



Pacific Northwest
NATIONAL LABORATORY

*Proudly Operated by **Battelle** Since 1965*

INTERNATIONAL CONFERENCE ON ENERGY STORAGE TRENDS AND OPPORTUNITIES

September 12, 2016
Kailua-Kona, Hawaii

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PNNL at a Glance



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FY15:
\$955
MILLION
in R&D
expenditures

FY15:
4,400
STAFF

98
R&D 100
AWARDS

81
Tech transfer
AWARDS

Intellectual property and startups

Average
ONE
INVENTION
per day

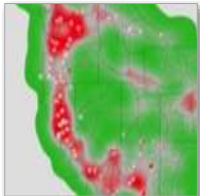
Average
ONE
PATENT
per week

822
LICENSES
since 1970s

170+
BUSINESSES
started with
PNNL IP
or executives



Transmission Reliability – *Seeing and operating the grid at the interconnection level in real-time*



Grid Analytics - *Leveraging high-performance computing and new algorithms to provide real-time situational awareness and models for prediction and response*



Distribution Systems and Demand Response – *Making demand an active tool in managing grid efficiency and reliability.*



Stationary Energy Storage – *Defining the location, technical performance, and required cost of storage; developing new materials and system fabrication approaches to meet requirements*



Cyber Security and Interoperability – *Developing tools and standards for secure, two-way communication and data exchange*

PNNL Energy Storage Research

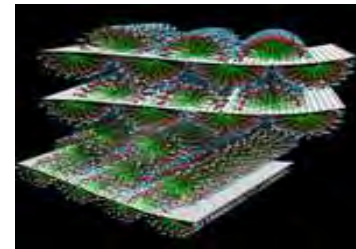
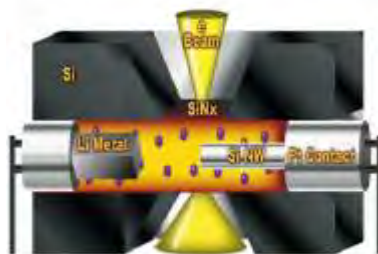


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- **Develop next generation battery technologies for electrical vehicles.**
- **Accelerate the development and deployment of cost effective solutions for grid scale energy storage.**

In-situ tools and
fundamental
understanding of
Electrode materials



New synthesis
and materials
development



Scale-up,
prototyping
and
commercialization



Grid analysis
and large scale
application



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The Background & Opportunity – the big picture

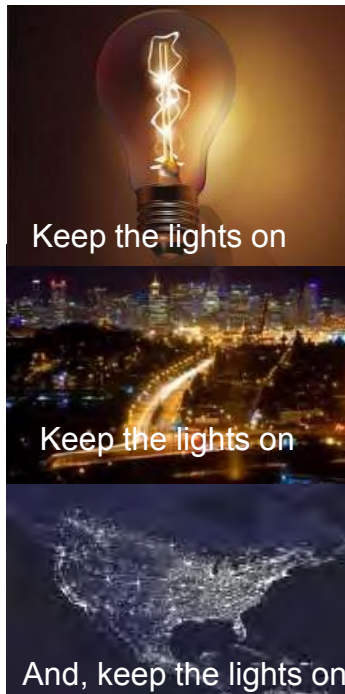
Electricity infrastructure is going through a complex transition



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20th Century Electric Utility Mission



21st Century Electric Utility Mission

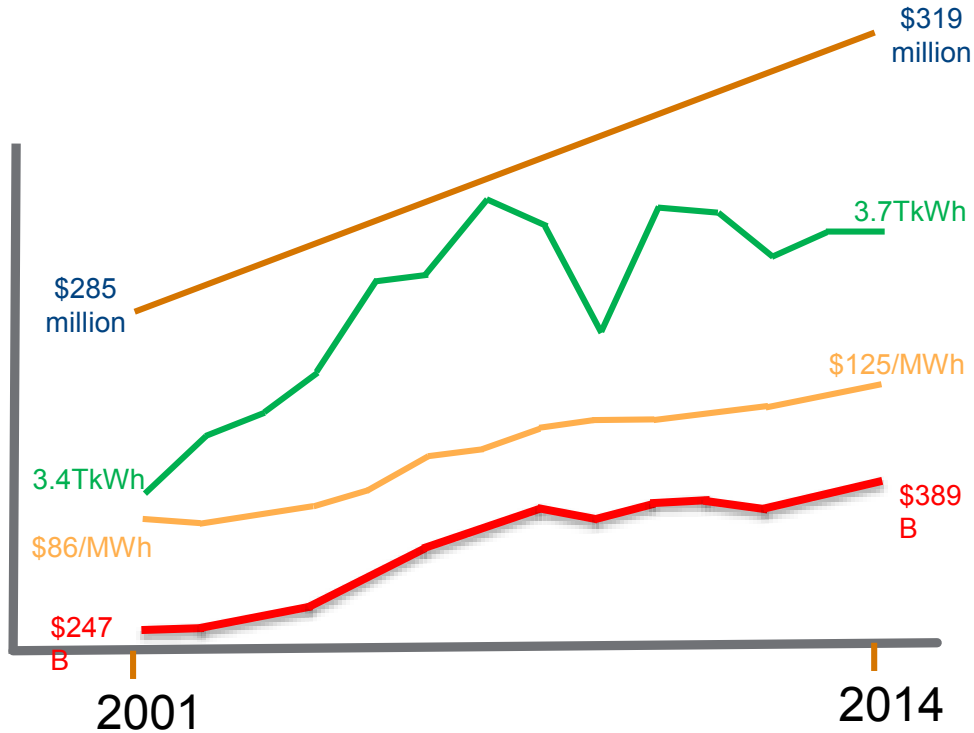


U.S. Electricity Trends



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- ▶ Population, +12%
- ▶ Sales, kWh +10 %
- ▶ Residential Price, +46%
- ▶ Revenue, +57%

Price and Overall Cost of Electricity by Regions across the U.S.

2014 Average Monthly Bill – Residential		
	Average Monthly Price (cents/kWh)	Average Monthly Bill (Dollars and cents)
Hawaii	37.04	187.59
D.C.	12.74	91.90
New Mexico	12.28	77.79
Colorado	12.18	83.73
Illinois	11.91	88.78
Idaho	9.72	95.50
California	16.25	91.26
Washington	8.67	87.14
Pennsylvania	13.32	113.72
U.S. Total	12.52	114.09

(Data from forms EIA-861- schedules 4A-D, EIA-861S and EIA-861U).
http://www.eia.gov/electricity/sales_revenue_price/pdf/table5_a.pdf

The Opportunity

21st Century Electric Utility Mission



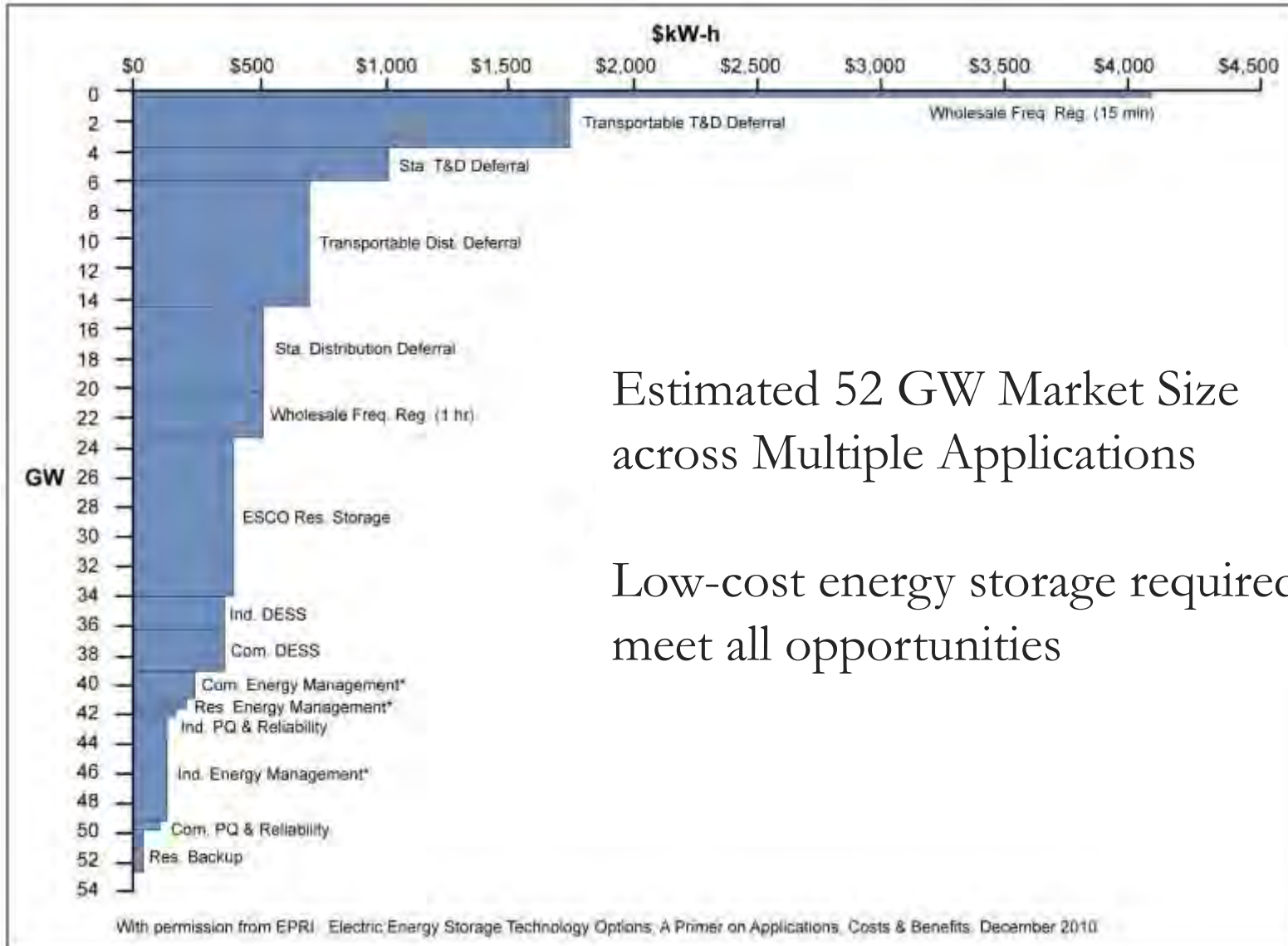
energy storage can contribute to all the attributes we would like see in our future grid

Potentially Large Grid Energy Storage Market Size



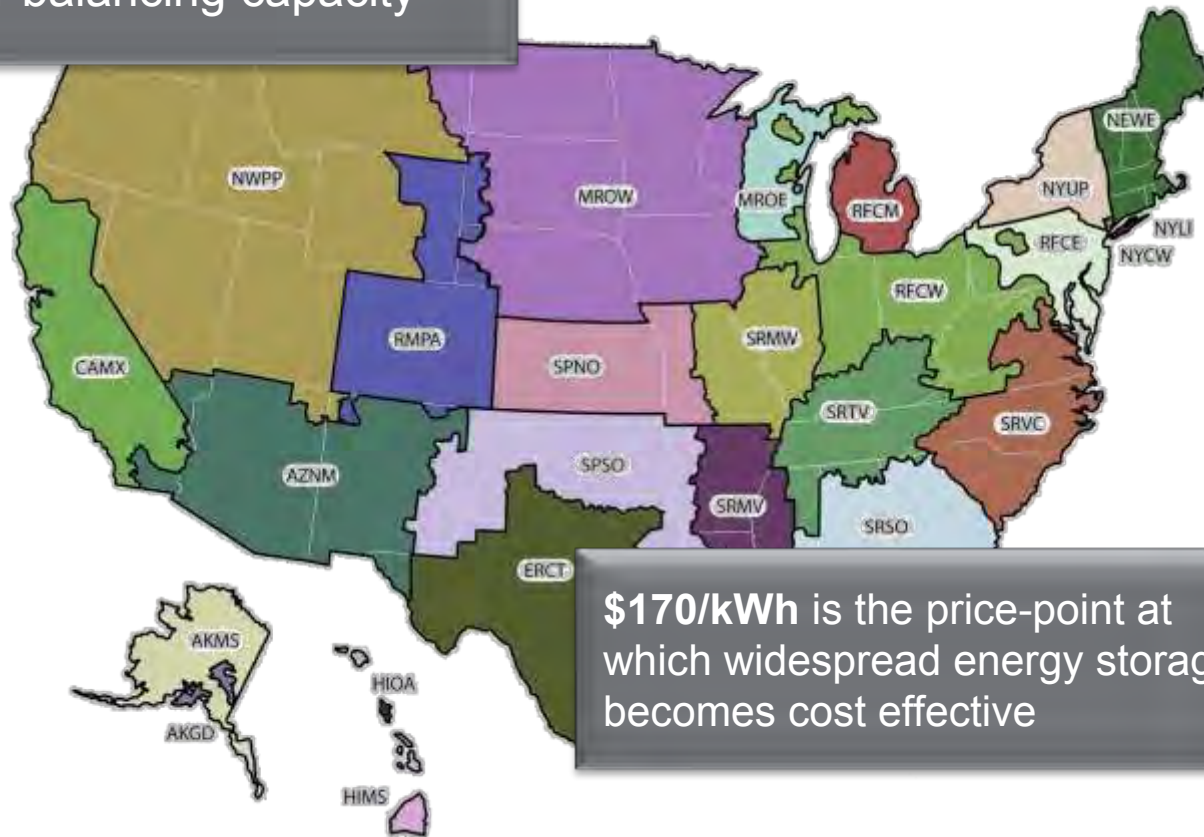
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Potential U.S. Energy Storage Market Size (20% renewables nationwide)

18.6GW, 8.6 GWh of additional
intra-hour balancing capacity



\$170/kWh is the price-point at
which widespread energy storage
becomes cost effective

There are Many Electric Grid Storage Services & Benefits

Table 1. Electric Grid Energy Storage Services Presented in This Handbook

Bulk Energy Services
Electric Energy Time-Shift (Arbitrage)
Electric Supply Capacity
Ancillary Services
Regulation
Spinning, Non-Spinning and Supplemental Reserves
Voltage Support
Black Start
Other Related Uses

Transmission Infrastructure Services
Transmission Upgrade Deferral
Transmission Congestion Relief
Distribution Infrastructure Services
Distribution Upgrade Deferral
Voltage Support
Customer Energy Management Services
Power Quality
Power Reliability
Retail Electric Energy Time-Shift
Demand Charge Management

DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA, SAND2015-1002, February 2015



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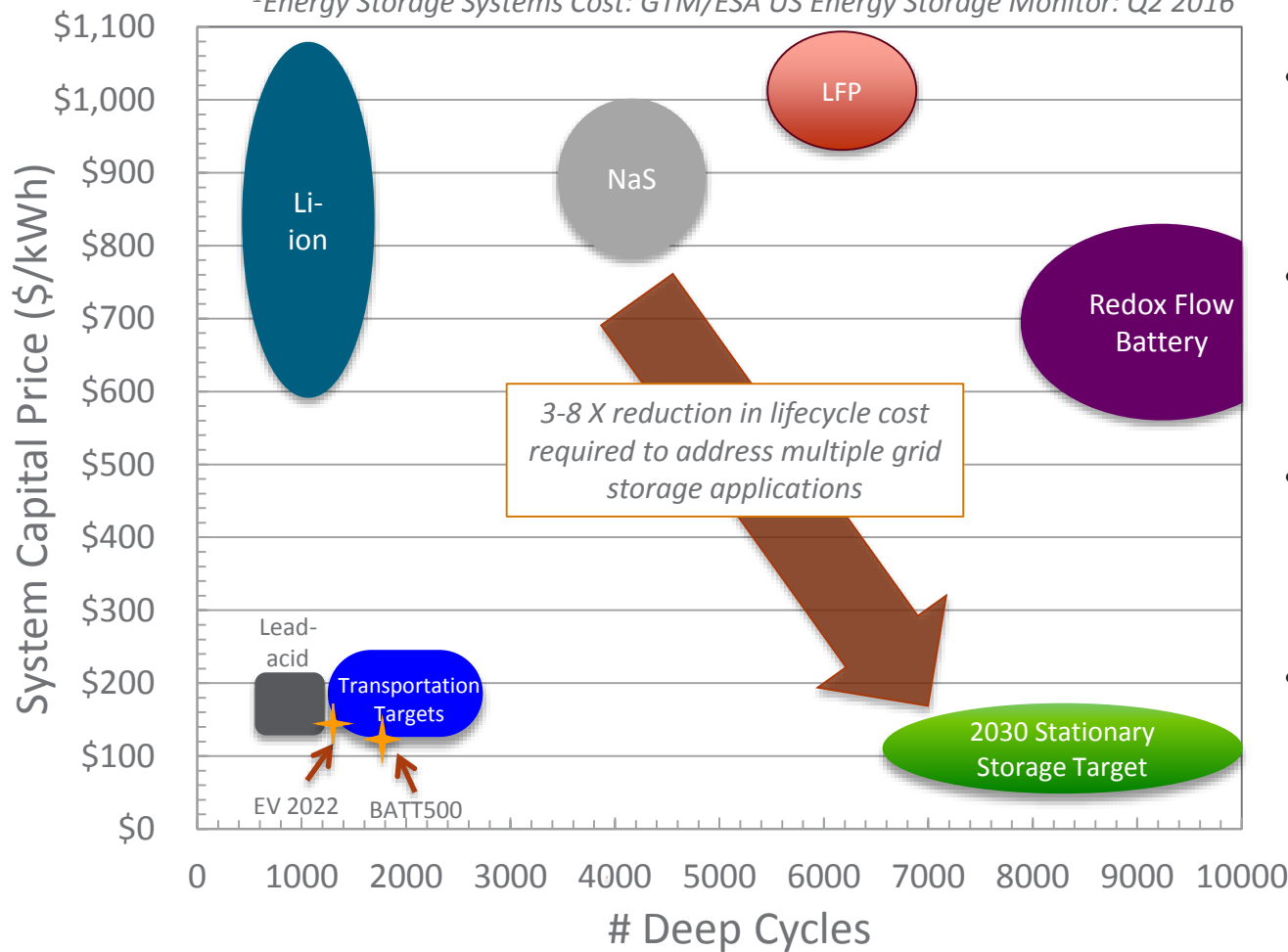
The TWO Main Challenges

1

Reduce Energy Storage Cost



¹Energy Storage Systems Cost: GTM/ESA US Energy Storage Monitor: Q2 2016



- Grid Scale Energy Storage requires longer cycle life than EV systems
- Grid Scale Energy requires deeper discharge to serve multiple grid applications
- Lithium ion best suited to meet transportation requirements
- Many chemistries can compete for grid-scale applications

2 Monetize Energy Storage Benefits for Multiple Grid Applications



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Challenge - Over 3000 utilities

- ✓ Different grid reliability, resiliency, flexibility, renewable integration challenges
- ✓ Different Market Structure
- ✓ Different cost of electricity
- ✓ Other competing solution approaches besides energy storage

What is needed

- ✓ Requires regional and local analysis of deployed storage technologies in diverse markets to develop full understanding of monetized and unmonetized benefits
- ✓ Development of industry standard design tools with fidelity to capture the multi-use value of storage in transmission, distribution, and behind the meter applications.
- ✓ New business models

Example - Puget Sound Energy Utility “Use Case”



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The Challenge

- ❑ Substations are capacity constrained
- ❑ Reliability issues with radial transmission and distribution

Potential Grid Benefits:

- ❑ Distribution Values
 - ✓ Transformer upgrade deferral
 - ✓ Outage management
 - ✓ Volt/Var control
- ❑ Transmission Values
 - ✓ Balancing
 - ✓ Economic energy dispatch
 - ✓ Capacity value system adequacy

Puget Sound Energy Utility “Use Case”



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1. Where should energy storage be sited and at what scale to maximize value in the PSE system?
2. What energy storage applications can the ESS provide and what values are derived from these services?
3. How do we build and test an energy storage control strategy to maximize value?
4. When optimized to maximize value, do the modeled benefits exceed the revenue requirements for the battery systems?

Energy storage applications – Optimized Solution

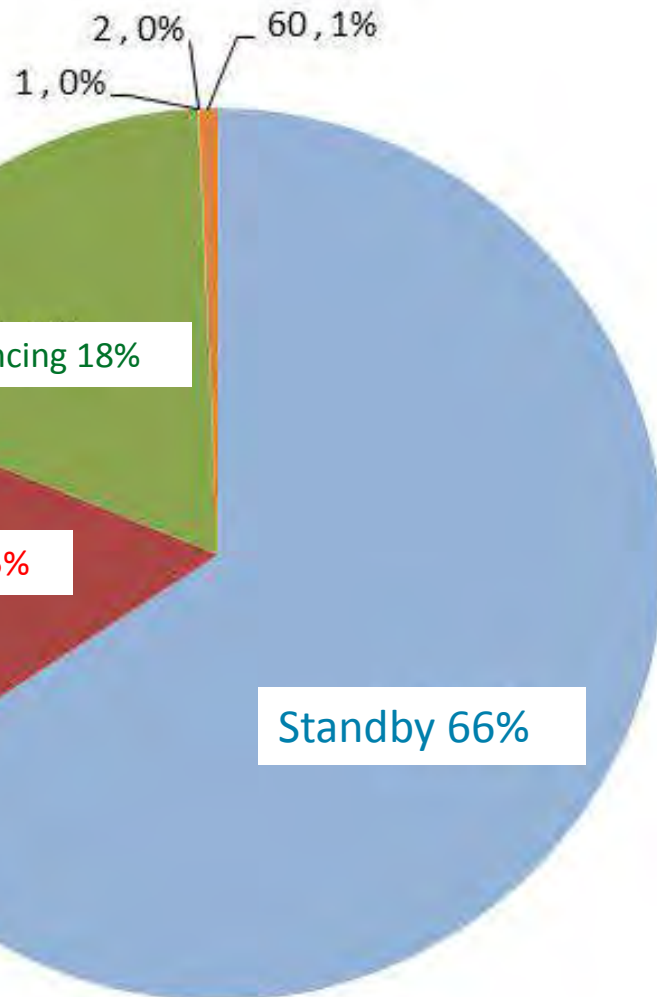
- ▶ Evaluate arbitrage, balancing services, outage mitigation, distribution upgrade deferral and capacity value
- ▶ Positive return required greater than \$20M in benefit over 20 years
- ▶ Evaluated battery performance characteristics (power and energy as a function of state of charge)



RESULTS - \$26M potential Benefit

- ▶ Outage Mitigation – 41%
- ▶ Capacity Value – 25%
- ▶ Deferral upgrade – 23%
- ▶ Balancing – 11%
- ▶ Arbitrage – 0.15%

How is the Battery used throughout the year?



Key Observation

- ▶ Battery on standby 66% of the year
- ▶ Arbitrage accounts for 15% of battery use but less than 0.1% of benefit
- ▶ Highest benefit applications only utilized 19% of time

BATTERY USAGE (1 year) FOR APPLICATION

Example: Micro grid- Energy Security with Maximum Additional Value



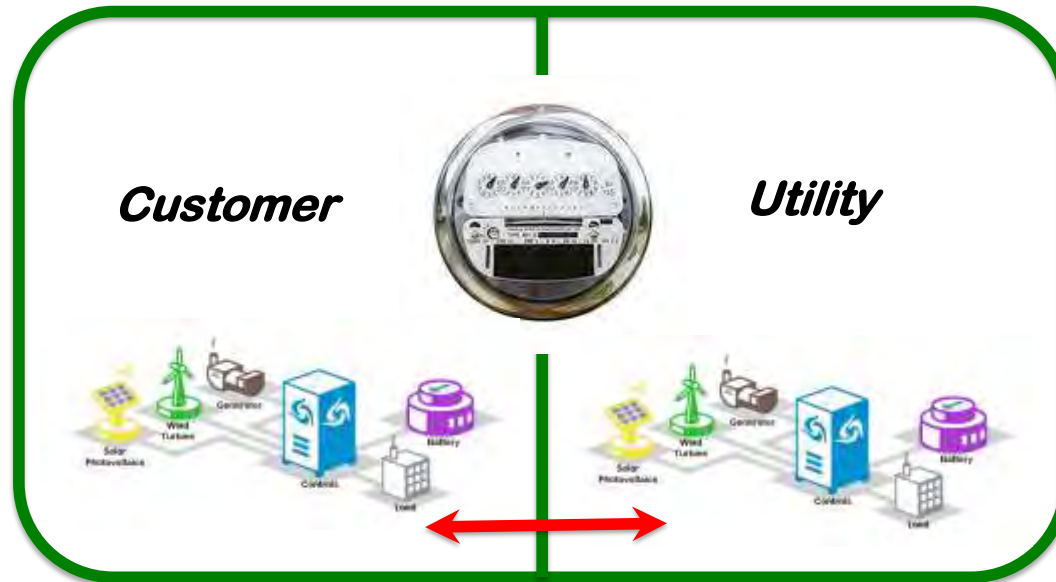
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90%
survivability
rate for a two-
week outage

PV, Diesel Gen
Sets, Energy
Storage

Fixed Budget



Benefits to Customer:

- Demand Charge Reduction
- Energy Charge Reduction
- Outage Mitigation

Benefits to Utility:

- Resource Adequacy
- Ancillary Services
- Arbitrage

Benefits to Customer:

- Outage Mitigation

Benefits to Utility:

- Resource Adequacy or Peak Capacity
- Ancillary Services
- Arbitrage
- Distribution Investment Deferral
- Volt/VAR Support

Micro grid - Outage Survivability Analysis

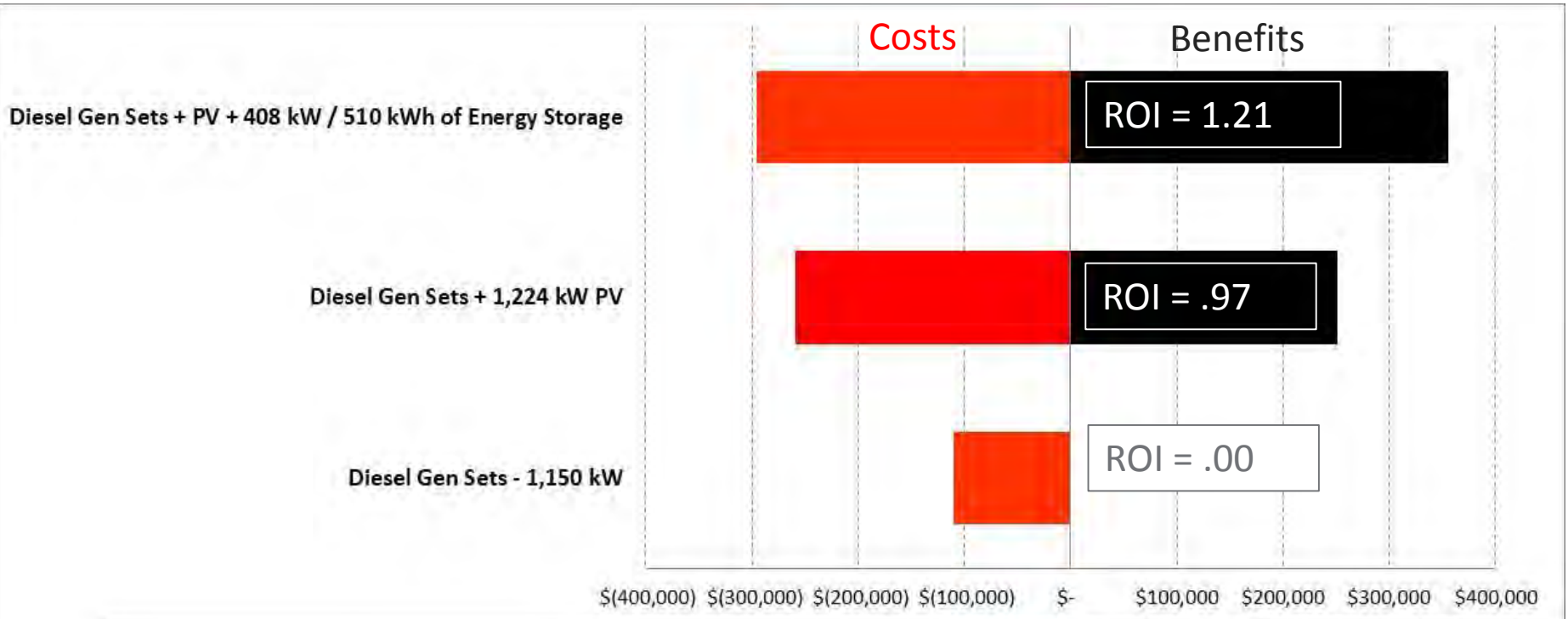
1. Evaluate ability of PV + energy storage to support base load across various
 - ✓ PV sizes
 - ✓ Energy storage sizes

2. Meet base load through prioritized dispatch
 - ✓ PV
 - ✓ Energy Storage
 - ✓ Diesel Generation

3. Energy storage is only charged when PV production exceeds base load.



Micro grid Return on Investment Annualized Benefits and Costs



Washington State Clean Energy Funds Energy Storage Projects (\$14.3M State/\$43M total)



2 MW / 4.4 MWh lithium-ion/phosphate battery – Glacier, WA



**2MW / 1 MWh Li-ion system
2MW, 8.8 MWh UET
vanadium-flow- Everett, WA**



**1 MW / 3.2 MWh UET vanadium-flow
battery – Pullman, WA**

DOE OE Funding PNNL to Analyze Use Cases



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Category	Services	Avista	PSE	SnoPUD
Bulk Energy Services	Electric Energy Time Shift (Arbitrage)	Y	Y	Y
	Electric Supply Capacity	Y	Y	Y
Transmission Infrastructure Services	Transmission Upgrade Deferral			
	Transmission Congestion Relief			
Distribution Infrastructure Services	Distribution Upgrade Deferral	Y	Y	
	Voltage Support	Y		Y
	Load Shaping Service	Y	Y	Y
Ancillary Services	Regulation Services	Y	Y	Y
	Load Following Services	Y	Y	Y
	Real-World Flexibility Operation	Y	Y	Y
	Black Start Capability	Y		
Customer Energy Management	Power Reliability	Y	Y	
	Demand Management			
	Retail Energy Time Shift			
	Power Quality			

What We Have Learned – Need a Detailed Methodology for Assessing ESS Value Proposition



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Siting 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 **varying types of utility** (e.g., PUDs, 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.

Battery Storage Evaluation Tool (BSET) and Optimization tool...



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Primus_main

Input Result

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Location

- Bainbridge Island
- Baker River 24

Services

- Arbitrage
- Balancing
- Capacity value
- Distribution deferral
- Planned outage
- Random outage

Battery parameters

Discharging efficiency:

Charging efficiency:

Energy capacity: MWh

Power capacity: MW

Initial SOC:

Price select

- All 50 prices
- Single price

25
26
27
28
29
30
31
32
33

Input files

Prices:

Balancing sig.:

Capacity value:

Deferral:

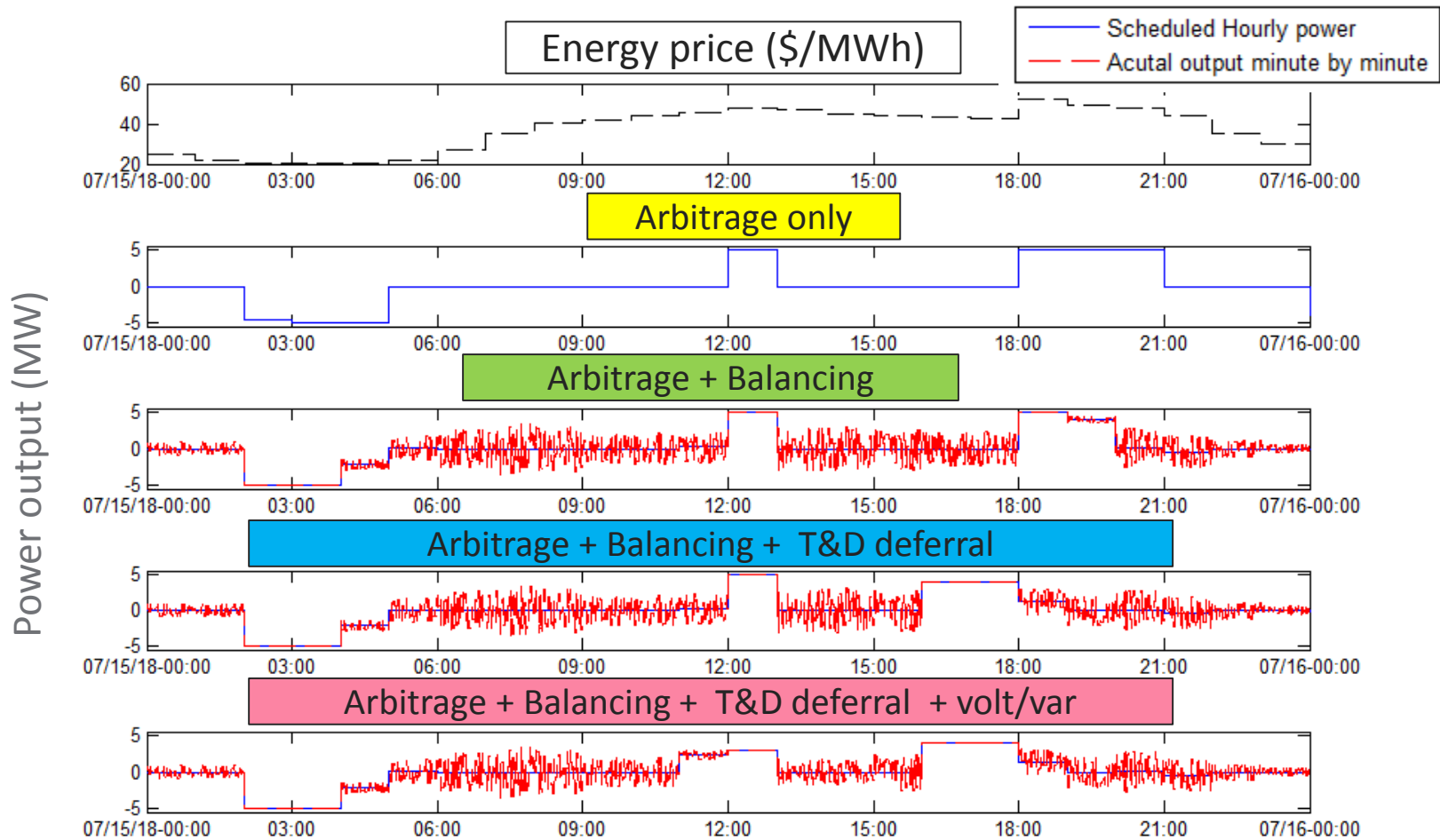
Outage:

Outage power:

Output

Output:

Energy Storage Bundled Services:



The potential market opportunity for energy storage is significant with two main challenges

- Reduce cost
- Determine value for multiple grid application across multiple utilities with varying grid challenges

Take advantage of all Field Demonstration by developing and sharing “use-case” analysis

- Ability to aid in the siting of energy storage systems by capturing/measuring **location-specific benefits**
- Differentiate benefits by region and **market structures/rules**
- Define benefits for **varying types of utility**
- Accurately characterize **battery performance**