Energy Storage Valuation and Analytics: Lessons, Methods, and Models Resulting from Recent Experience

Patrick Balducci, Chief Economist

Pacific Northwest National Laboratory

Arizona Tribal Energy Assoc. Annual Meeting

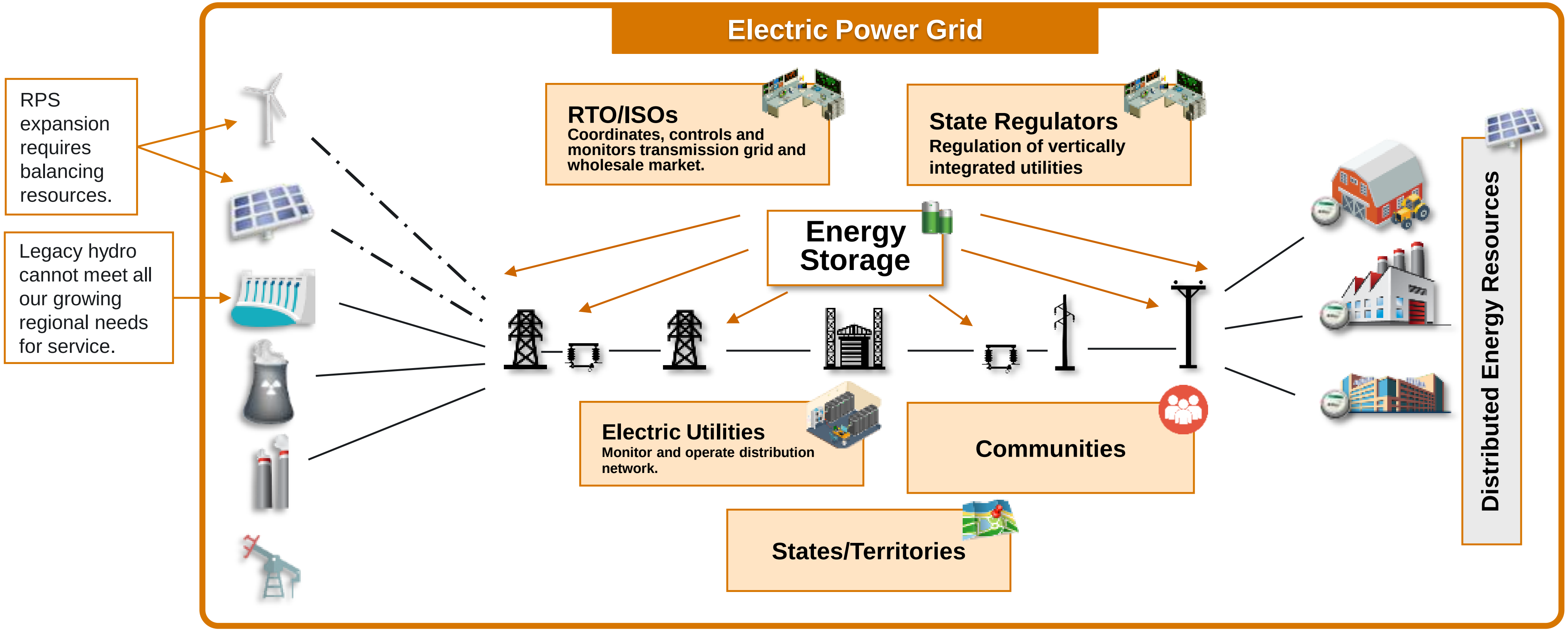
January 24, 2019

Support from DOE Office of Electricity Delivery & Energy Reliability

ENERGY STORAGE PROGRAM

PNNL is operated by Battelle for the U.S. Department of Energy

Energy Storage Critical for Flexible, Efficient Grid of the Future



***Electrical Energy Storage* –**

Bi-directionally capable of ***consuming*** and ***producing*** specific amounts of electric power as it is made available at specific times; e.g., batteries, flywheels, supercapacitors, pumped hydro, etc.

Pacific Northwest
NATIONAL LABORATORY

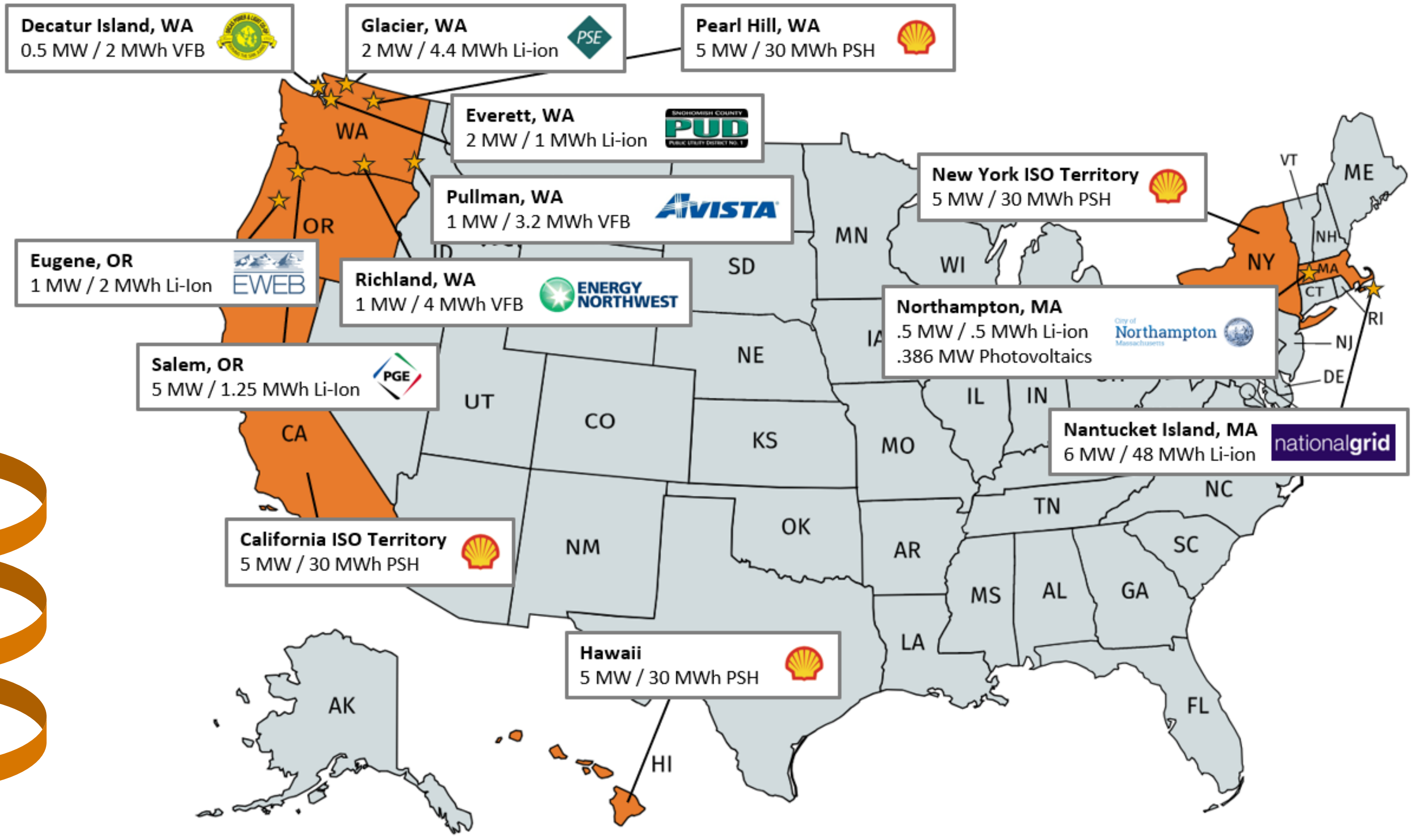
Energy Storage Demonstration Project Assessments as PNNL

PNNL Storage Analytics Program

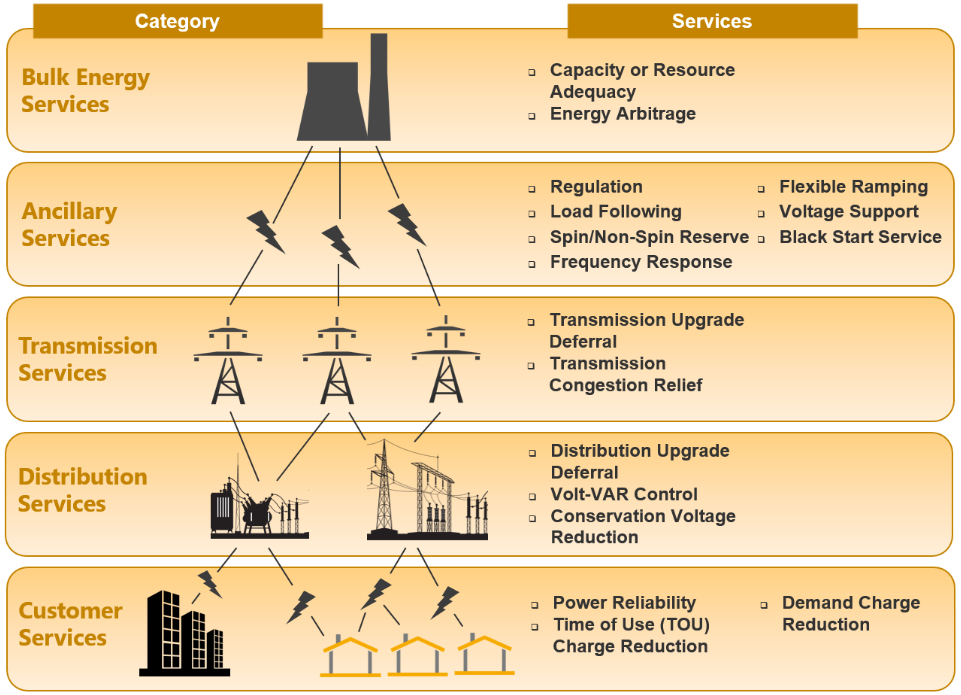
26 MW 103 MWh at 14 Sites

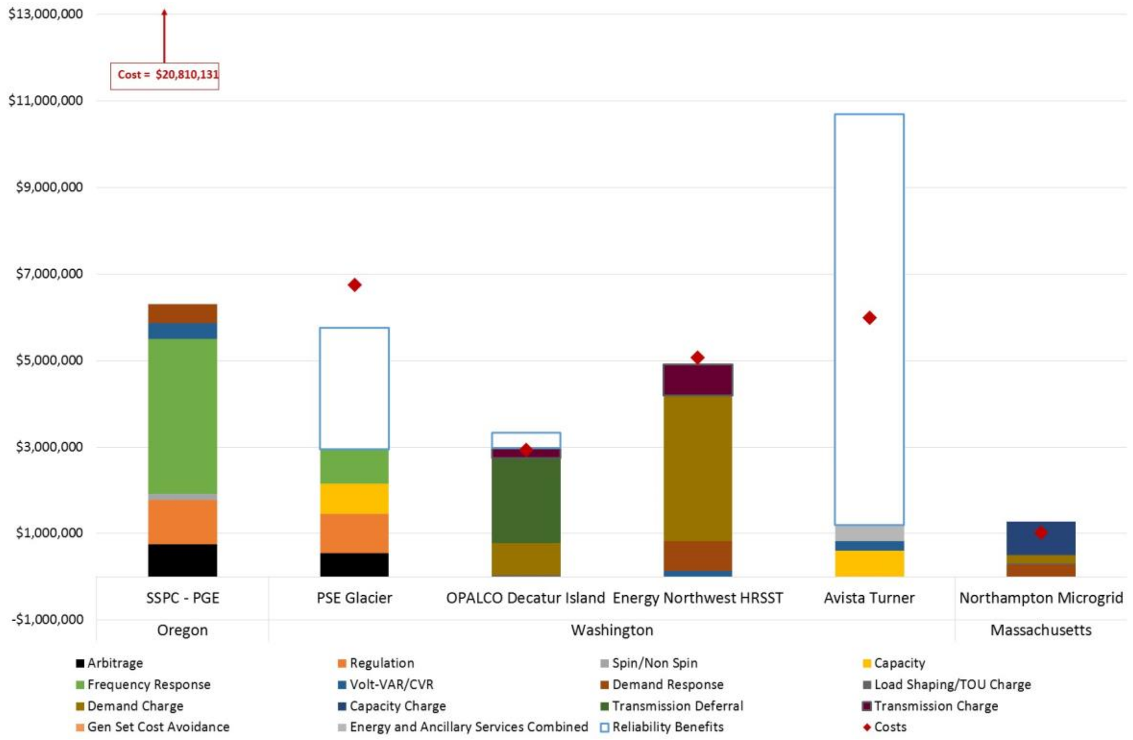
PNNL Analytics Task-flow

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



Defining and Monetizing the Value of Energy Storage and DERs More Broadly





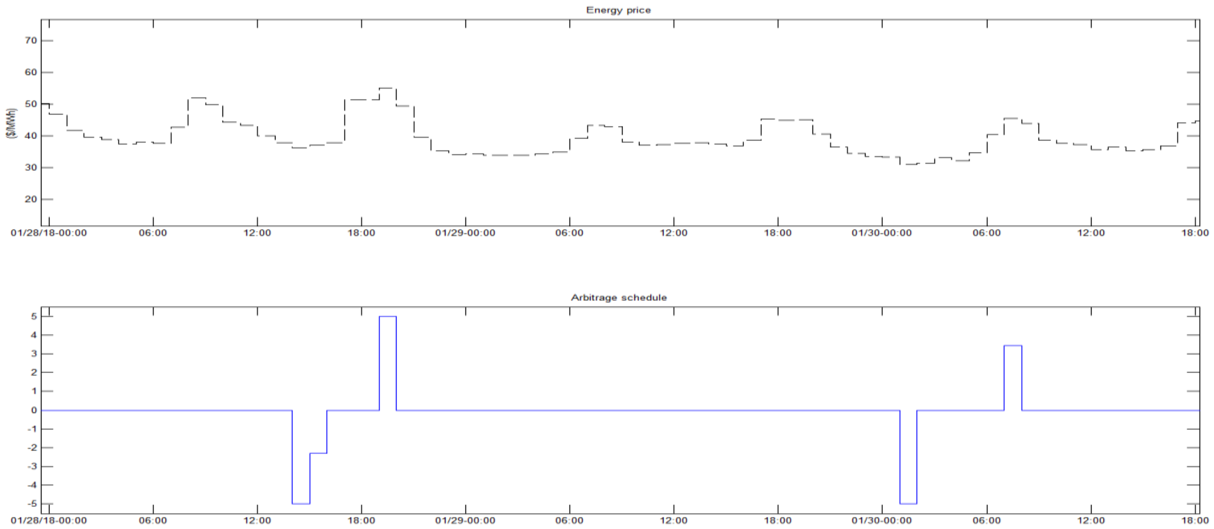
Key takeaways:

- ❑ We have developed a broad taxonomy and modeling approach for defining the value of distributed energy resources (DER)
- ❑ Economic value is highly dependent on siting and scaling of energy storage resources; many benefits accrue directly to customers
- ❑ Benefits differ based on utility structure (e.g., PUDs, co-ops, vertically integrated investor-owned utilities) and market participation
- ❑ Accurate characterization of battery performance, and development of real-time control strategies, are essential to maximizing value to the electric grid

Pacific Northwest
NATIONAL LABORATORY

Energy Arbitrage

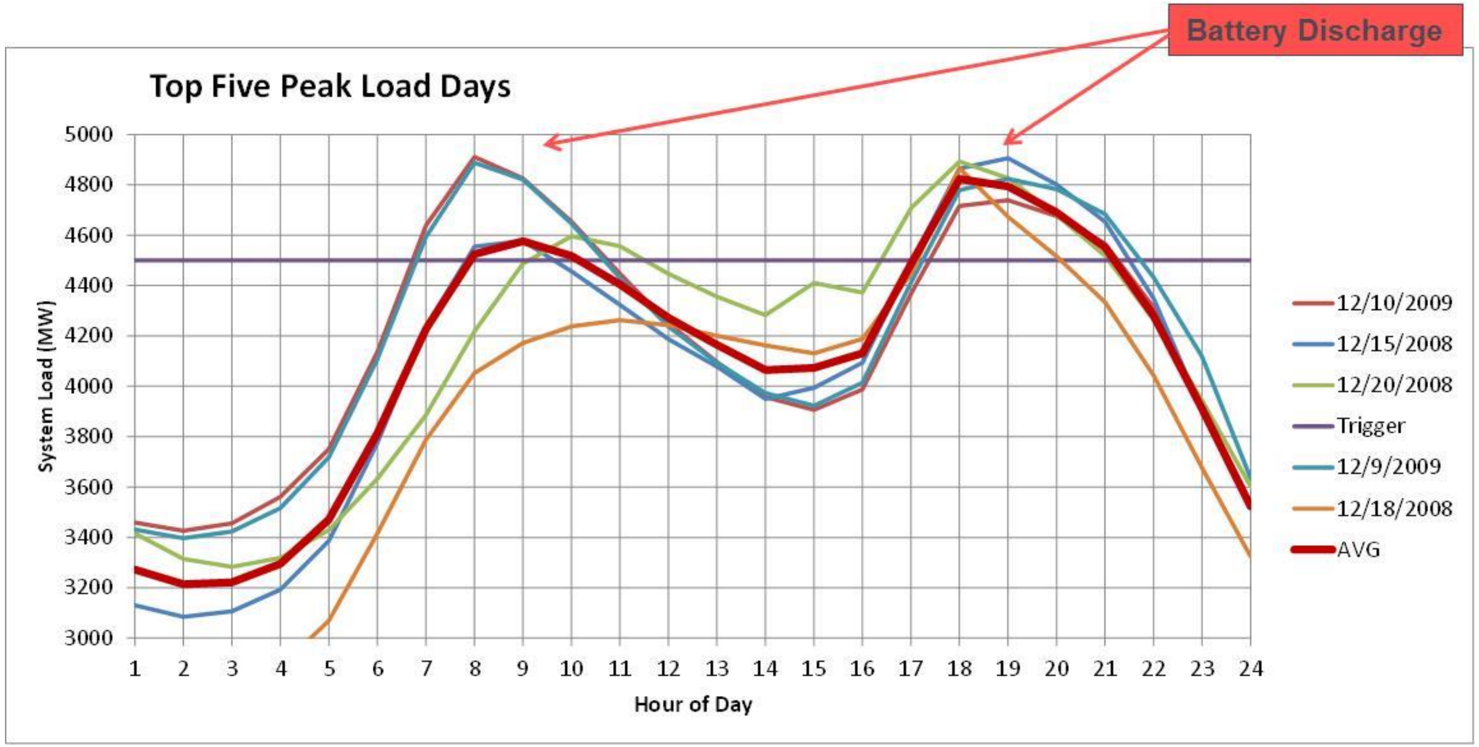
- Hourly wholesale energy market used to determine peak / off-peak price differentials (e.g., Mid-C prices in Pacific NW or California Independent System Operator (ISO) LMPs in California)
- Value obtained by purchasing energy during low price hours and selling energy at high energy price hours – efficiency losses considered
- Energy time shift still generates value even in the absence of markets
- 85% efficiency => 117.6% price difference
- 65% efficiency => 153.8% price difference



Key Lesson:
While one of the first recognized use cases for energy storage, arbitrage typically yields a small value.

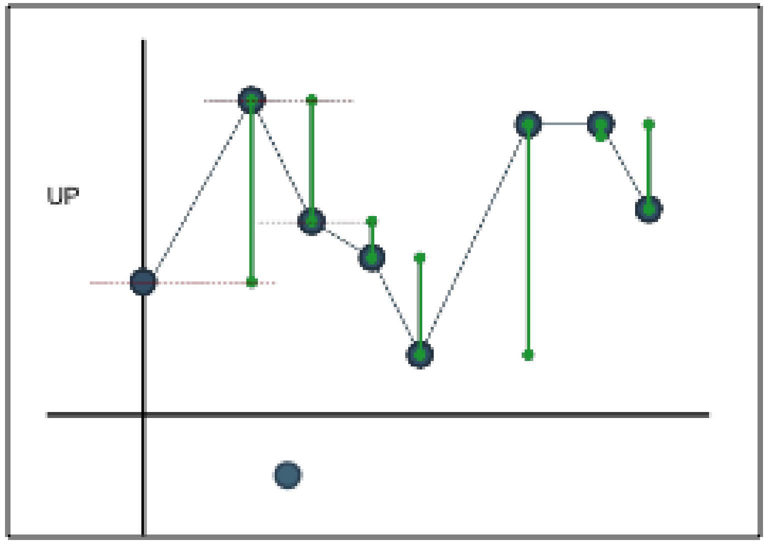
Capacity / Resource Adequacy

- 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



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. Batteries represent an efficient resource for providing frequency regulation; however, market prices can be driven downward as a result, undermining the profit potential to storage operators in the process.

Outage Mitigation

- Outage data
  - Outage data obtained from utility for multiple years
  - Average annual number of outages determined and outages randomly selected and scaled to approximate average year
  - Outage start time and duration
- Customer and load information
  - Number of customers affected by each outage obtained from utility
  - Customer outages sorted into customer classes using utility data and assigned values
  - Load determined using 15-minute SCADA information
- Alternative scenarios
  - Perfect foreknowledge – energy storage charges up in advance of inclement weather
  - No foreknowledge – energy on-hand when outage occurs is used to reduce outage impact

Duration	Cost per Outage ($2008)*		
	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.

Transmission and Distribution Deferral

- 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*

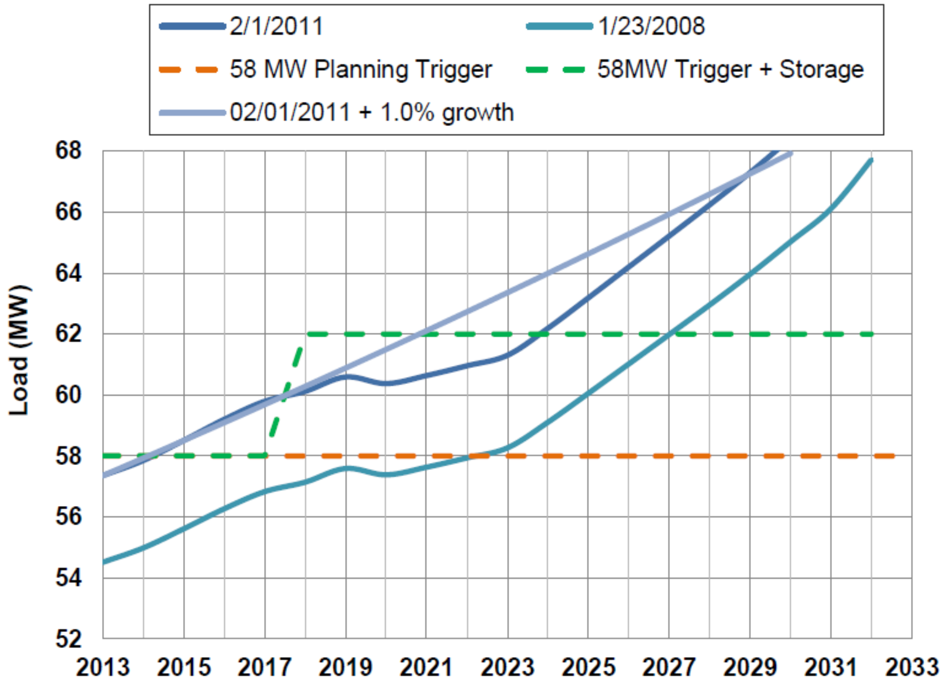
PV = Present value

FV = Future value

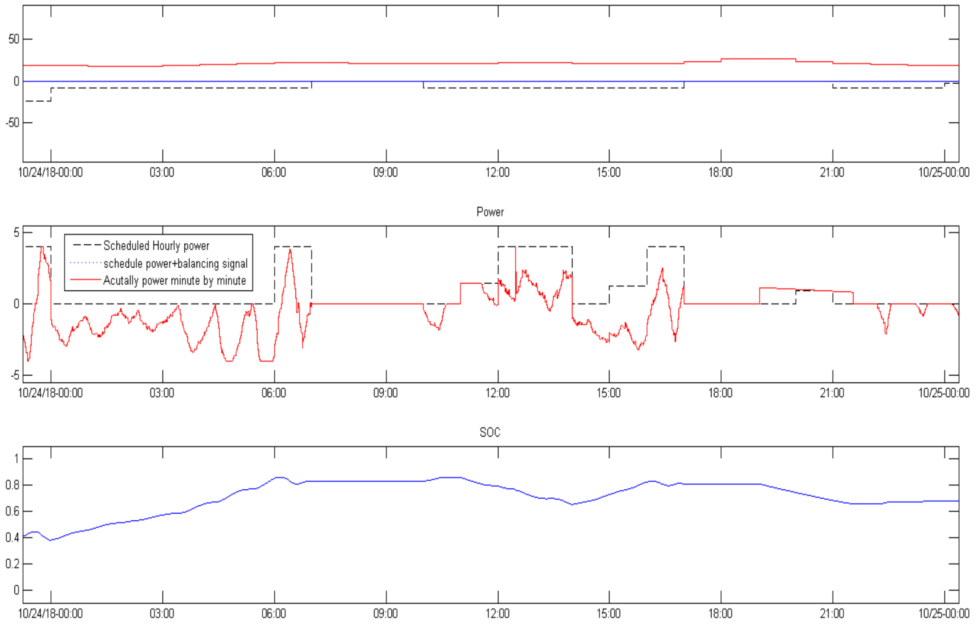
i = Cost of capital

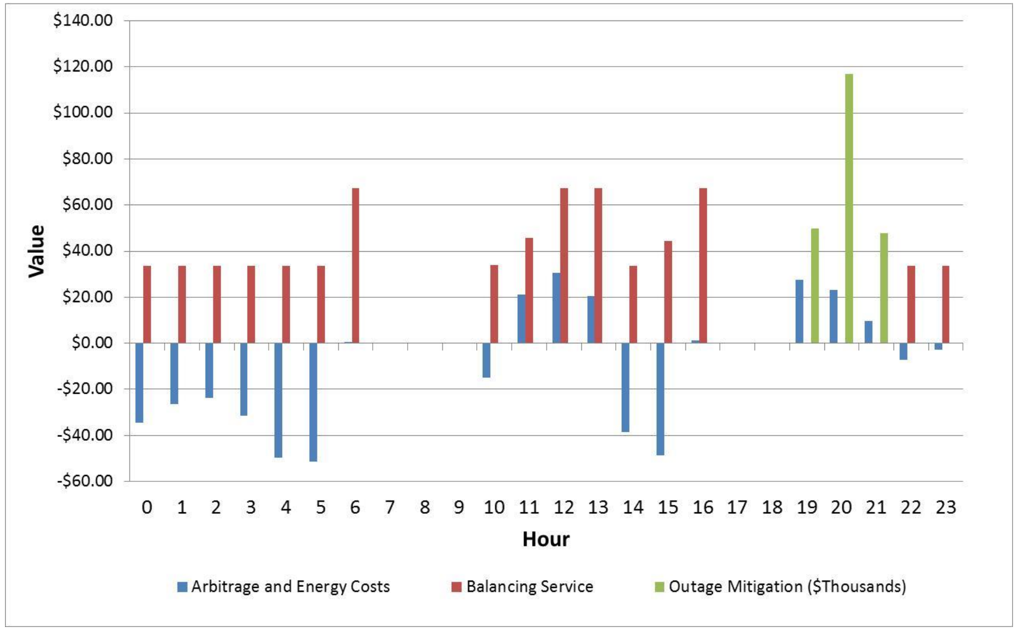
n = Number of years

*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 – PV = $10 million*1.03^6 / (1+.08)^6 = $7.5 million.*



Bundling Services: How To Do it Optimally





Key Lesson: A valuation tool that co-optimizes benefits is required to define technically achievable benefits.

- Multi-dimensional co-optimization procedures required to ensure no double counting of benefits
  - ESSs are energy limited and cannot serve all services simultaneously
  - By using energy in one hour, less is available in the next hour
- Energy storage valuation tools are required

Example Energy Storage Projects

1. Portland General Electric – Salem Smart Power Center

2. U.S. Department of Defense – Joint Forces Training Base Los Alamitos

(1) Portland General Electric (PGE) Salem Smart Power Center (SSPC)

- Developed as an R&D project under the Pacific Northwest Smart Grid Demo as part of the American Recovery and Reinvestment Act of 2009
- The U.S. Department of Energy (DOE) provided half of the funding
- 5 MW – 1.25 MWh lithium-ion battery system built and managed by PGE

- Potential energy storage benefits:
  - Energy arbitrage
  - Participation in the Western Energy Imbalance Market (EIM)
  - Demand response
  - Regulation up and down
  - Primary frequency response
  - Spin reserve
  - Non-spin reserve
  - Volt-VAR control
  - Conservation voltage reduction

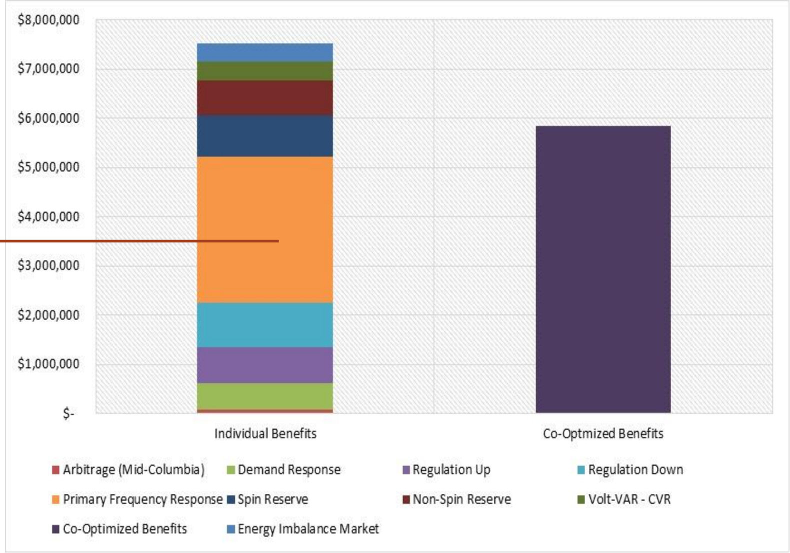
Western Energy Imbalance Market

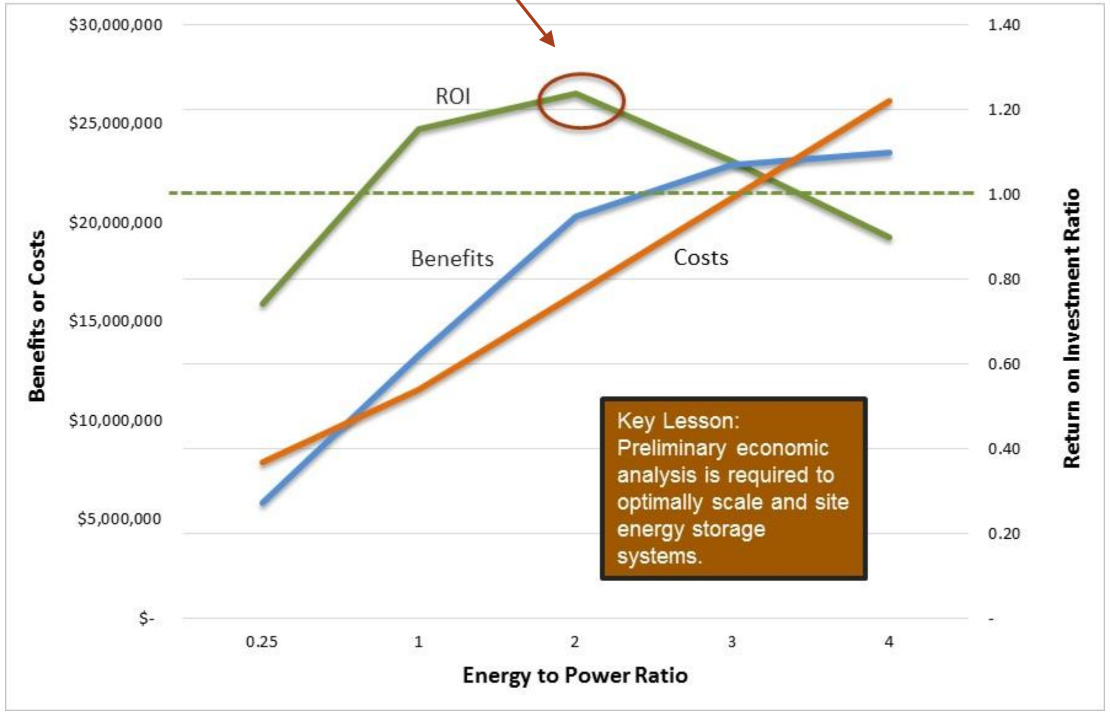
Optimal Scaling of the SPCC

- Evaluated individually the total 20-year value of SSPC operations exceeds $7.5 million in PV terms. When co-optimized, revenue falls to $5.8 million
- At an energy to power ratio of 0.25, the SSPC is not well suited to engage in most energy-intensive applications, such as arbitrage and ancillary services, so revenue is lost during the co-optimization process.

- By upsizing the energy storage capacity to 10 MWh, the return on investment ratio yields a positive result at 1.24

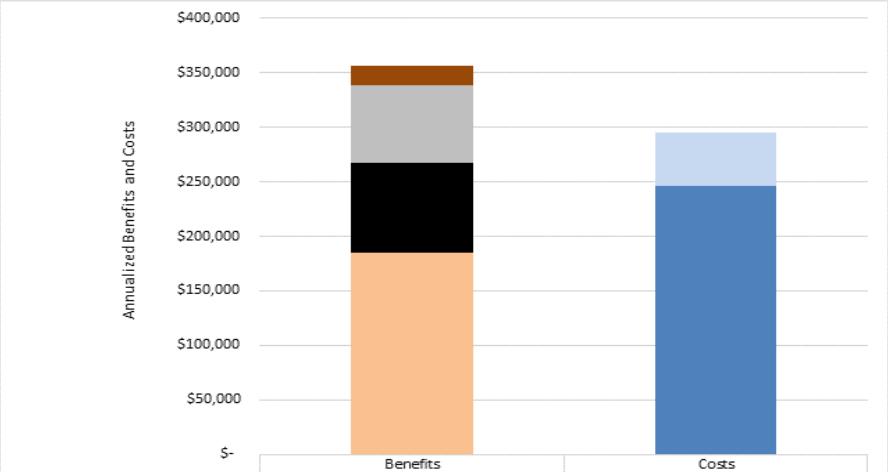
Technically Unachievable



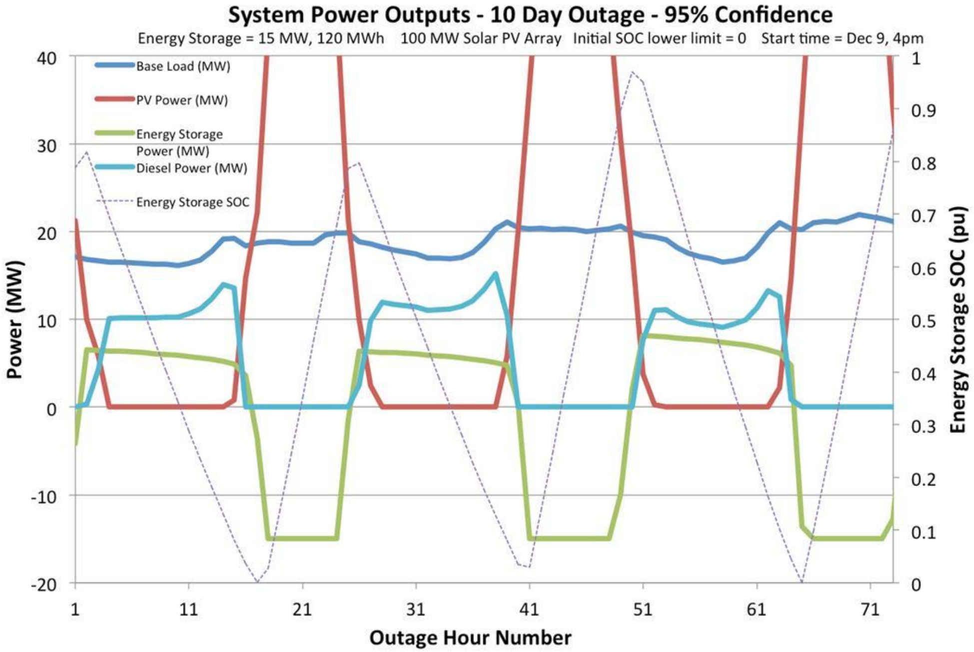


(2) Joint Forces Training Base Los Alamitos, CA.

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



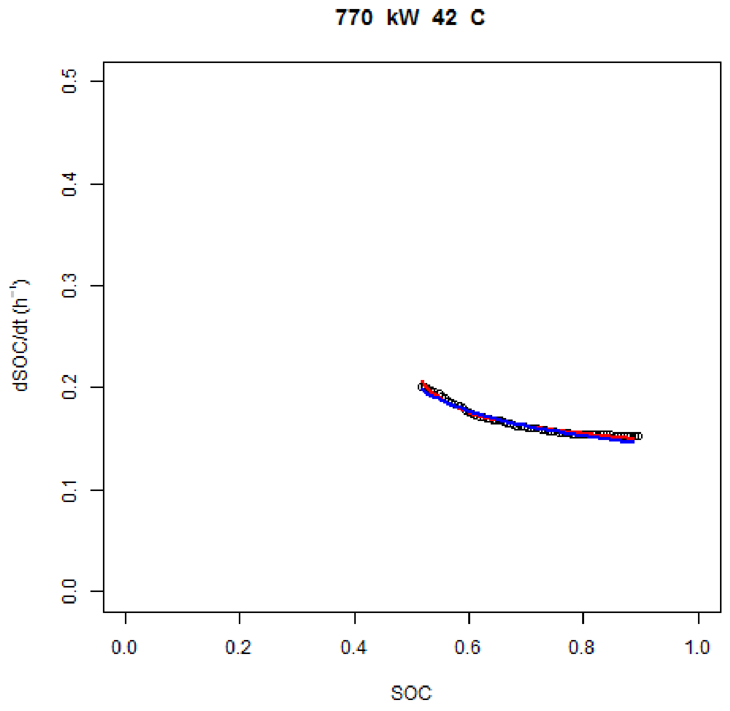
	Benefits	Costs
Mid-peak demand charge red.	$17,500	
On-peak demand charge red.	$71,400	
Facility demand charge red.	$81,900	
Energy charge red.	$185,100	
O&M costs		$49,030
Capital Costs		$245,751



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

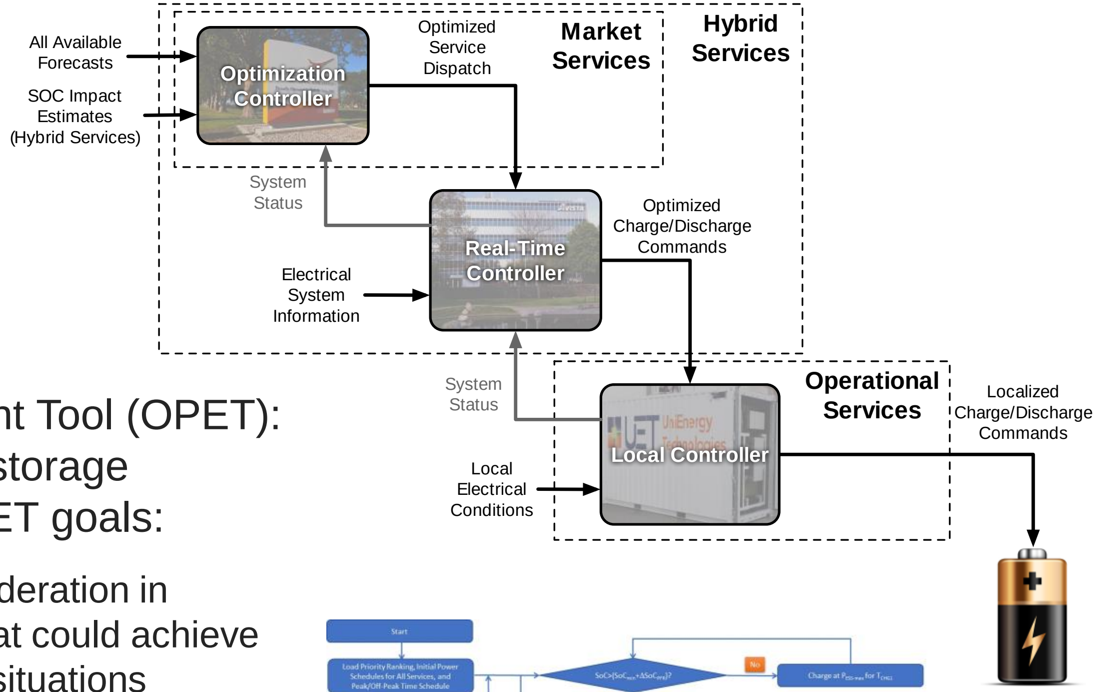
Importance of Operational Knowledge in Defining Value for Energy Storage and Capturing it in Real Time

- Results
  - Flow battery power and energy capacity ratings can be confusing; 1 MW / 3.2 MWh battery provides ~ 2 MWh of energy when discharged at 1 MW
  - Battery performance, measured in round-trip efficiency (RTE) varies based on power output level, state of charge (SOC) operating range, and temperature
  - Li-ion batteries provide RTEs in the 70-87% (83-91% w/o aux) for C/6 to C/2 cycling range; flow battery RTEs in the 58-65% range (66-75%) for C/9 to C/3 cycling
- Non-linear Performance Modeling
  - Model allows estimation of SOC during operation taking into account operating mode, power, SOC, and temperature
  - Model has been validated with data
  - Actual battery performance can be anticipated, thus providing a high degree of flexibility to the BESS owner/operator
  - Self-learning model applicable to energy type of storage system
- PNNL Building a Battery State of Health Model using CEF Data

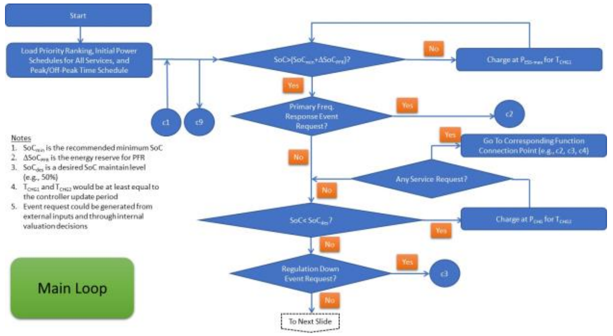


Energy Storage Control Algorithms

- Development of control strategies
  - Outline control strategies
  - Develop detailed design of control functions and reporting
  - Simulation/implementation of control functions.



- Optimization Performance Enhancement Tool (OPET): Tool for evaluating commercial energy storage controllers operating at utility sites. OPET goals:
  - Enhance learning of the inputs for consideration in developing storage control strategies that could achieve targeted economic values in real-world situations
  - Enhance performance by finding logic errors in control strategies
  - Evaluate impacts of forecast error on control strategies.



Key Lesson: Development of control strategies is required to obtain value in real-time. We should not compete in developing real-time control systems; rather, we should propel the industry forward through development of advanced algorithms and OPET.

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., PUDs, co-ops, large utilities operating 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 states of charge and battery degradation caused by cycling.

Acknowledgments

Dr. Imre Gyuk, DOE – Office of Electricity Delivery and Energy Reliability

Bob Kirchmeier, Clean Energy Fund Grid Modernization Program, Washington State Energy Office

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

Patrick Balducci
PNNL
Patrick.balducci@pnnl.gov
(503) 679-7316

https://energystorage.pnnl.gov/