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Challenges and Opportunities Associated with Energy Storage: Assessing Financial and Technical Performance

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August 25, 2015
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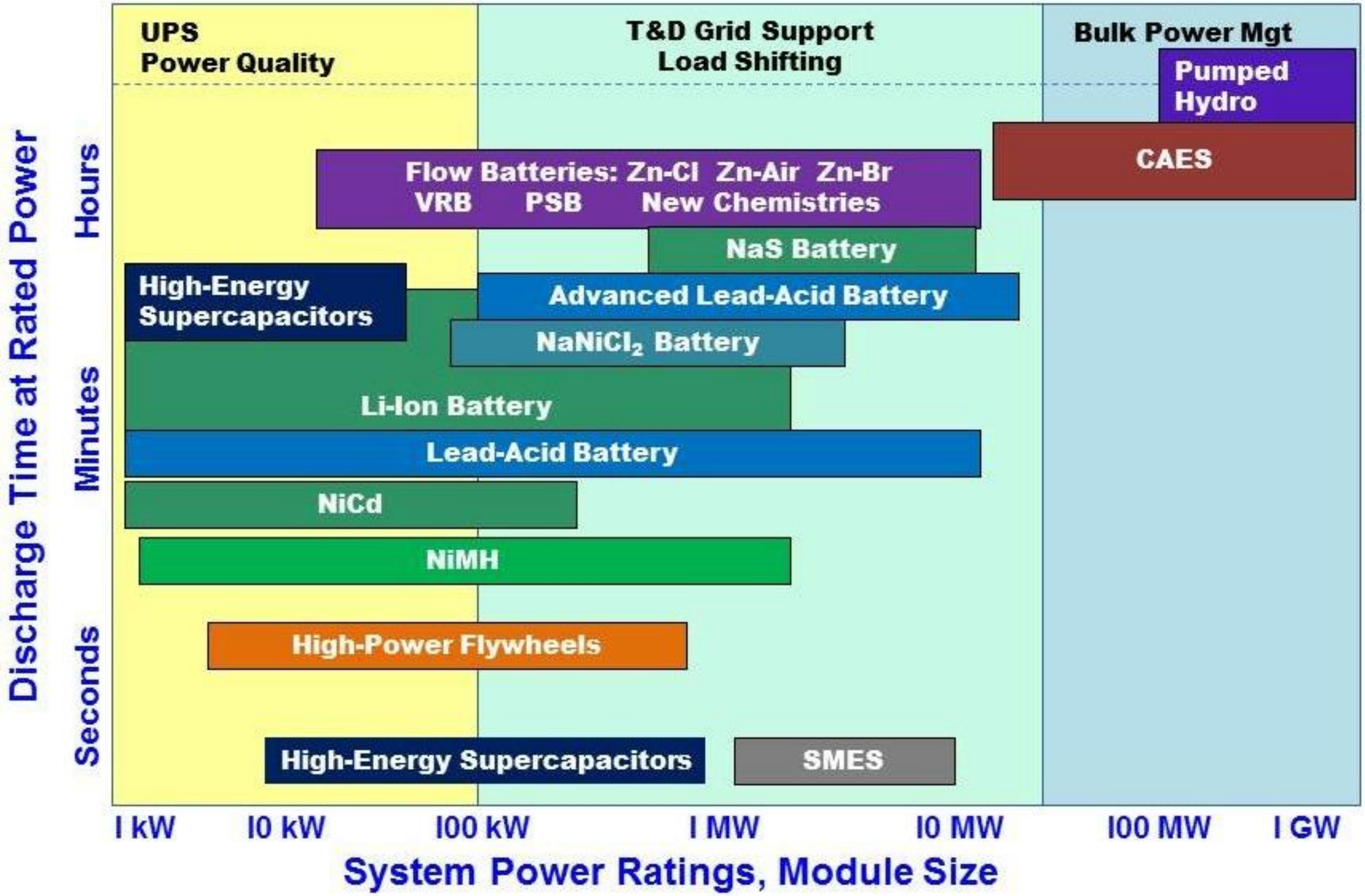
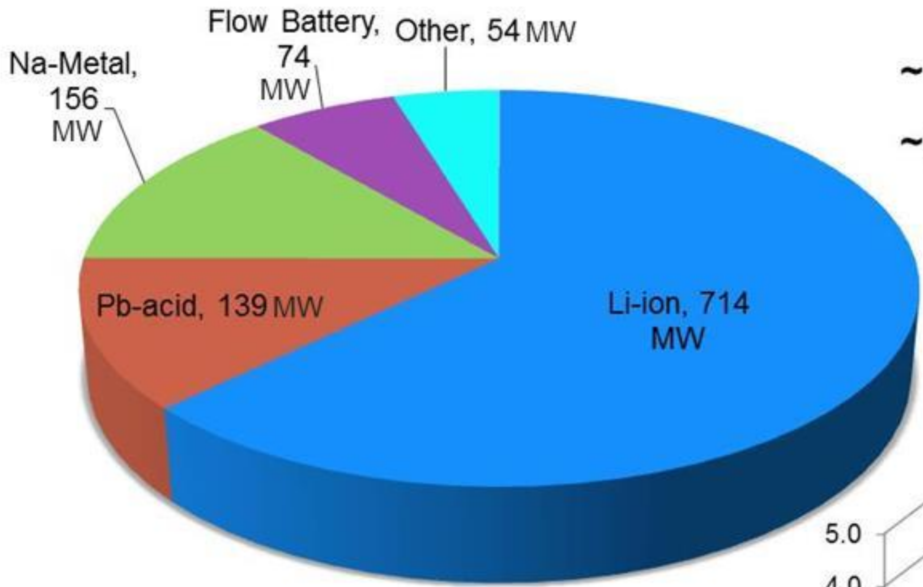
Key Questions Addressed in This Presentation

- What are the existing electric energy storage options for deployment in the grid and how are costs expected to change in the next 5-10 years for certain key chemistries?
- What grid services can energy storage systems (ESS) 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 are the primary challenges and barriers to expanded energy storage adoption?
- What lessons have been learned by evaluating recent energy storage projects?

Electrical Energy Storage Options

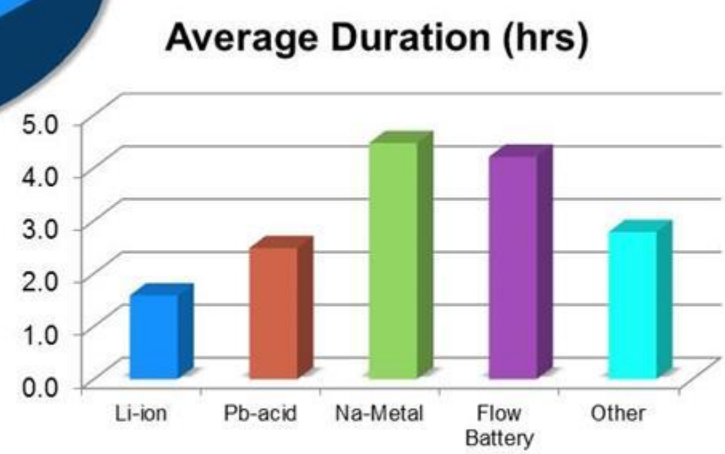


Current Battery Energy Storage Deployments



~ 1.1 GW of Battery Energy Storage

~110 GW of Pumped Hydro



- *Will focus on Li-ion and redox flow technology*

Source: *DOE Global Energy Storage Database http://www.energystorageexchange.org/*

Li-Ion History and Cost Reductions

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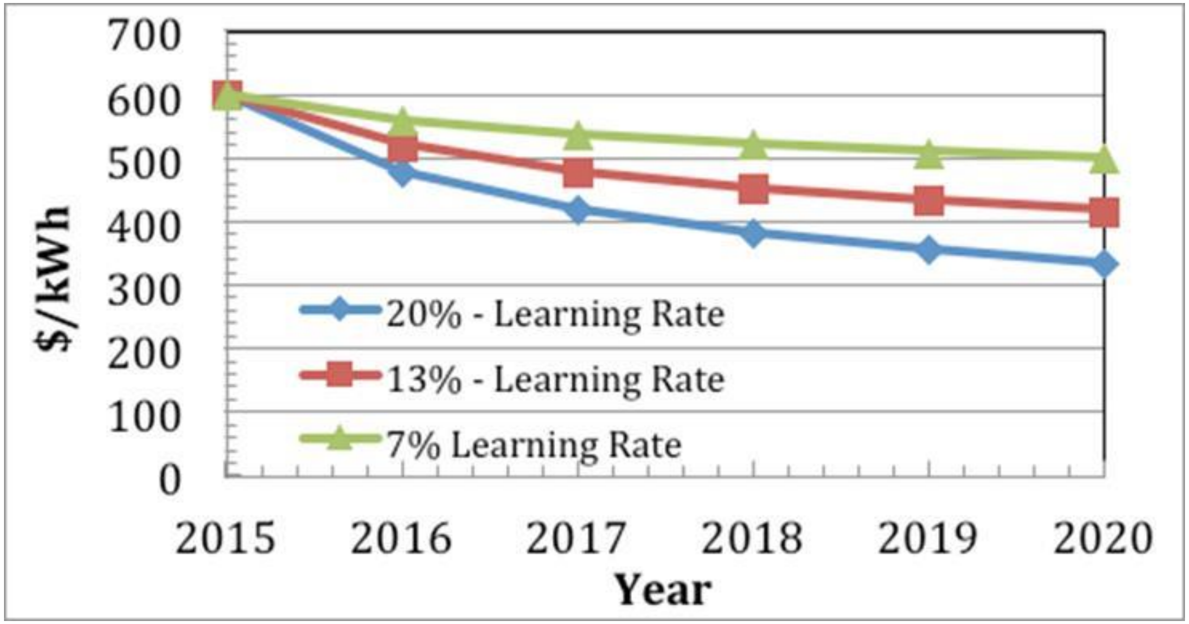
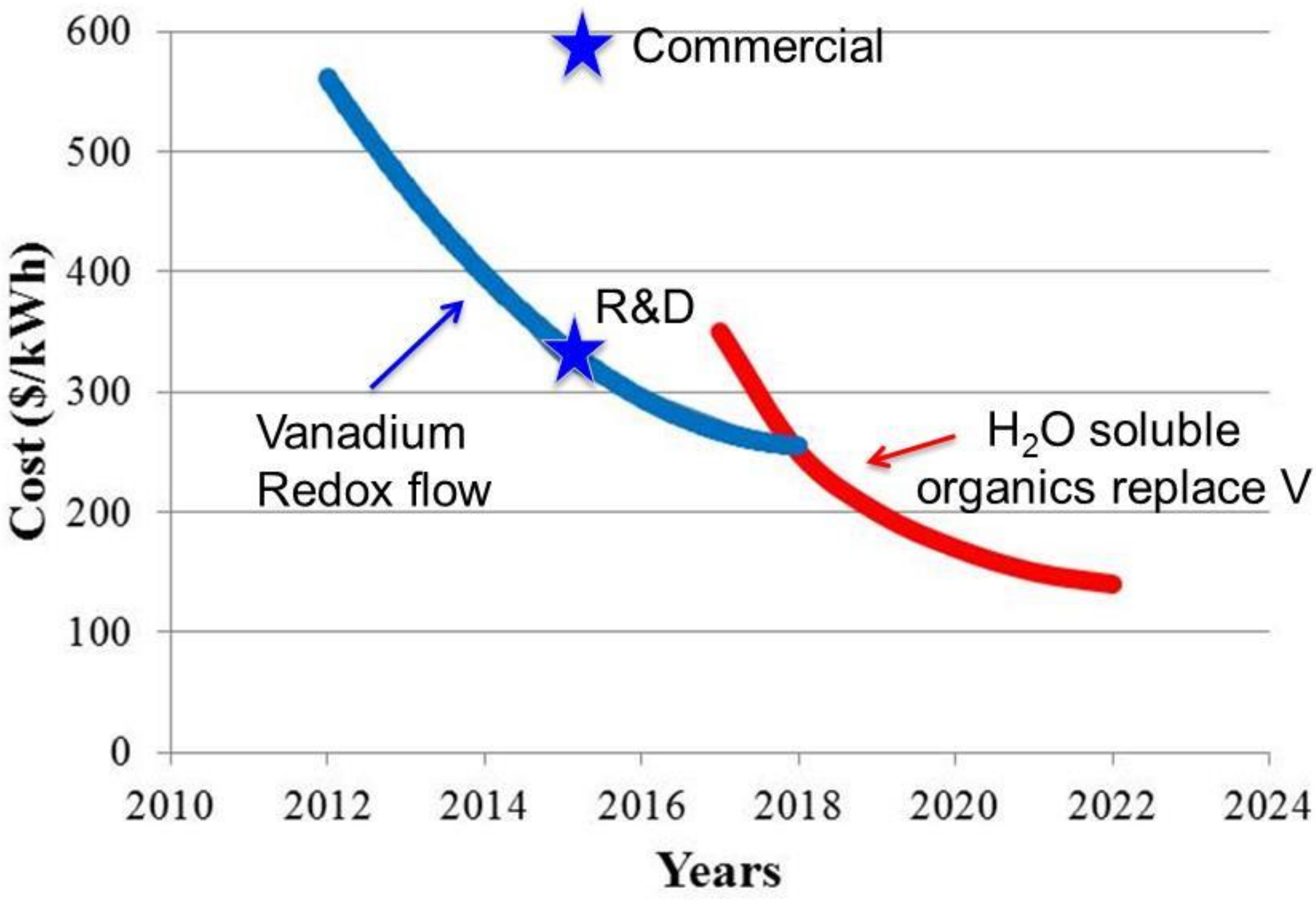
- History of Li-ion batteries:
  - Modern Li-ion battery (LiCoO2, C anode) developed in 1979/80
  - 1991 Sony releases first commercial product
  - 2014 estimate - 5 billion Li-ion batteries produced
- Li-ion consumer battery costs have dropped steeply
  - $1000/kWh in 2008
  - $250/kWh in 2015



- 2015 large battery system cost estimated to be $550 to $600/kWh: includes Battery Management System (BMS) and Power Conditioning System (PCS)
- Estimated volume growth for plug-in hybrid electric vehicle and electric vehicle helping increase battery production rate and lower costs.

Redox Flow Battery Cost Projections



Valuation Challenges

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Software Type	Number Reviewed
Electric System Planning Software	
Portfolio Planning	8
Energy Production Cost Simulation	11
Bulk Transmission Planning	7
Distribution System Planning	9
Real-Time Grid Operations	6
Energy Storage Systems	21
TOTAL	**62**

	Energy Storage Industry Stakeholders								
	ISOs/RTOs	Generators / IPPs	Utilities	R&D / Consulting	Project Developers	Technology Providers	End Users	Finance Community	State & Federal Regulators
System Planning									
Portfolio Planning	X	X	X	X	X				
Energy Production Cost Simulation	X	X	X	X	X				
Transmission System Planning	X	X	X	X	X				
Distribution System Planning			X	X	X				
Real Time Grid Operations									
Generation & Transmission System Operation	X	X	X						
Distribution System Operation			X	X					
Energy Storage System									
Estimate & Demonstrate Value		X	X	X	X	X	X	X	X
Calculate System Size		X	X	X	X	X		X	
Control & Operate Installed Systems	X	X	X	X	X	X	X		
Optimize System Performance	X	X	X	X	X	X	X		

- **Transmission and Distribution Planning**

  Models lack standard features that allow the user to properly model energy storage

- **Portfolio Planning**

  Gaps exist for recognizing storage in planning and energy production cost models

- **Energy Storage System Tools**

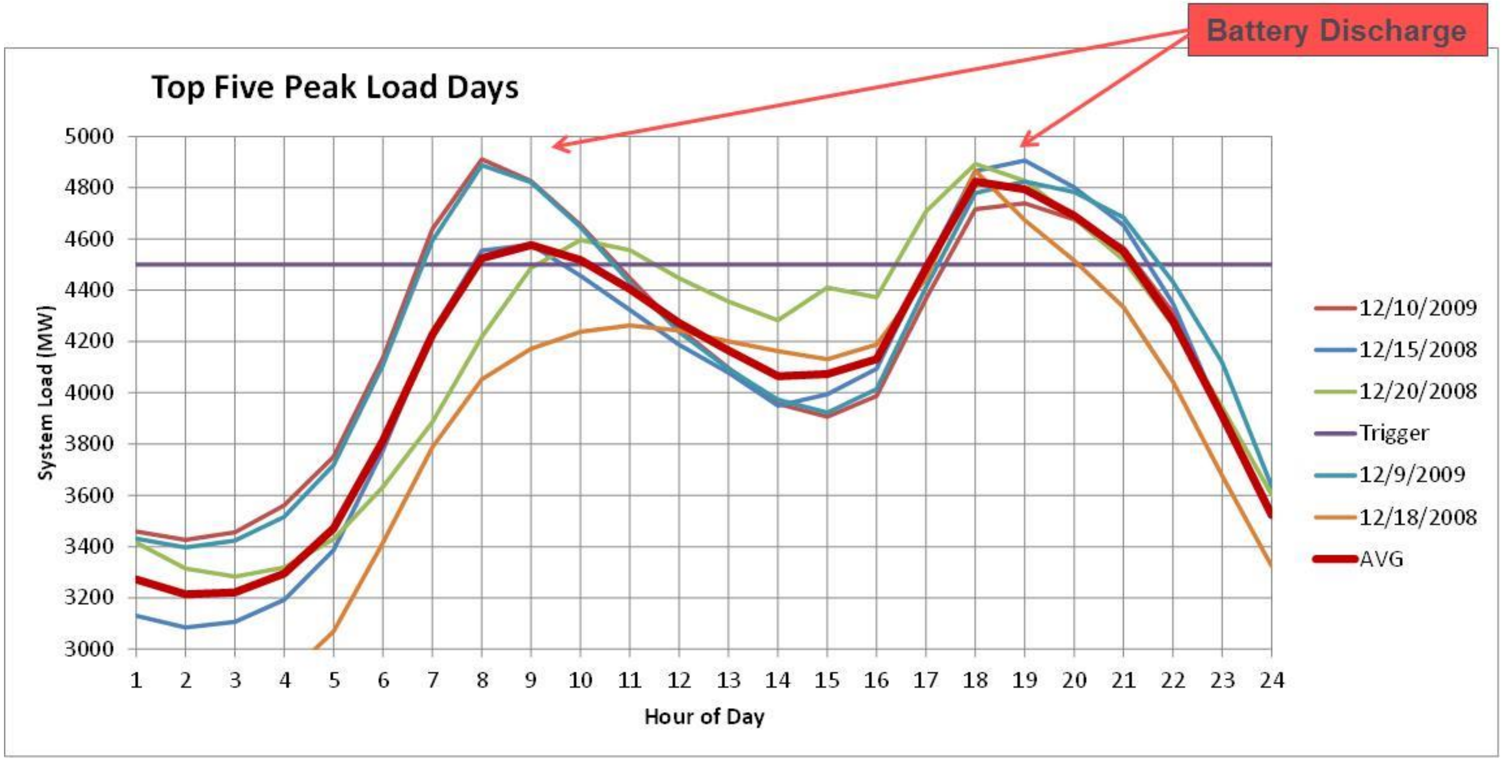
  Despite the variety of tools available, many stakeholders still feel that numerous gaps exists in ES-Specific software packages

Source: Navigant for Energy Storage Association
Presented: December 2013

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

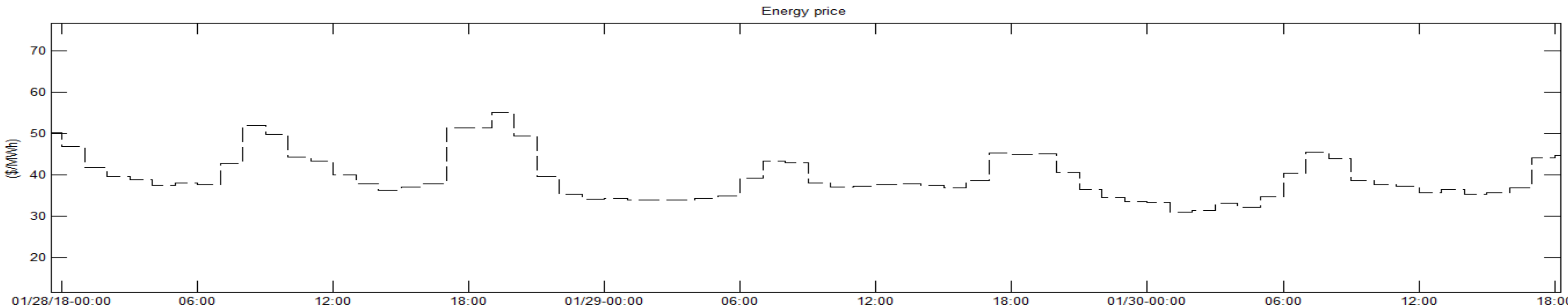
Key Lesson: Values will differ based on presence of markets, local distribution system conditions, and valuation policies.

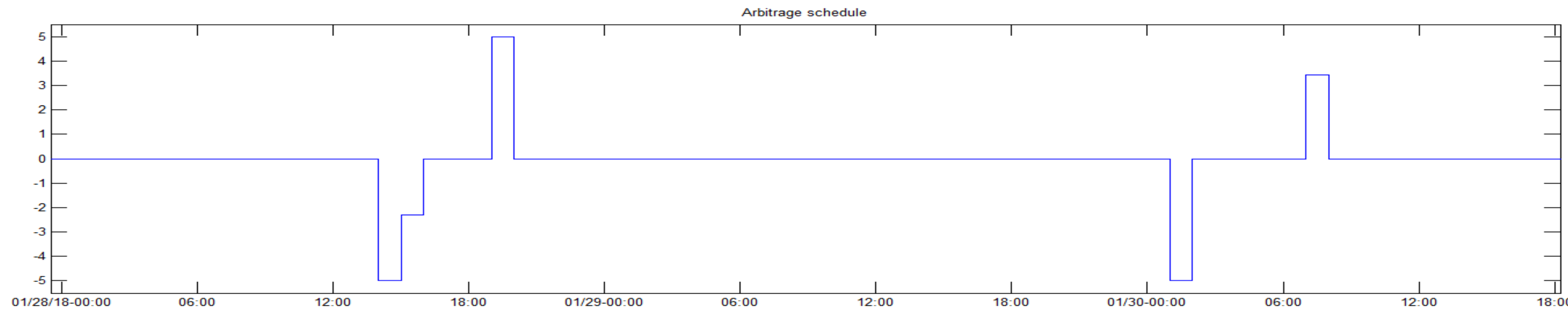


Benefit Example 2 – Energy Arbitrage

- Hourly indexed day-ahead energy market for mid-Columbia 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

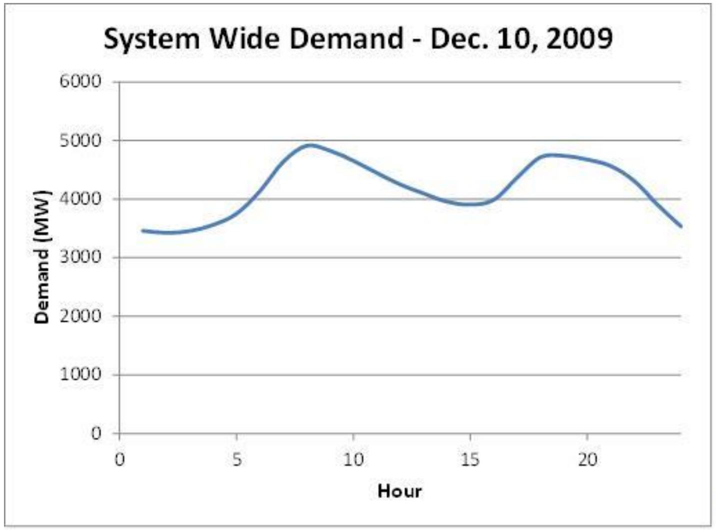
Key Lesson: Profitability differs significantly by region; profit also affected by round trip efficiency of the ESS.

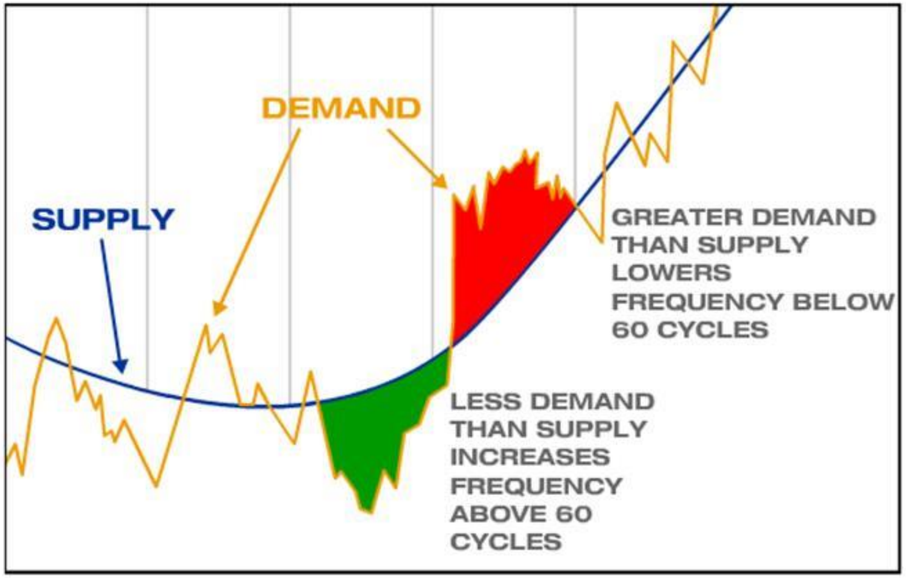




Benefit Example 3 – System Flexibility

- 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

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- 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.

Energy Storage for the Puget Sound Energy (PSE) Region

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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

Battery Storage Evaluation Tool (BSET) User Interface

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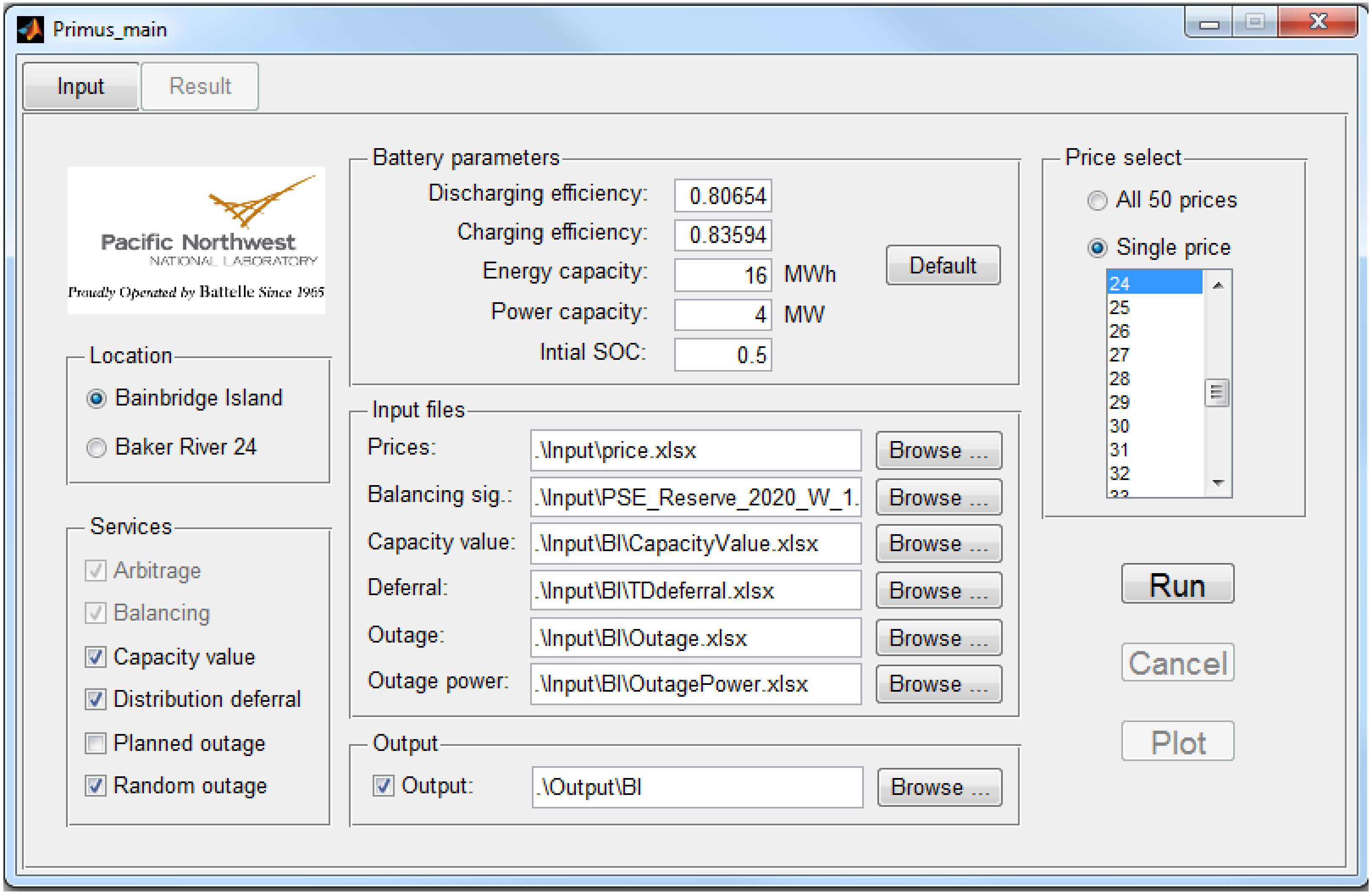
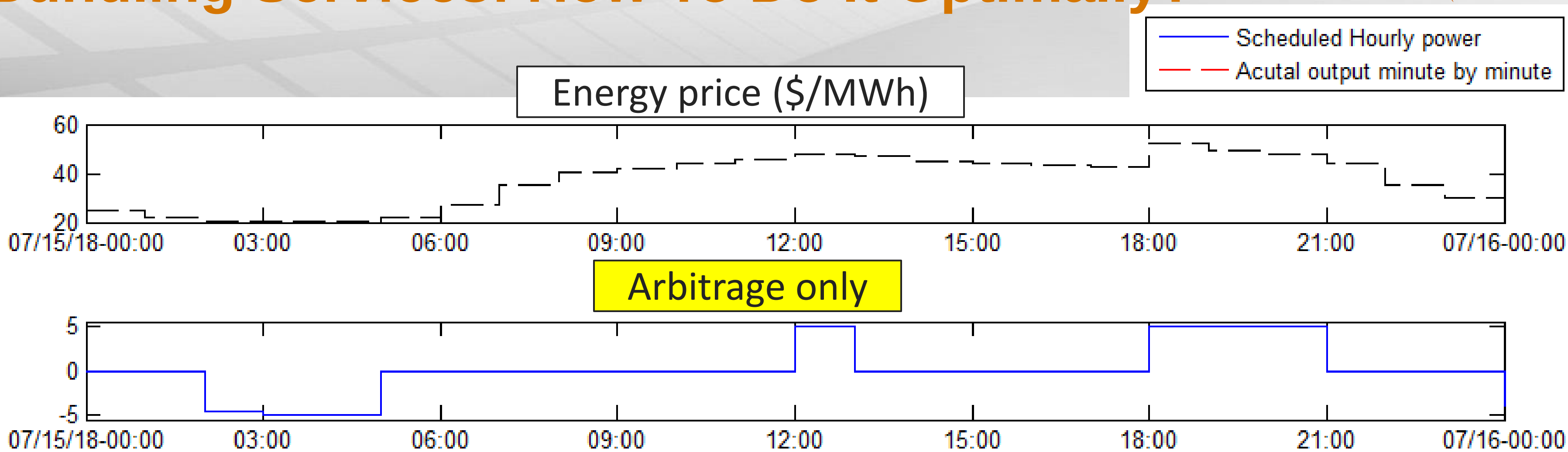


Bundling Services: How To Do It Optimally?



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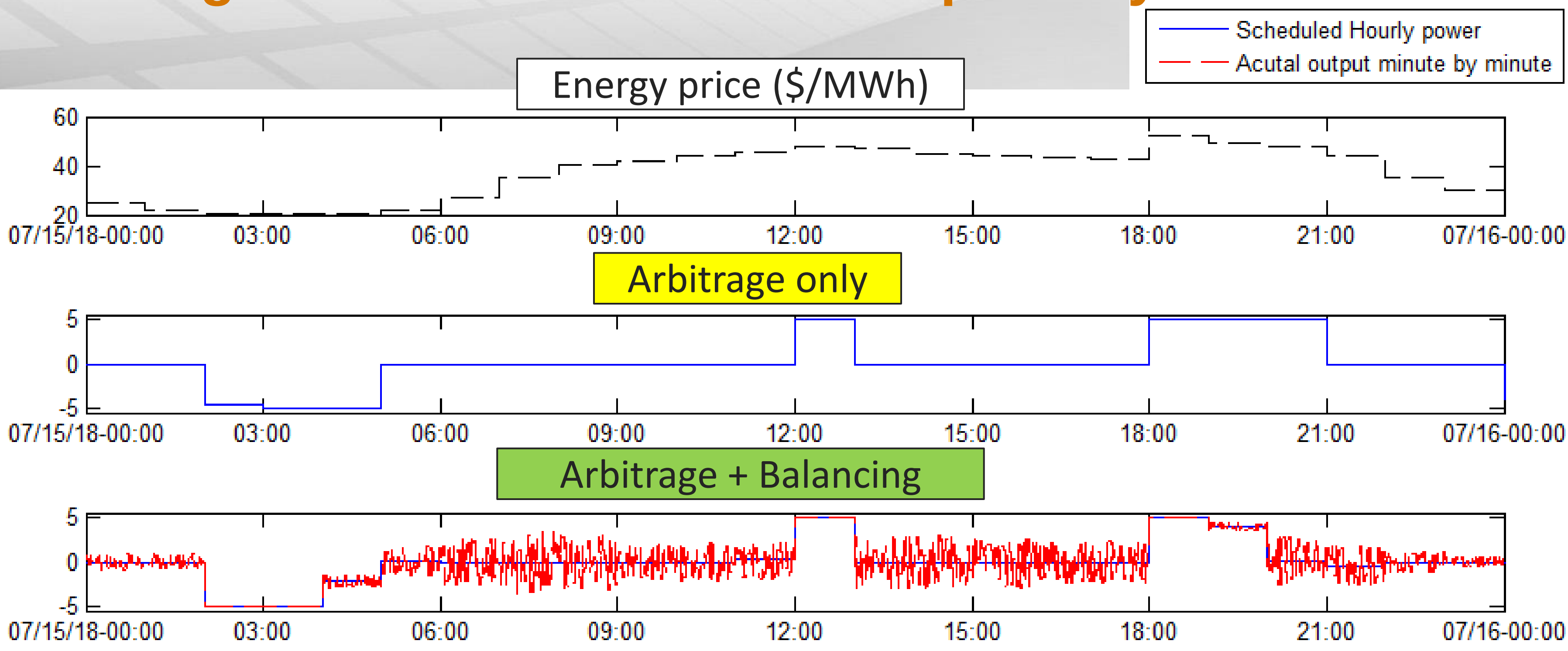

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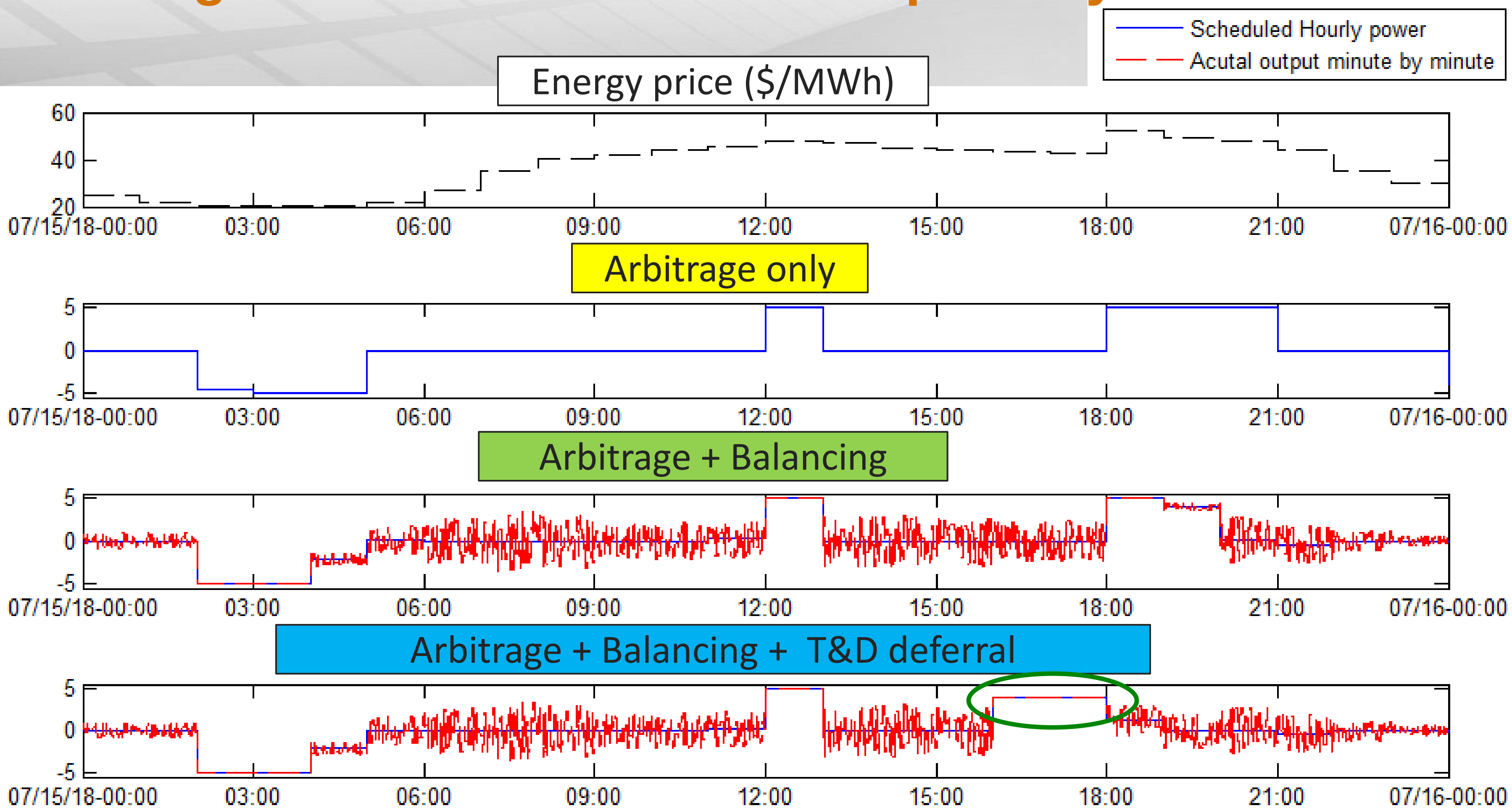
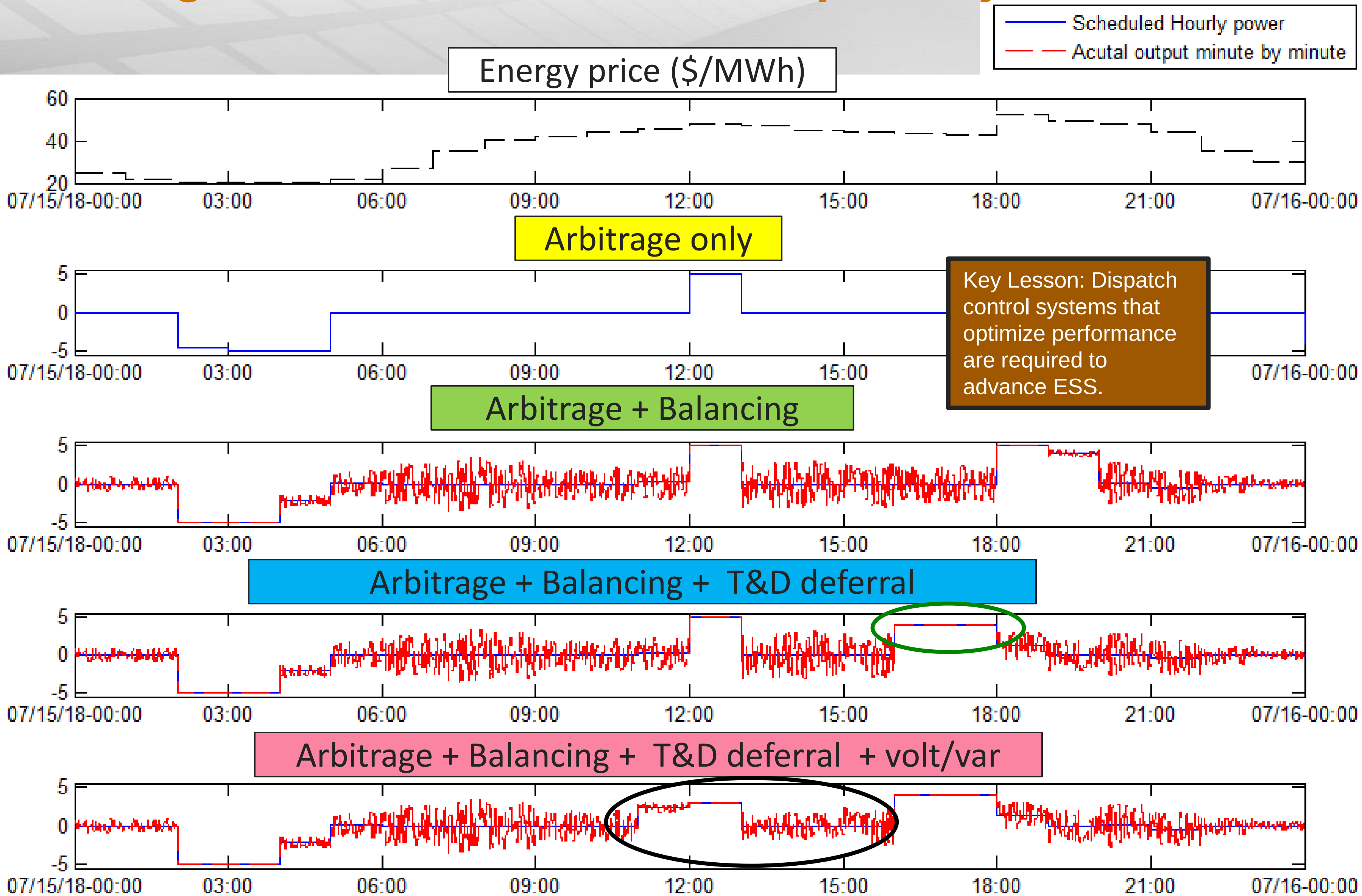
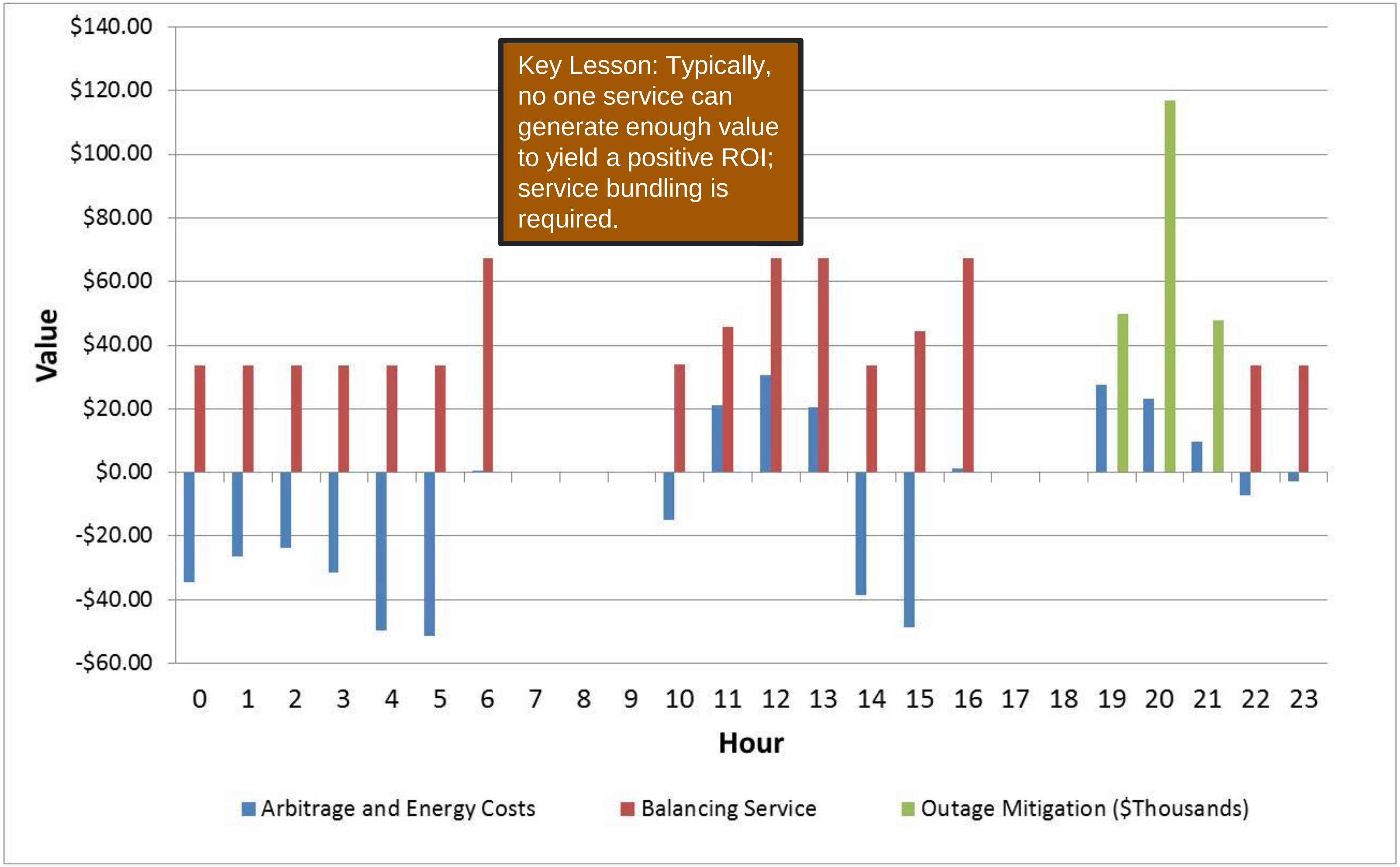


Bundling Services: How To Do It Optimally?

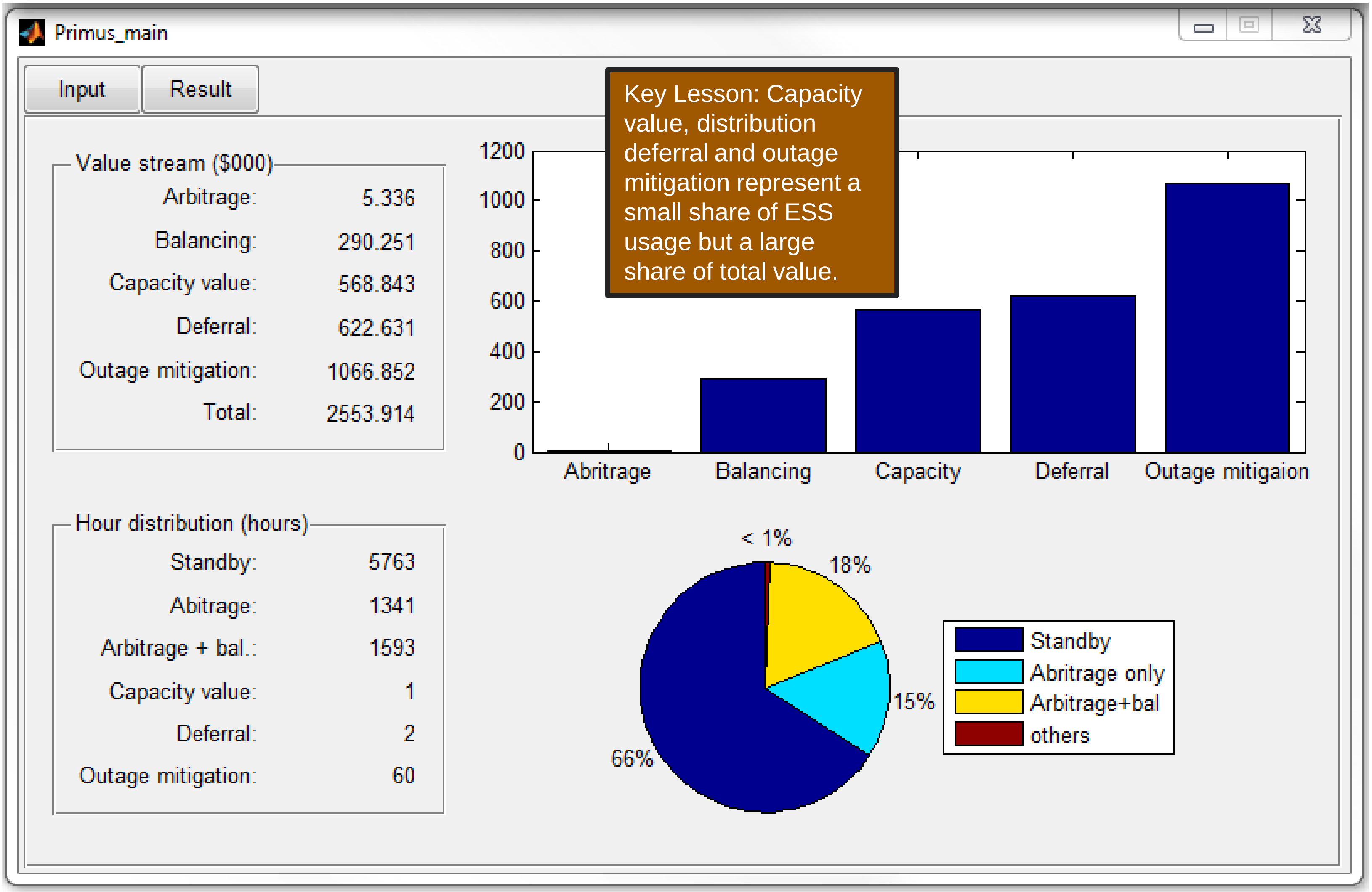


Key Lesson: Dispatch control systems that optimize performance are required to advance ESS.

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

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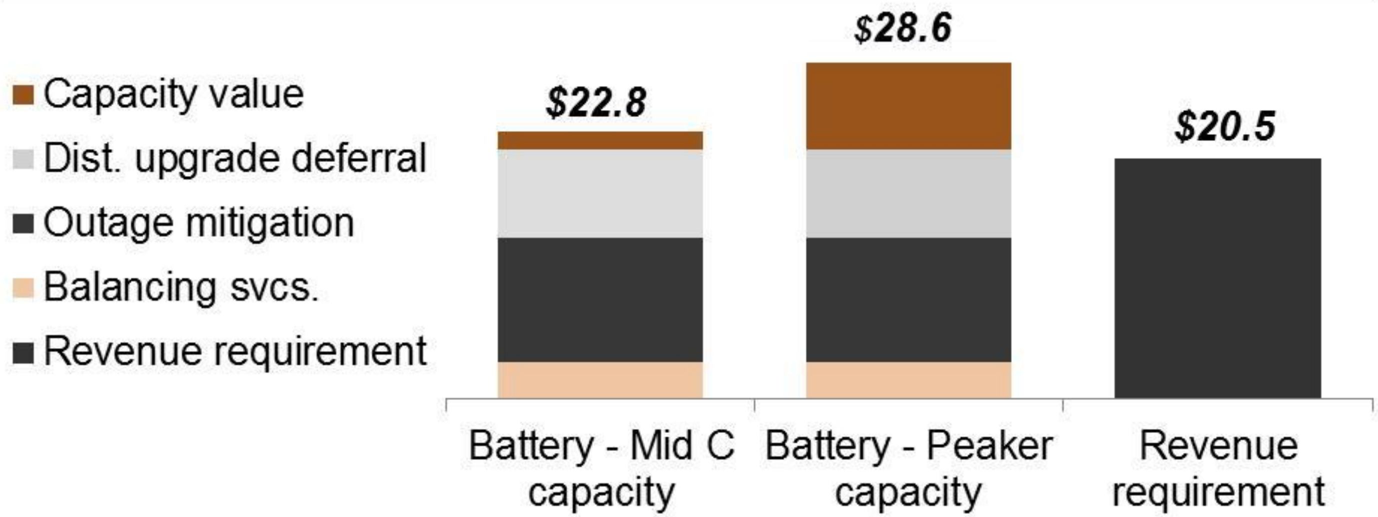
Present value of storage benefits/costs
$M, USD



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

Sizing Energy Storage Optimally to Maximize Net Benefits

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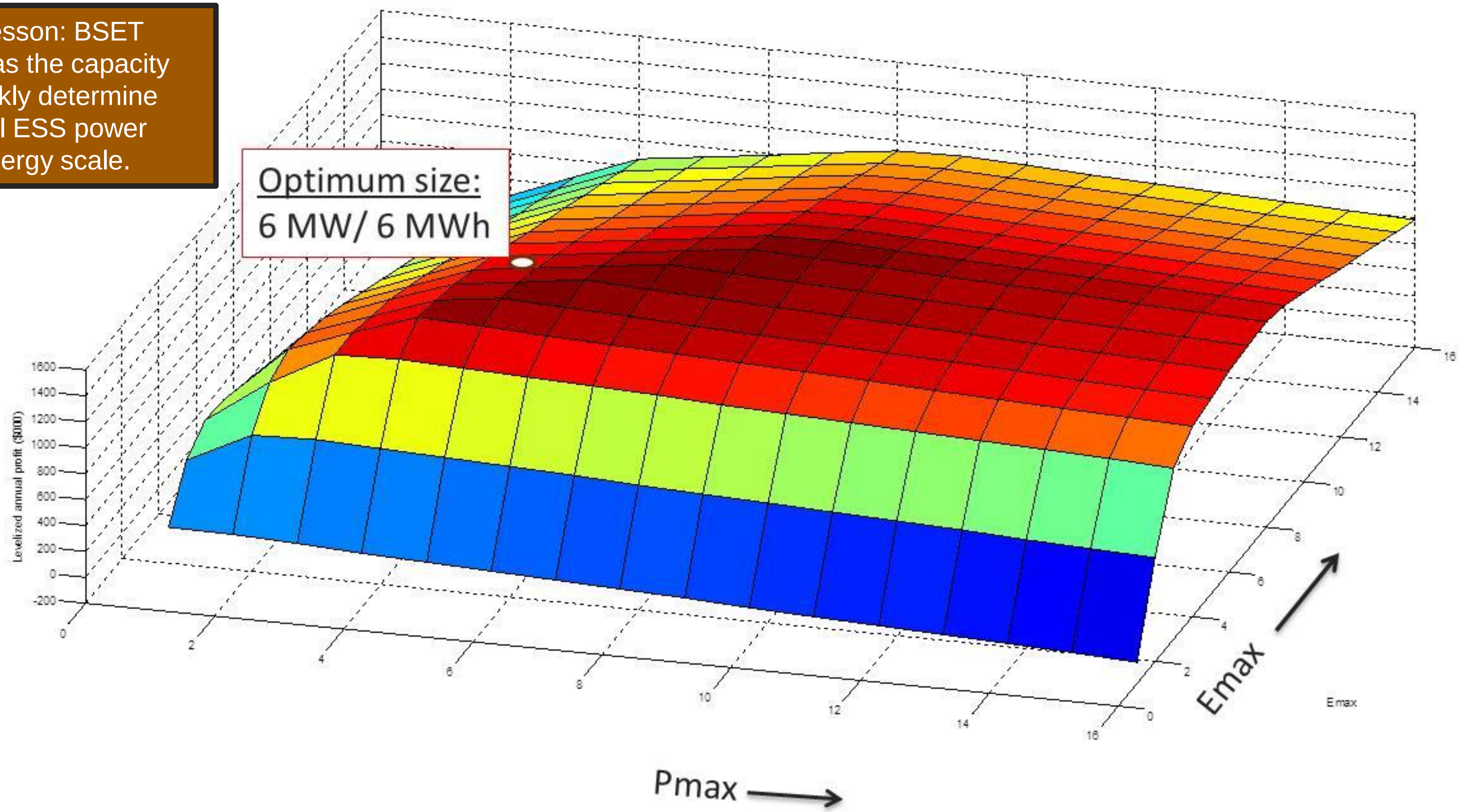
Key Lesson: BSET now has the capacity to quickly determine optimal ESS power and energy scale.



Washington State Clean Energy Fund (CEF) Energy Storage Projects

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MESA
Open Standards for Energy Storage

SNOHOMISH COUNTY PUD PUBLIC UTILITY DISTRICT NO. 1

PSE PUGET SOUND ENERGY

AVISTA

<u>Avista</u>
1 MW / 3.2 MWh vanadium-flow battery

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

<u>Snohomish PUD</u>
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

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Washington CEF 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.

Washington CEF - Next Steps

Task or milestone	Owner(s)
❑ Refine methods for estimating value for each utility	PSE Puget Sound Energy; Pacific Northwest National Laboratory; Avista; Snohomish County PUD Public Utility District No. 1
❑ Financial/technical data collection	PSE Puget Sound Energy; Pacific Northwest National Laboratory; Avista
❑ Develop data acquisition / storage methods and sampling requirements for battery testing	PSE Puget Sound Energy; Pacific Northwest National Laboratory; Snohomish County PUD Public Utility District No. 1
❑ Test and validate data systems	PSE Puget Sound Energy; Pacific Northwest National Laboratory; Snohomish County PUD
❑ Initiate use case testing	PSE Puget Sound Energy; Pacific Northwest National Laboratory; Avista; Snohomish County PUD Public Utility District No. 1

Conclusions

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- We have developed procedures to site and size energy storage systems (ESS) and have made our tool (Battery Storage Evaluation Tool) available for use
- Site-specific non-battery costs can be significant ($750-$1,500 per kW); however, these costs are similar to those experienced when investing in traditional assets
- Any single use would rarely yield positive returns on investment; services must be bundled and co-optimized
- Dispatch control systems that optimize performance are required to advance ESS
- We are evaluating a broader set of use cases through our Washington Clean Energy Fund engagement
  - Energy shifting
  - Grid flexibility (regulation services, load following, real-world flexibility operation)
  - Improving distribution systems efficiency (Volt/VAR control, load-shaping service, distribution investment deferral)
  - Outage management
  - Enhanced voltage control
  - Grid-connected and islanded microgrid operations (black start operation, microgrid operation while grid-connected, microgrid operation in islanded mode)
- We will also be testing ESS to evaluate performance and will be developing dispatch control algorithms.