Energy Storage Applications and Value Streams

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Key Questions Discussed in This Session

- What grid services can energy storage systems (ESSs) provide, and what is the significance of "stacking benefits"?
- Are the values associated with grid services provided by ESS consistent between, or specific to, individual utilities? If specific, why do they differ and what is the nature of these differences? How can they be measured?
- How can utilities effectively site, size and control energy storage in order to maximize benefits, and how important is this process?
- What regulatory engagement is PNNL currently involved in?

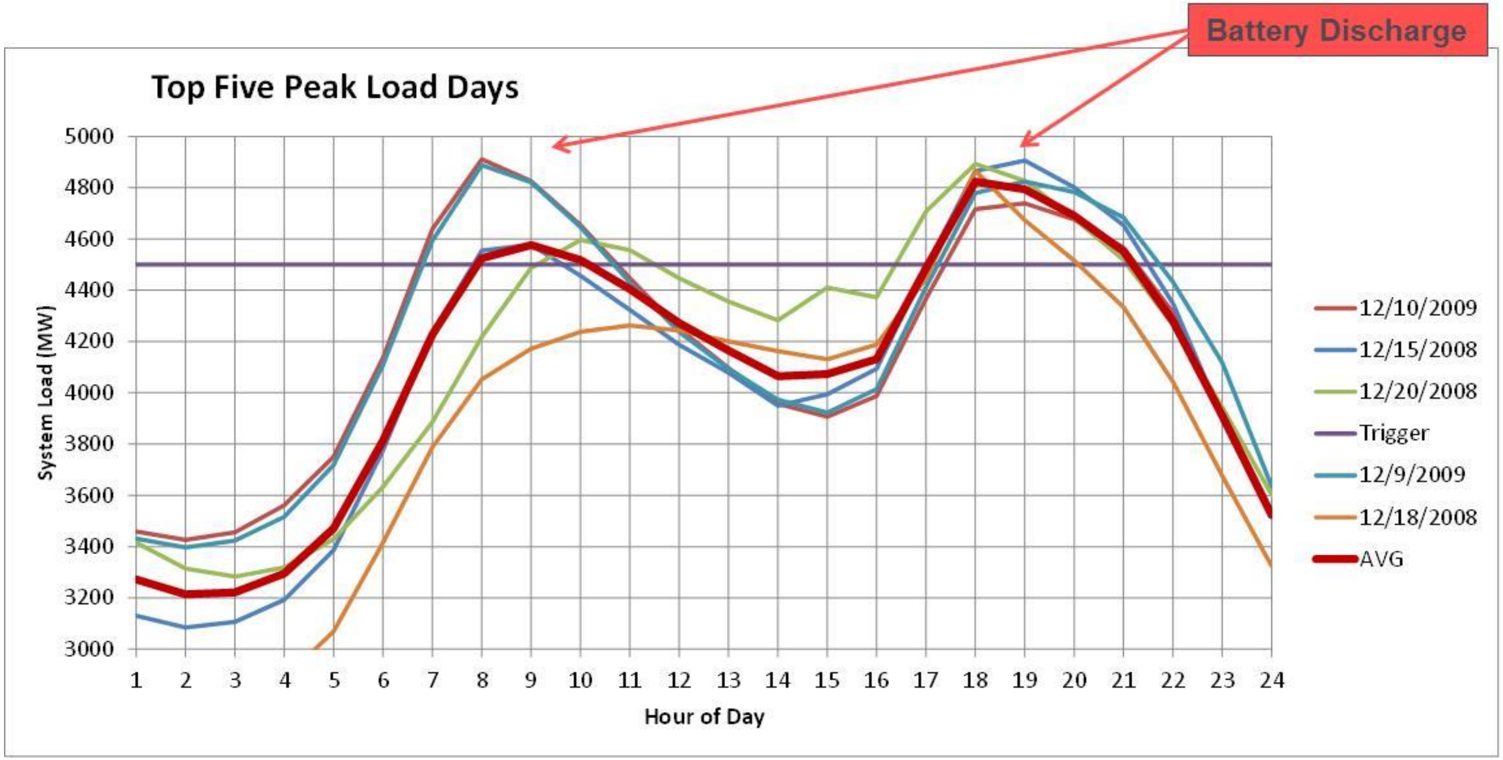
Key Concepts

- ESSs provide services or functions or values; a use case is a service that is specific to an installation
- Energy storage comes in many forms:
  - Battery energy storage (li-ion, flow batteries, na-s)
  - Compressed air energy storage
  - Pump storage hydro
  - Flywheels
- Categories of services:
  - Bulk energy – arbitrage and capacity
  - Ancillary services – regulation, spin and non-spin reserve, load following
  - Transmission congestion relief and asset deferral
  - Distribution deferral and voltage support
  - Customer benefits – bill reduction, outage mitigation, power quality
- Services/functions/values have to be stacked properly to avoid double counting, and a simulation/co-optimization process is required
- ESSs have both power and energy capacities and optimal sizing is important.

Benefit 1 – Peak Shaving

- Capacity value based on the incremental cost of next best alternative investment (peaking combustion turbine) with adjustments for the incremental capacity equivalent of energy storage and line losses
- Distribution upgrade deferral based on present value benefits of deferring investment in distribution system upgrades

Key Lesson: Values will differ based on presence of markets, local distribution system conditions, and valuation policies.



Benefit Example 2 – Energy Arbitrage

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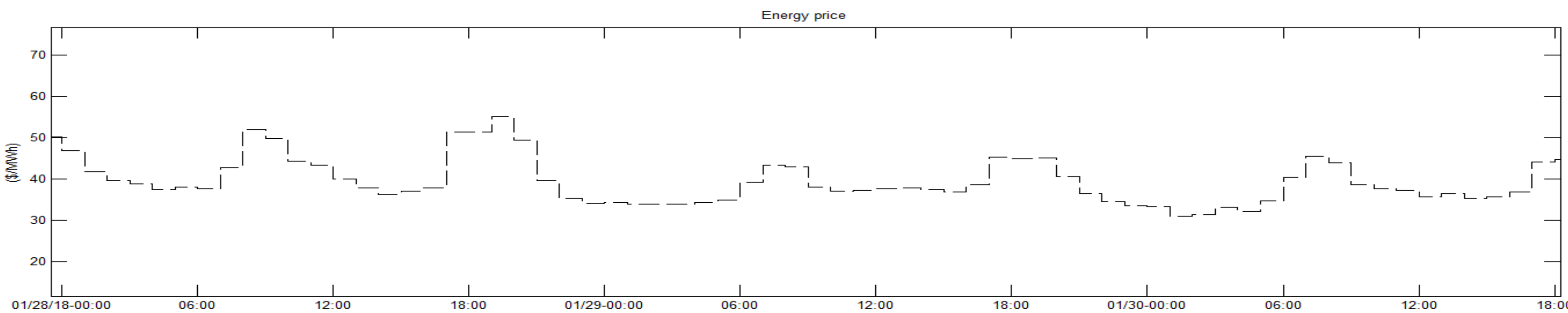
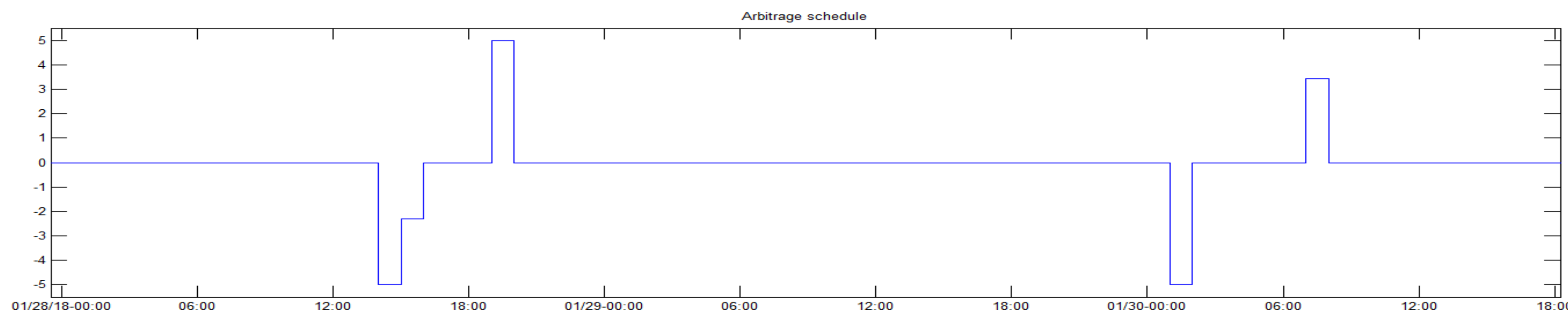
- Hourly indexed day-ahead or real-time energy market used to determine peak / off-peak price differentials
- Value obtained by purchasing energy during low price hours and selling energy at high energy price hours – efficiency losses considered

Key Lesson: Profitability differs significantly by region; profit also affected by round trip efficiency of the ESS.





Benefit Example 3 – System Flexibility

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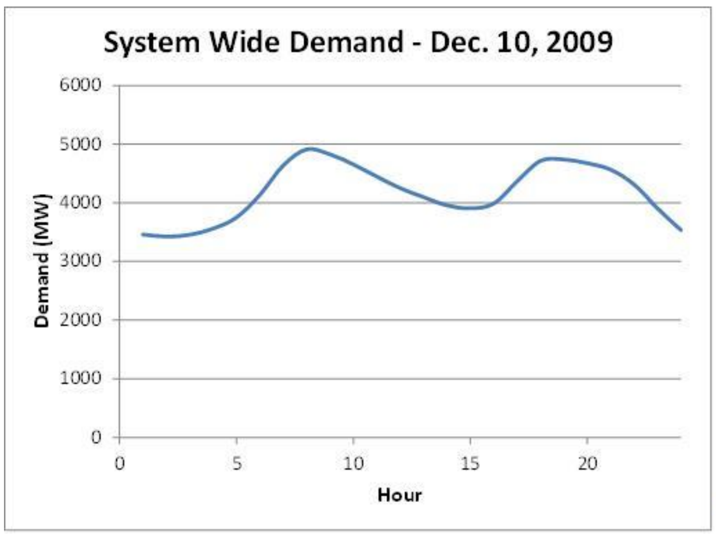
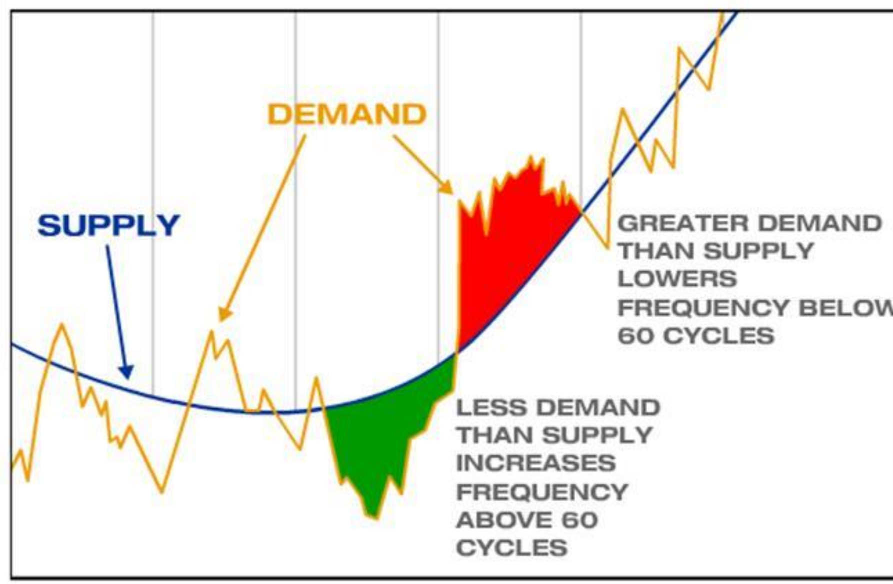
- Battery fills the short-term gaps between supply and demand
- Reduces cost and emissions associated with idling fossil-fuel burning plants





Benefit Example 4 – 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 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

	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.

Key Lesson: Benefits, which can be very large, accrue primarily to the customer and are largely dependent on the effective placement of the ESS. If focused on utility benefits, we would focus on violation costs or lost energy sales.

Grid Functions and Tools to Estimate Values

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	Location/Service	Analysis Tools
	Transmission System	
1	Arbitrage	Production cost modeling
2	Balancing Regulation	Stochastic model w. & w/o valuation, KERMIT
3	Capacity	Financial models
	Distribution System	
4	Transformer Deferral and Volt/VAR Control	GridLab-D, OpenDSS
5	Upgrade Deferral	Financial Models
6	PV Integration	Gridlab-D, OpenDSS
7	Outage Mitigation	
	Customer Side	
	Industry, School, Multifamily	Optimization tools
	Bundled Services	Energy Storage Evaluation Tool (E3/EPRI), Battery Storage Evaluation Tool (PNNL), ESWare™ (24M), ES-Select™ (DNV-KEMA)

Eugene (OR) Water and Electric Board

Microgrid Project

- 500kW energy storage + 125kW PV + diesel gen sets at three aggregated sites
- Benefits of energy storage:
  - Peak shifting
  - Transmission congestion relief
  - Minimizing balancing service payments to BPA
  - Energy arbitrage
  - Volt-VAR control
  - Outage mitigation
  - Capacity / resource adequacy.
- EWEB working with Sandia National Laboratories and PNNL:
  - Define and monetize value of use cases
  - Evaluate design of planned microgrid.
- Energy storage at the three sites can be aggregated to provide grid benefits.

Northampton (MA) Microgrid Project

- Microgrid will bring multiple grid assets together in order to improve resiliency
  - Biomass
  - Photovoltaics
  - Diesel generators
  - Energy storage
- Microgrid would island three abutting campuses in the event of an outage
  - Northampton Dept. of Public Works
  - Smith Vocational and Agricultural High School
  - Cooley Dickinson Hospital
- Potential energy storage benefits:
  - Reduce energy and demand charges
  - Provide black start capability to the biomass facility, thereby allowing it to run during extended outages
  - Reduce diesel consumption during an outage and improve resiliency
  - Forward capacity market revenue
  - Regional network service revenue.

With DOE support, PNNL will model microgrid operations in order to evaluate the financial benefits; PNNL will also optimally scale the energy assets during the design phase.

Salem (OR) Smart Power Center

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- Salem Smart Power Center is comprised of a 5 MW – 1.25 MWh lithium-ion battery system built and managed by Portland General Electric (PGE)
- Recent demonstrations of value
  - Integration of renewables onto the grid (reduce intermittency of local 114-kW solar array)
  - Stabilization of grid frequency during recent power sag
  - Simulation of local microgrid, establishing a high-reliability zone
- Potential energy storage benefits:
  - Energy arbitrage
  - 400 kW of demand response capacity
  - 2-4 MW of real-time frequency and voltage regulation
  - kVAr support and control on the distribution feeder
  - Renewables integration
  - 5 MW of load response to under-voltage
  - Adaptive conservation voltage reduction
  - Emergency power for OR National Guard command
  - Intra-hour load balancing.

With DOE support, PNNL will model battery operations to determine the long-term financial benefits or value to PGE.

Energy Storage for the Puget Sound Energy (PSE) Region*

Project objective: Analyze and demonstrate the benefits of electrical energy storage on the distribution grid

Situation

- 25MVa transformers at radial substations at Murden Cove and Winslow operate at or above target load

Requirements

- Multiple hours of capacity required
- Small footprint to fit within a substation
- Year-round operation capabilities
- Flexibility to perform multiple applications (e.g., balancing svcs., islanding)

Novel technical solution

- Containerized, electrochemical energy storage with a 2nd generation flow battery technology

*Research Funded by the U.S. Department of Energy, Office of Electricity Delivery and Energy Reliability, Energy Storage Program and the Bonneville Power Administration.

Battery Storage Evaluation Tool (BSET) User Interface

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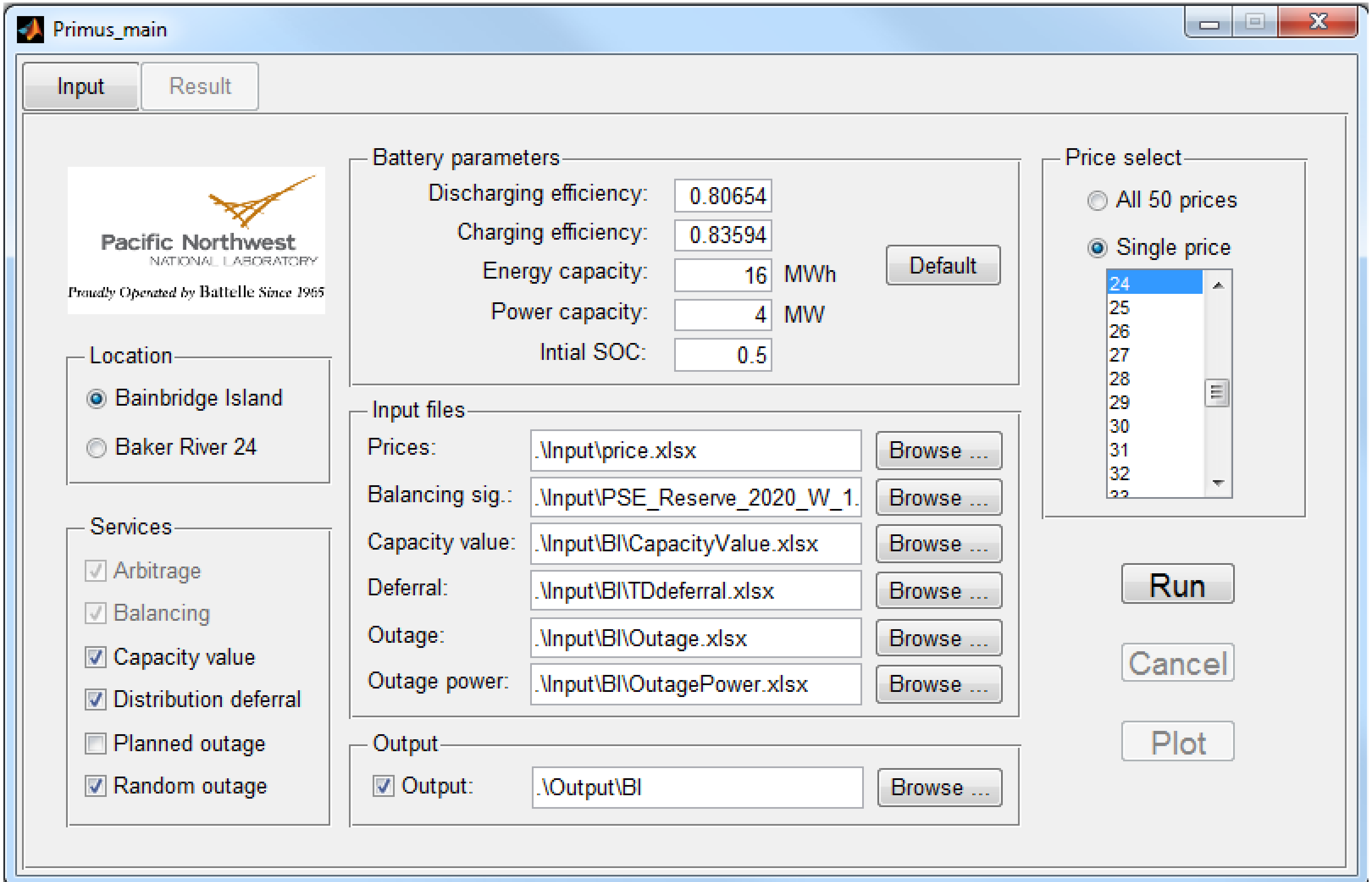
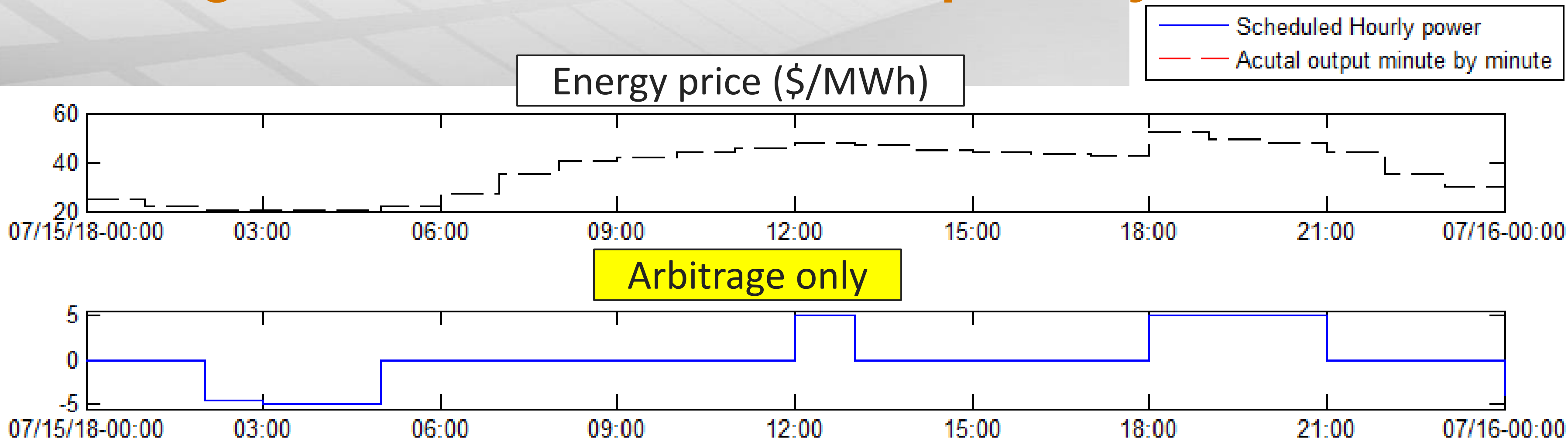


Bundling Services: How To Do It Optimally?



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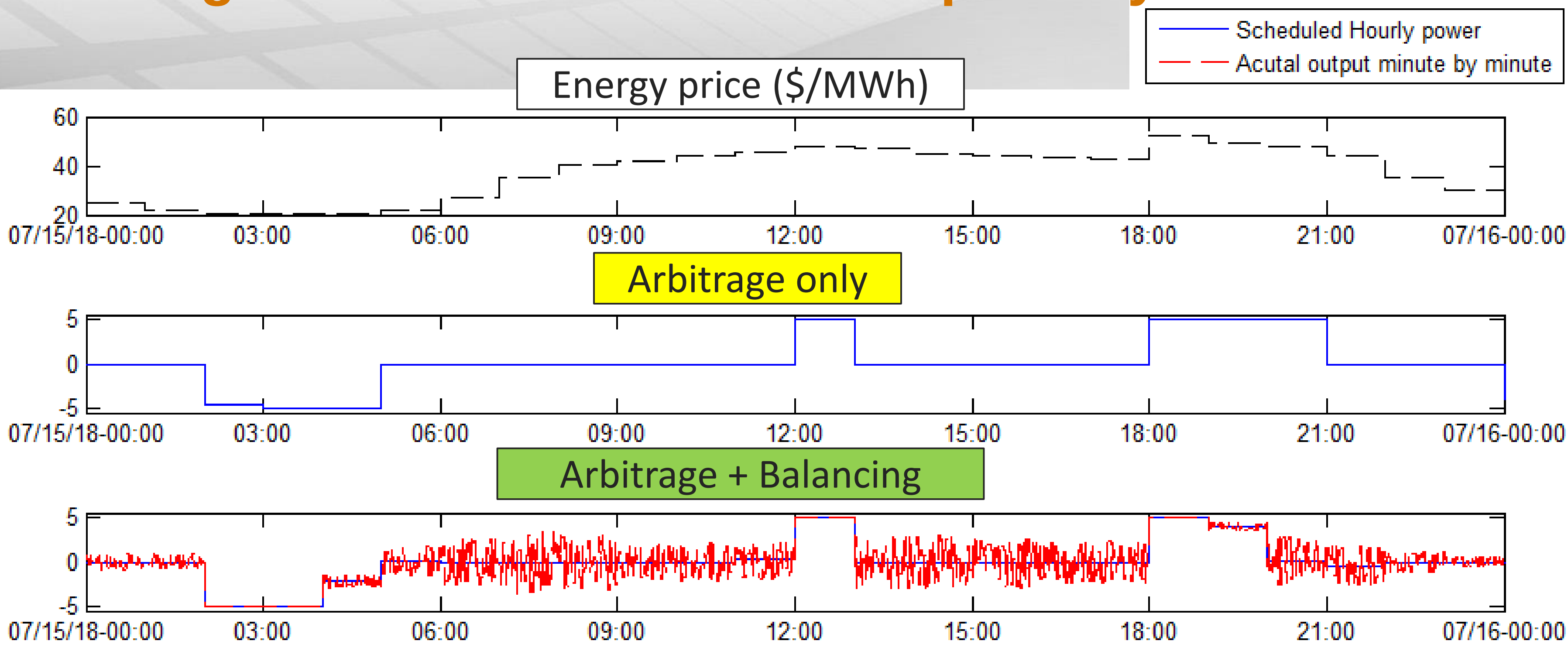

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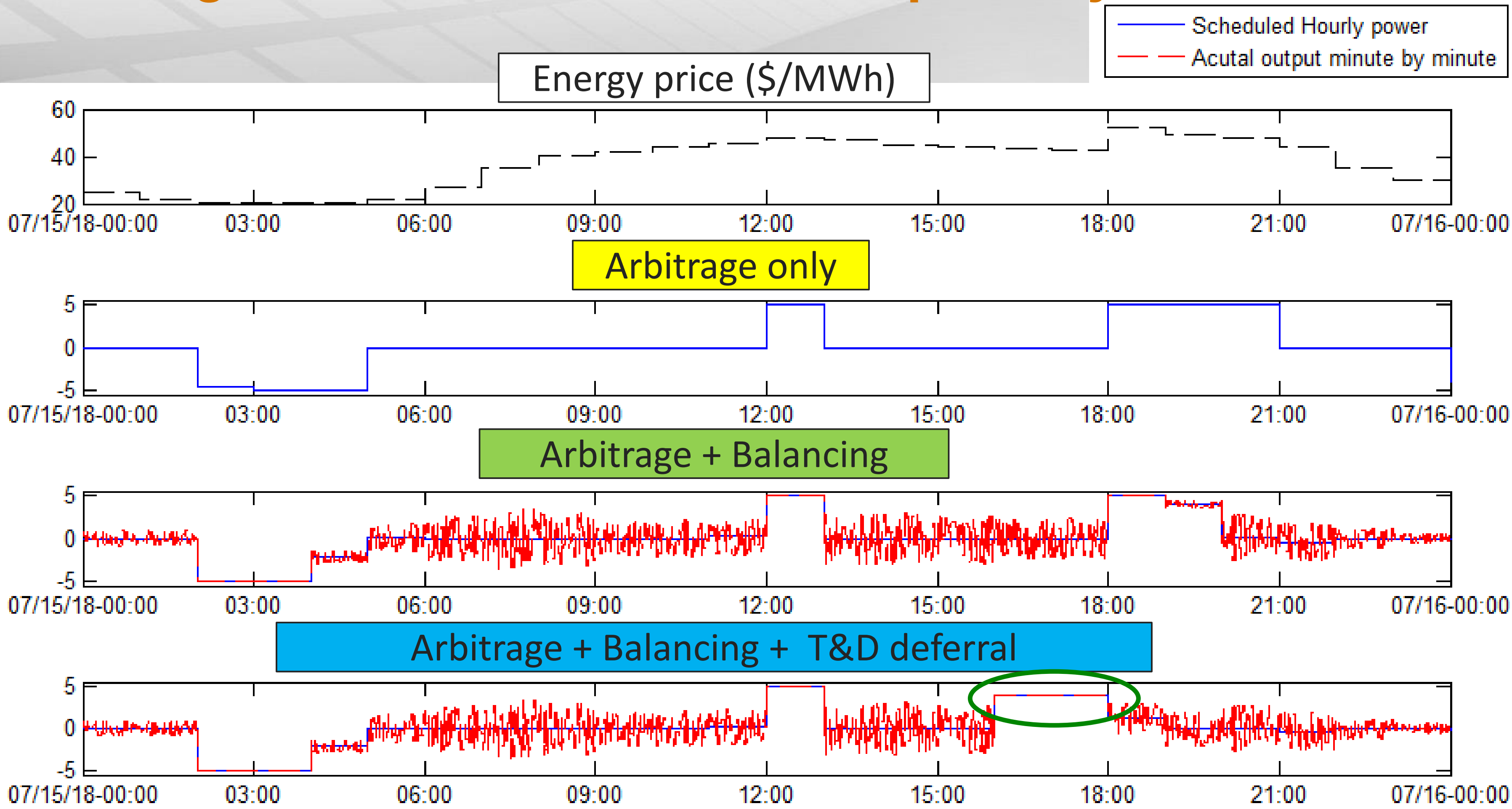

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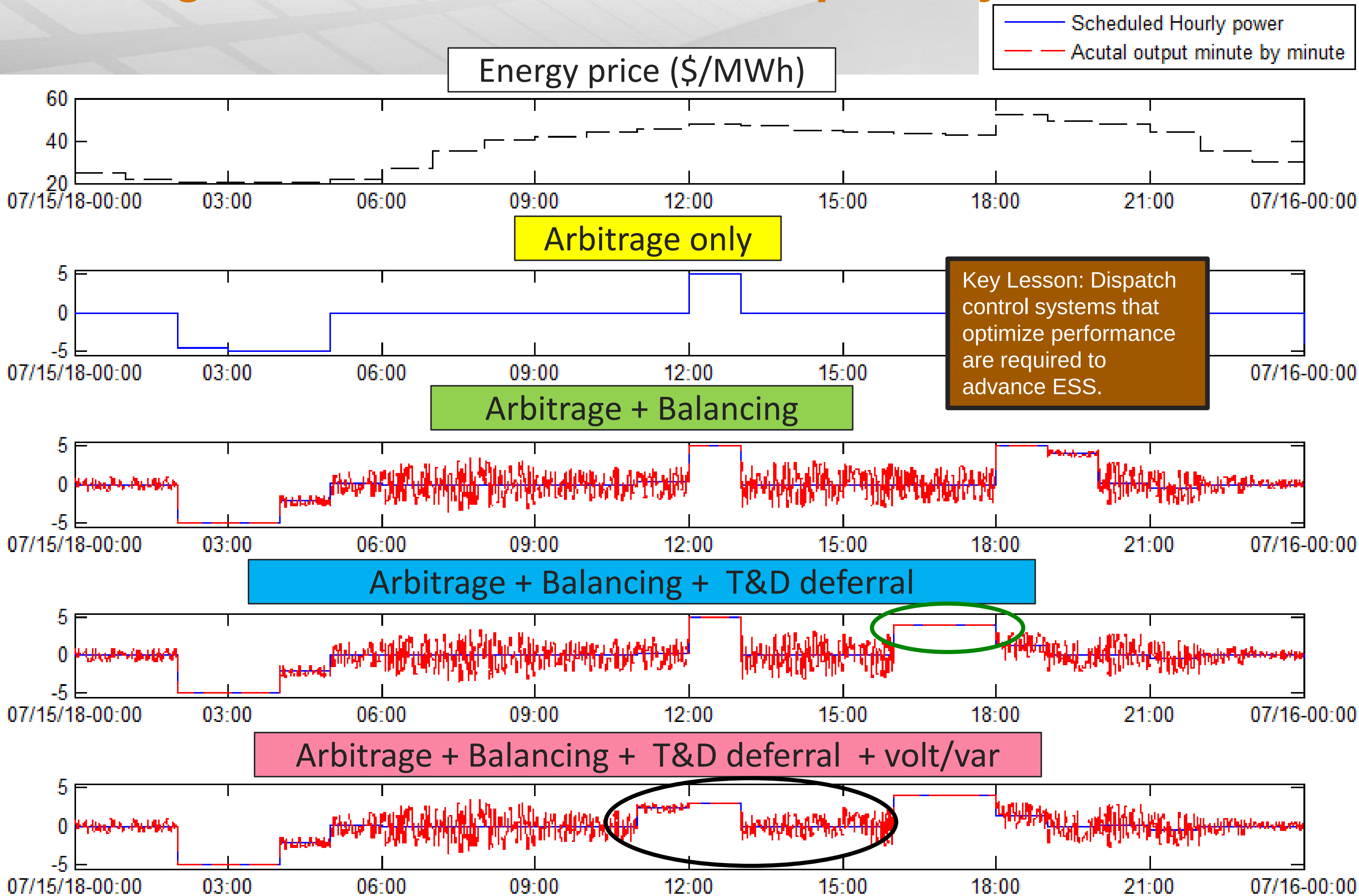
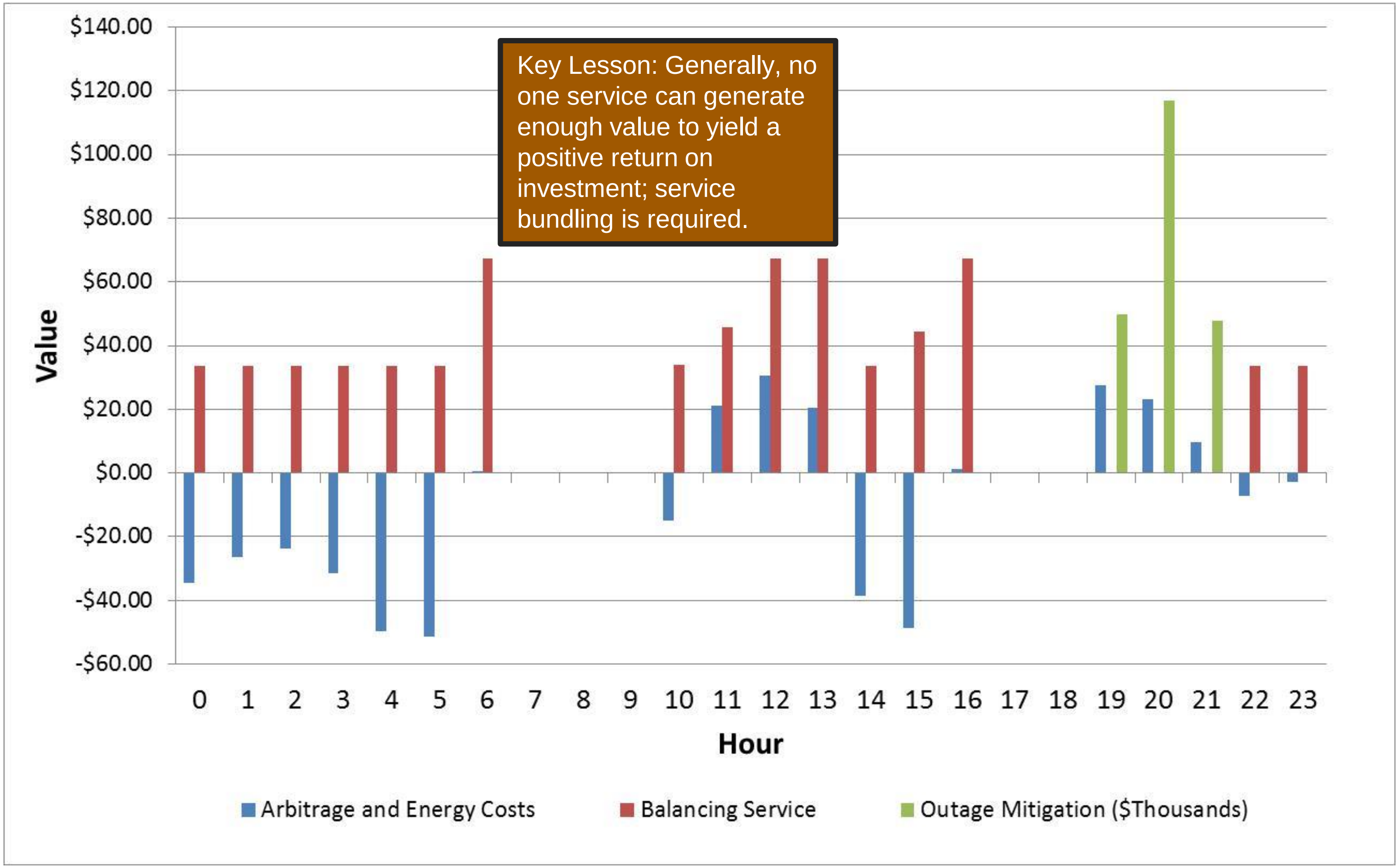
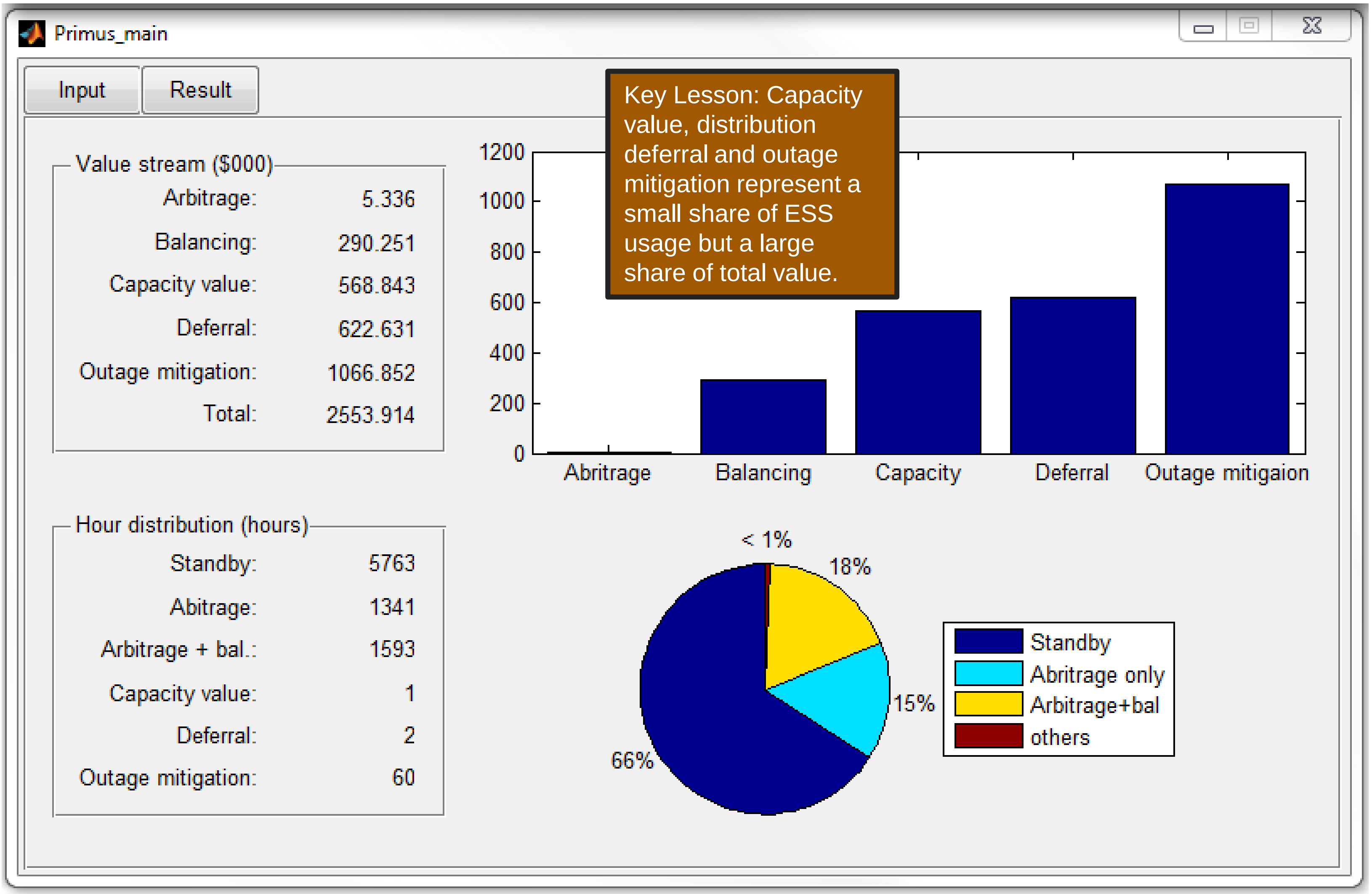


Key Lesson: Dispatch control systems that optimize performance are required to advance ESS.

Hourly Value at Bainbridge Island for 24-Hour Period

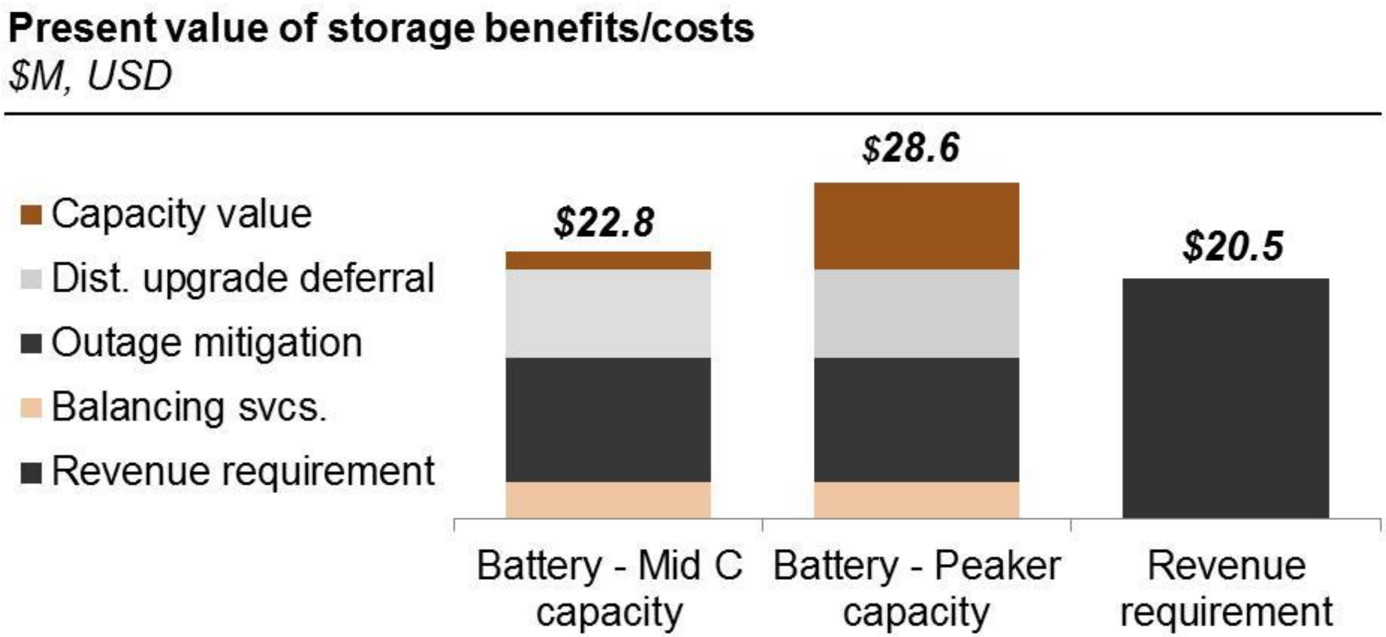


BSET Output



Key Lesson: Capacity value, distribution deferral and outage mitigation represent a small share of ESS usage but a large share of total value.

Economics and Additional Benefits Bainbridge Island, WA



Key Lesson: When effectively sited and operated, energy storage can yield positive returns to investors.

- Regardless of capacity assumption economics "pencil out"
- Additional "difficult to quantify" value in
  - Knowledge transfer
  - Institutional know-how
  - Public awareness

Washington Clean Energy Fund (CEF) Energy Storage Analytics Program Synopsis

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Objective

- Provide a framework for evaluating the technical and financial benefits of energy storage, and exploring the value that energy storage can deliver to Washington utilities and the customers they serve.

Phases

Phase 1: **Data and Data Systems** → ***Phase 2: Use Cases / Performance Monitoring*** → ***Phase 3:*** **Evaluation**

1) Develop Data Requirements and Data Systems
2) Install Energy Storage Systems (ESS), Run Use Cases, and Document Technical Performance
3) Evaluate Technical and Financial Performance

Team

- **PNNL:** Brings expertise in energy/economics/environment system analysis and modeling
- **PSE, SnoPUD, and Avista:** Bring deep operational experience and required utility data / test sites
- **Washington Dept. of Commerce**: Program management

Department of Commerce
Innovation is in our nature.

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AVISTA

PSE PUGET SOUND ENERGY

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

Washington State Clean Energy Fund Energy Storage Projects

Avista
1 MW / 3.2 MWh vanadium-flow battery

Puget Sound Energy
2 MW / 4.4 MWh lithium-ion/phosphate battery

Snohomish PUD
MESA 1 – 2 MW / 1 MWh lithium-ion battery
MESA 2 – 2 MW / 6.4 MWh vanadium-flow battery

Total – 7 MW / 15 MWh; $14.3 million state investment / $43 million total investment for energy storage systems

Washington Clean Energy Fund Use Case Matrix

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Use Case and application as described in PNNL Catalog	Avista	PSE	Sno – MESA1	Sno – MESA2	Sno - Controls Integration
UC1: Energy Shifting					
Energy shifting from peak to off-peak on a daily basis	Y	Y	Y	Y	
System capacity to meet adequacy requirements	Y	Y	Y	Y	
UC2: Provide Grid Flexibility					
Regulation services	Y	Y		Y*	
Load following services	Y	Y		Y*	
Real-world flexibility operation	Y	Y		Y*	
UC3: Improving Distribution Systems Efficiency					
Volt/Var control with local and/or remote information	Y		Y	Y	
Load-shaping service	Y	Y	Y	Y	
Deferment of distribution system upgrade	Y	Y			
UC4: Outage Management of Critical Loads		Y			
UC5: Enhanced Voltage Control					
Volt/Var control with local and/or remote information and during enhanced CVR events	Y				
UC6: Grid-connected and islanded micro-grid operations					
Black Start operation	Y				
Micro-grid operation while grid-connected	Y				
Micro-grid operation in islanded mode	Y				
UC7: Optimal Utilization of Energy Storage	Y	Y			Y

* A simulated set of signals will be provided by PNNL to test these use cases.

Regulatory Engagement Agenda This Year

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Analysis of resource planning applicability to energy storage

- Problem Statement: Traditional resource planning approaches do not provide visibility into energy storage system benefits. Resource plans evaluate the costs and risks of various resource portfolios in meeting forecasted load profiles with planning margins. The purpose of resource planning is primarily adequacy, with some accounting for flexibility.
  - Common practice for utilities to evaluate energy storage in resource planning on par with generating resources given an assigned cost rate ($/MW) with system portfolios generated at hourly intervals.
  - Resource plans are not designed to look at benefits that accrue to the transmission or distribution system; models are not intended to review sub-hourly services.
  - PacifiCorp: "Modeling tools that capture [all energy storage system] value streams are needed to evaluate potential incremental benefits (beyond what the traditional IRP models are capable of simulating)." Presentation at UM 1751 Oregon PUC Docket, February 29, 2016.

- Objective and Outcome: a report that provides state Commission staff with perspective on how well traditional resource planning tools evaluate energy storage opportunities and describes alternative methods to revealing energy storage system benefits within utility regulatory frameworks. If not IRPs, then how?

Regulatory Engagement Agenda This Year (ii)

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Incentive design

- Problem Statement: Traditional energy efficiency and renewable energy programs provide incentives on energy saved or generated. This architecture does not fit a storage system, which provides frequency regulation or benefits through absorption of energy.
  - Currently federal incentives are only available for storage to the extent that the system is associated with and stores energy from a solar energy system. The IRS recently invited comment on these practices by February 2016 (Notice 2015-70).
  - Federal proposals such as the federal STORAGE Act (introduced 2011 and 2013) and the Energy Storage Tax Incentive and Deployment Act (2016) would offer commercial and residential investment tax credits for storage; Hawaii's SB 2738 would offer a 25% tax credit for behind-the-meter residential and commercial energy storage systems.
- Objective and Outcome: a report describing the current suite of incentive mechanisms offered by utilities, states, and the federal government; and an analysis of the suitability of existing incentive mechanisms to energy storage development for maximum impact, considering cost drivers for technology deployment including upstream supply chain and manufacturing limitations

Conclusions

- Resource adequacy requirements and penetration of renewable, intermittent power are driving the need for investment in ESSs
- We have developed procedures to site and size ESSs and have made our tool (BSET) available for use; DOE has demonstrated a willingness to provide analytical support for proposed and existing ESS projects
- Any single use would rarely yield positive returns on investment; services usually must be bundled and co-optimized
- Maximizing the value of energy storage requires optimal siting, sizing, control and design of the ESS
- We are evaluating a broader set of use cases through our Washington CEF engagement; use case values differ significantly by utility
- Dispatch control systems that optimize performance are required to advance energy storage.
- Traditional resource planning approaches do not provide visibility into energy storage system benefits.

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Acknowledgments

Dr. Imre Gyuk - Energy Storage Program Manager, Office of Electricity Delivery and Energy Reliability, U.S. Department of Energy

Bob Kirchmeier - Senior Energy Policy Specialist, Clean Energy Fund Grid Modernization Program, Washington State Energy Office

More Information

- PNNL:
  - National Assessment of Energy Storage:
    http://energyenvironment.pnnl.gov/pdf/National_Assessment_Storage_PHASE_II_vol_1_final.pdf
    http://energyenvironment.pnnl.gov/pdf/National_Assessment_Storage_PHASE_II_vol_2_final.pdf
  - Energy Storage Valuation for Distribution Systems
    http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23040.pdf
  - Codes and Standards for Performance Measurements
    http://energyenvironment.pnnl.gov/pdf/PNNL_22010_ESS_Protocol_Final.pdf
  - Optimization Tool
    http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23039.pdf
- DOE/EPRI Storage Handbook
  http://www.sandia.gov/ess/publications/SAND2013-5131.pdf