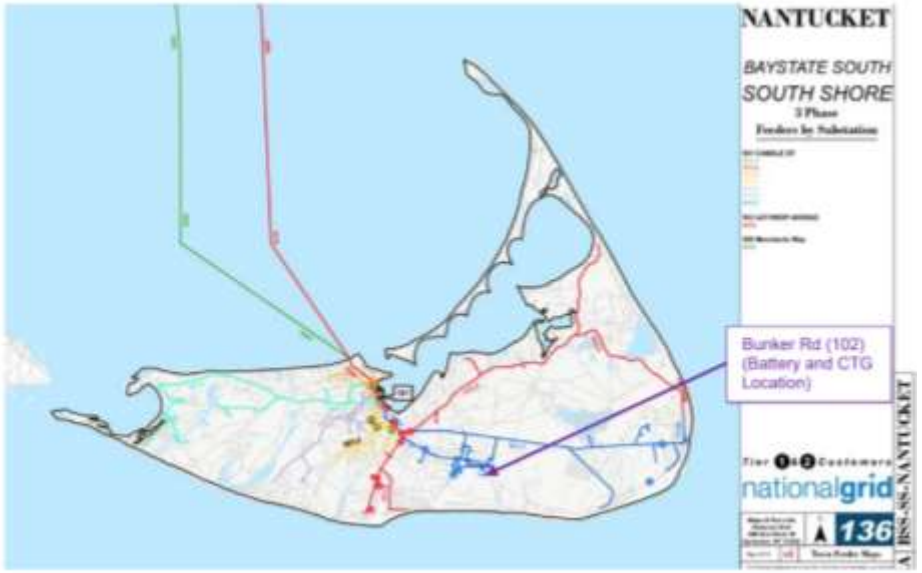
The SSPC is currently underutilized, operating an average of 14 hours per month, using the BESS for primary frequency response.



- $264,000 annually from primary frequency response
- Additional $170,000 annually from stacked value streams

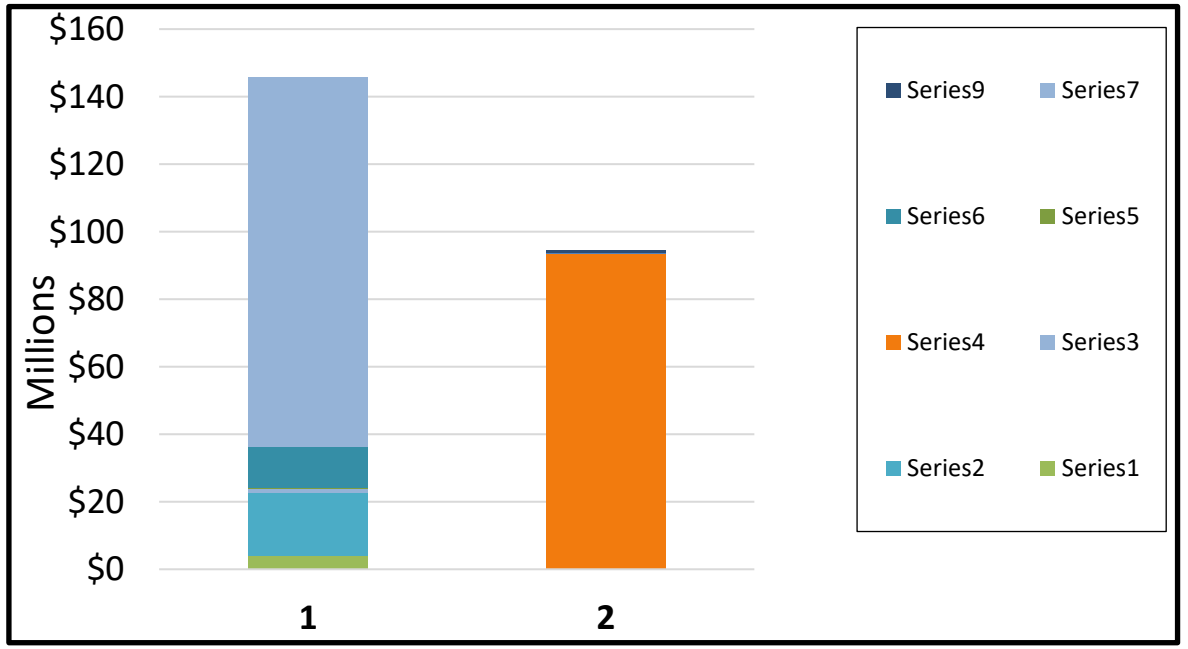
Nantucket Island 6 MW/48 MWh Li-ion

Nantucket Island, southeast coast of Massachusetts



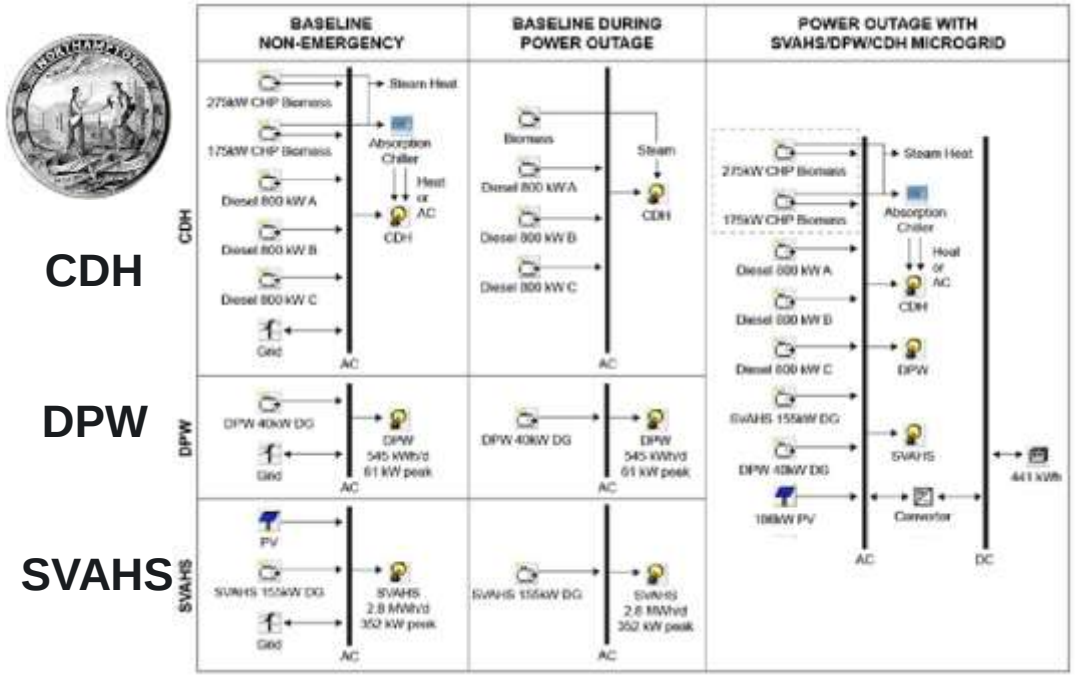
BESS + CTG to ride through N-1 contingency events, deferring o investment in a third submarine transmission cable

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



- Return on investment (ROI) ratio: 1.55
- Benefits are largely driven by the transmission deferral use case, about 75% of the total benefits

Northampton Microgrid 441 kW/441 kWh Li-ion



CDH

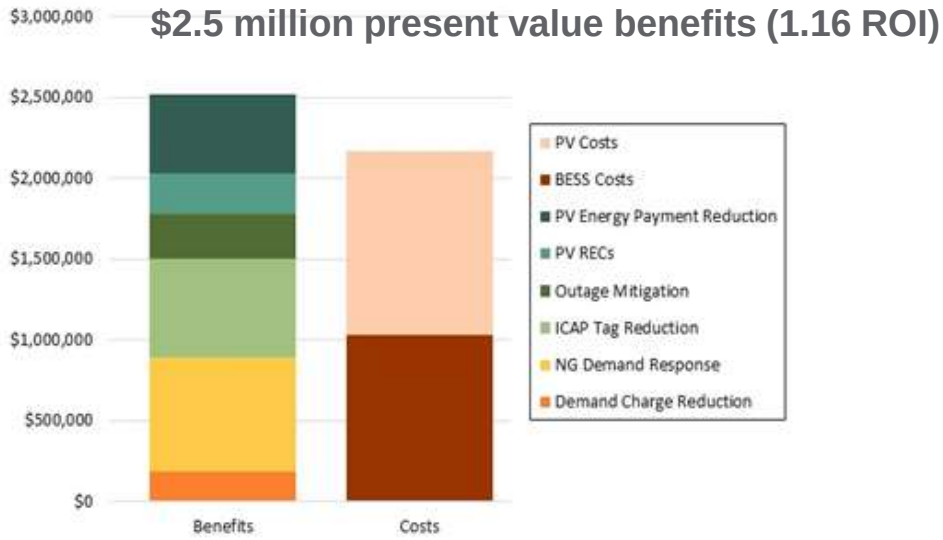
DPW

SVAHS

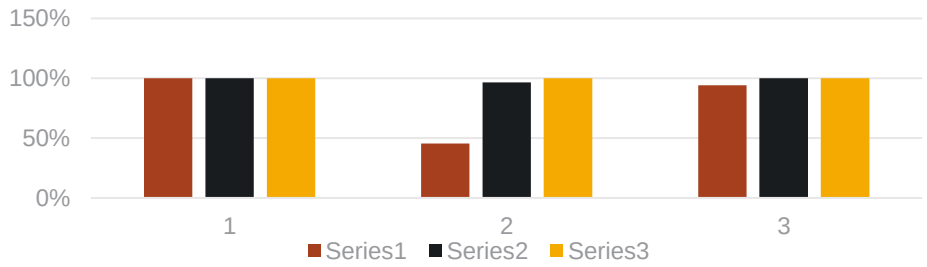
New DERs: 386 kW PV + BESS at CDH

- Resilience
  - Outage duration: 3, 7, and 14 days
  - Season: summer vs. winter
  - System connectedness: separation, limited power-sharing, and full power-sharing
  - DG failure: fail to start, load, and run

- Economic benefits



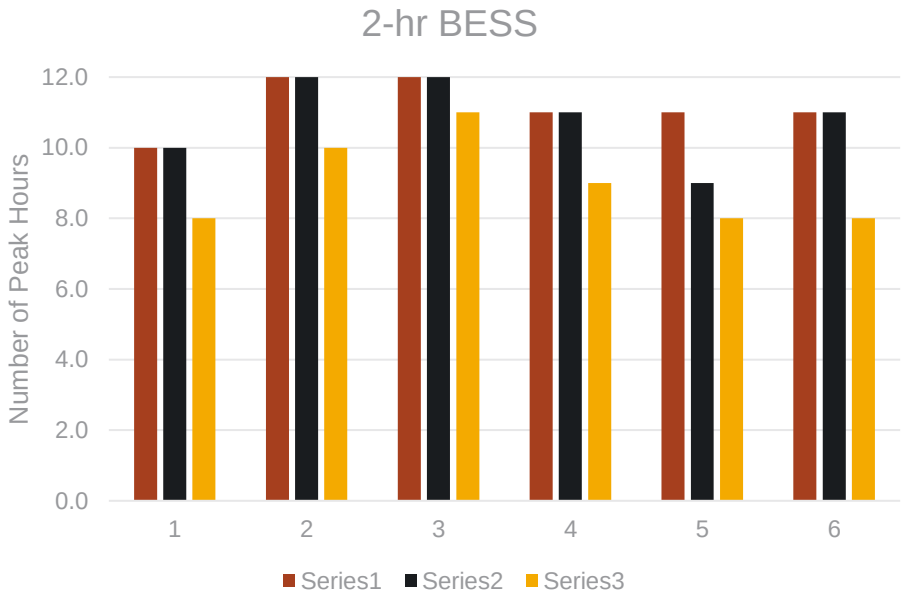
$2.5 million present value benefits (1.16 ROI)

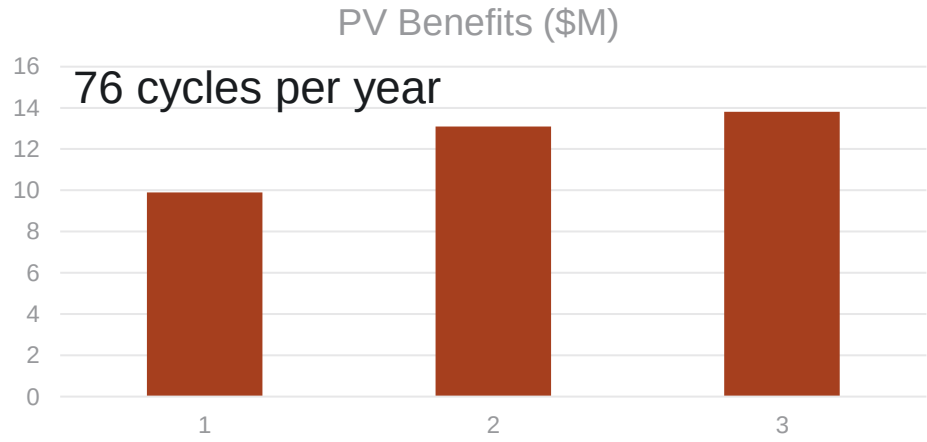


Power sharing among three facilities helps to improve survivability at SVAHS and DPW

ElectriCities 5 MW/2-4 Hour Li-ion

- Capacity charge rate: > $20/kW-month from Duke Energy Progress
- **ElectriCities does not know exactly when the peak hour will occur**
  - Cannot tell exactly whether tomorrow is the peak day of the month
  - Cannot tell exactly whether the next hour is the peak of the day
- Two-step dispatch under uncertainties with a 2-hour battery:
  - Capture peak hours in 11 months a year
  - 7-8 cycles per month





Numerous Factors Affect ESS Value Proposition

- **Use cases**
  - Vertically integrated utilities, electricity markets, small utilities, or end-user customers
- **Applications**
  - Bulk energy, ancillary service, transmission-level, distribution-level, and end-user services
- **Region and system**
  - Different generation mix, grid infrastructure, market structures/rules, distribution system capacity, and load growth rate
- **Energy storage characteristics**
  - Energy storage technology, physical capability and characteristics

Importance of Energy Storage Modeling

- A set of equations and constraints, or tables representing operational flexibility and physical constraints
- Often black- or grey-box models at system level

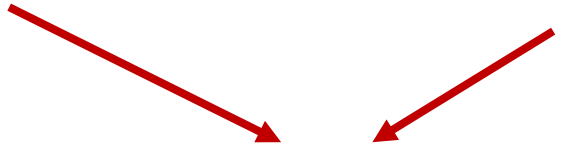
BESS example:

Operational flexibility (fast dynamics)

- Constant-efficiency model
  - Round-trip efficiency
  - One-way efficiency
- High-fidelity nonlinear model

Degradation effects (slow dynamics)

- Equivalent degradation cost model
- State-of-health model
  - Loss of life
  - Degradation in performance



Integrated model

Importance of Appropriate Valuation Approach

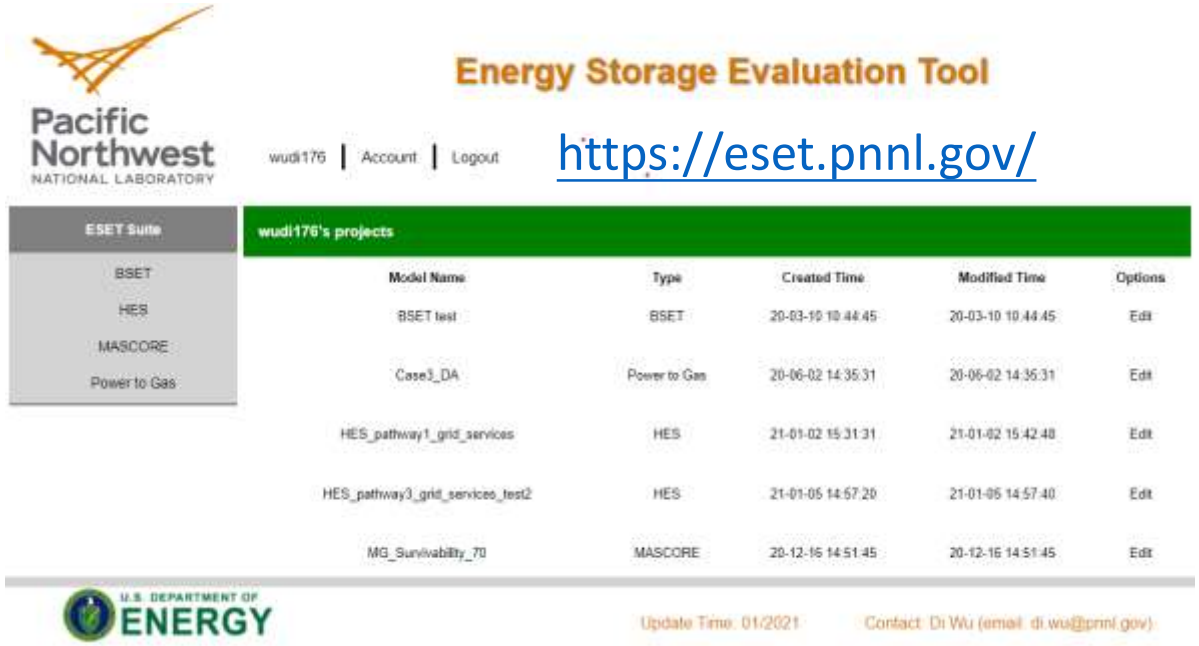
Valuation approaches largely depend on use cases and applications

- Vertically integrated utilities vs electricity market vs small co-ops
- Price-taker vs system-level analysis
- Evaluation vs sizing
- Deterministic vs stochastic
- Linear vs nonlinear
- Direct vs iterative
- Off-the-shelf solvers vs customized algorithms

Energy Storage Evaluation Tool (ESET)

A set of web-based apps for energy storage modeling and analytics

- The modular structure facilitates maintenance and expansion
- The encapsulated environment eliminates the need for customized settings
- The separation of data and applications improves data security
- The dynamic GUI provides an interactive interface for easy configuration and settings



- Battery Energy Storage Evaluation Tool (**BSET**)
- Microgrid Asset Sizing considering Cost and Resilience (**MASCORE**)
- Hydrogen Energy Storage Evaluation Tool (**HESET**)
- Pumped-Storage Hydropower Evaluation Tool (**PSHET**)
- Virtual Battery Assessment Tool (**VBAT**)

Acknowledgments

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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

Q/A and Further Information

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