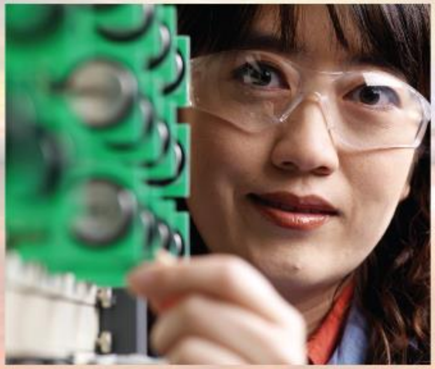

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Grid Scale Energy Storage: *Emerging Technologies and Use Cases*

Vincent Sprenkle
Chief Scientist– Energy Storage
Pacific Northwest National Laboratory

Emerging Priorities in Energy Research Day
Anchorage, AK
October 31st, 2018.

DISCOVERY in Action

U.S. DEPARTMENT OF ENERGY

PNNL-EX-10140

Energy Storage Technologies

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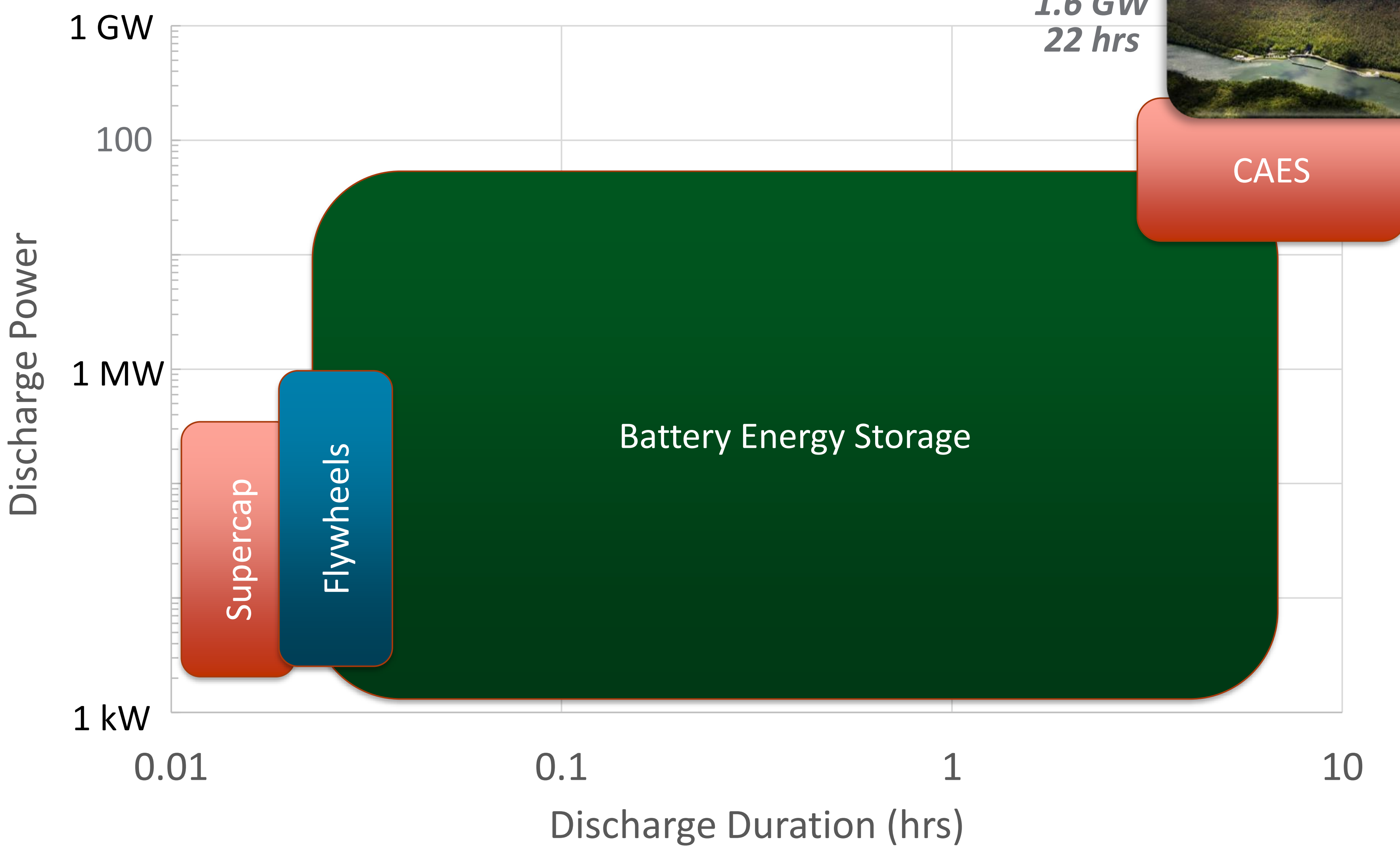
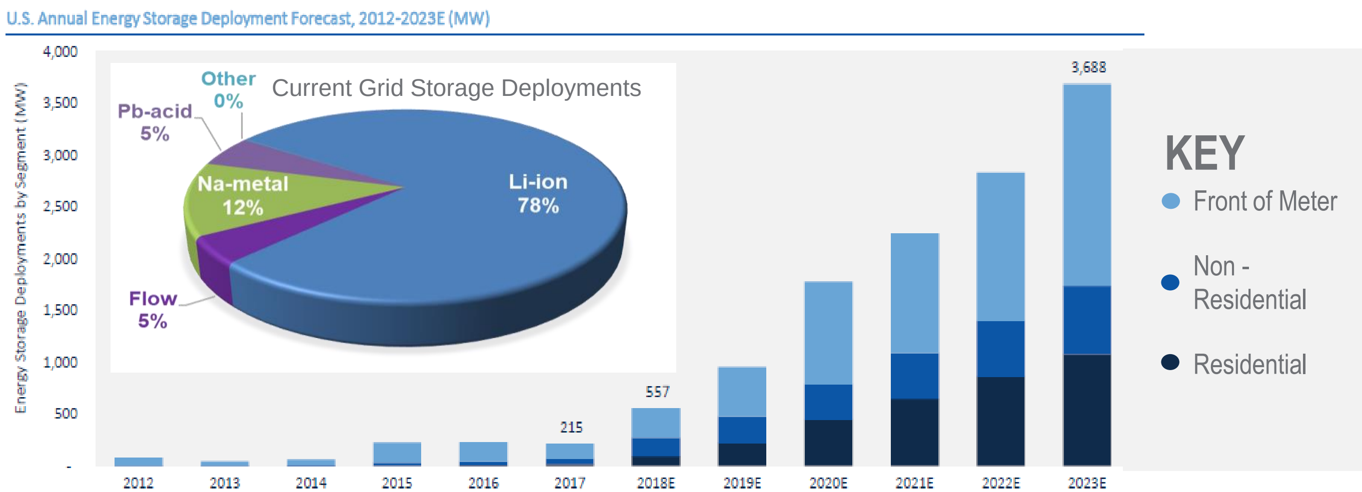


Growth in Battery Energy Storage over Past Decade



However

- Grid-Scale Energy Storage still < 0.1% of U.S. Generation Capacity
- EV’s < 1% of vehicles sold in U.S.

Growth in Energy Storage Fueled by Falling Li-ion Prices

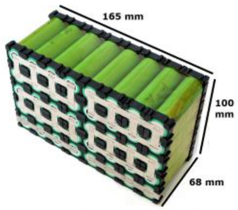
Battery surveys include electric vehicles. Source: Bloomberg New Energy Finance

$80/kWh cell

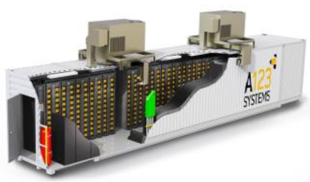
$~300/kWh installed

Cell

Pack
X 1.4



System
X 2.0



Installed
X 1.3

Primary Objective of OE Energy Storage Program

Reducing Cost while quantifying entire value stream

The Cost of a Storage System depends on the Storage Device, Power Electronics, and Balance of Plant

The Value of a Storage System depends on Multiple Benefit Streams, both monetized and unmonetized

DOE OE Energy Storage Program

Objectives

Cost Competitive Technology

- Materials and chemistry
- Systems and manufacturing
- Cost reduction
- Expanded applications

Reliability & Safety

- Lab testing
- Codes and standards
- Expected lifetime
- R&D Improvements

Regulatory Environment

- Policy analysis
- Valuation methods
- Resolution of benefits

Industry Acceptance through Demonstrations

- Stakeholder engagement
- Proving success
- Seamless integration
- Consumer benefits

DOE OE Addressing Entire Suite of Barriers for Continued Deployment of Energy Storage

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U.S. DEPARTMENT OF ENERGY | Electricity Delivery & Energy Reliability

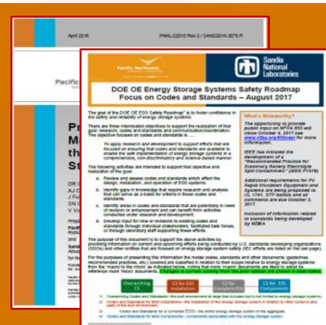
Cost Competitive Technologies

Redox Flow

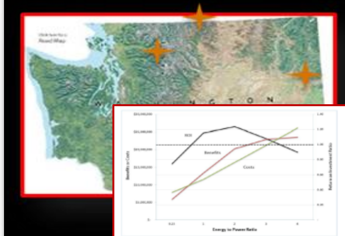
Sodium

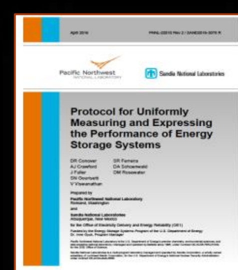
$Zn\text{-}MnO_2$

Safety and Reliability


DOE OE Energy Storage Systems Safety Roadmap Focus on Codes and Standards – August 2017

Industrial Acceptance




Protocol for Uniformly Measuring and Expressing the Performance of Energy Storage Systems

Regulatory Support

Oregon PUC Public Utility Commission

PUCN

WASHINGTON UTC UTILITIES AND TRANSPORTATION COMMISSION

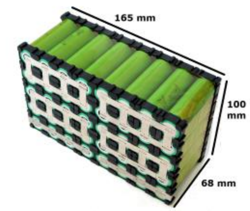
CO DORA

STATE OF HAWAII PUBLIC UTILITIES COMMISSION

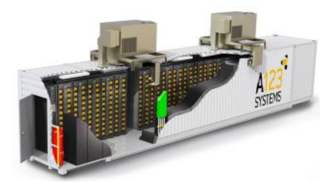
PUBLIC UTILITY COMMISSION OF TEXAS

Cell

Pack
X 1.4



System
X 2.0



Installed
X 1.3

Next Generation
Cost Competitive Storage Technologies

1) **Redox Flow Batteries**
   - Development of water soluble organic materials to replace vanadium can lead to systems at ~ $100/kWh

2. **Zn – MnO_2**
   - Primary Alkaline battery materials ~ $25/kWh, low-cost materials and installed manufacturing base if we make fully reversible and durable.

3. **Na based batteries**
   - Na-ion – utilizes existing Li-ion capacity with lower cost materials if performance can be improved. Potential for > 30% reduction in cost over Li-ion
   - Na-metal – Resolving materials and manufacturing issues to target < $140/kWh

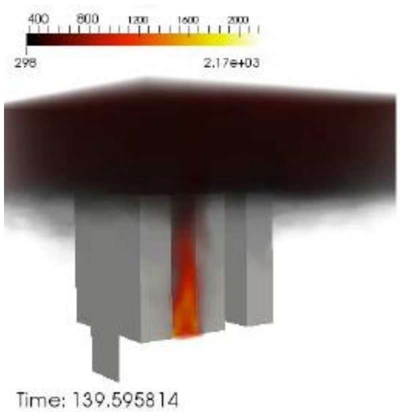
Energy Storage Safety

Energy Storage Safety

SAFETY COLLABORATIVE

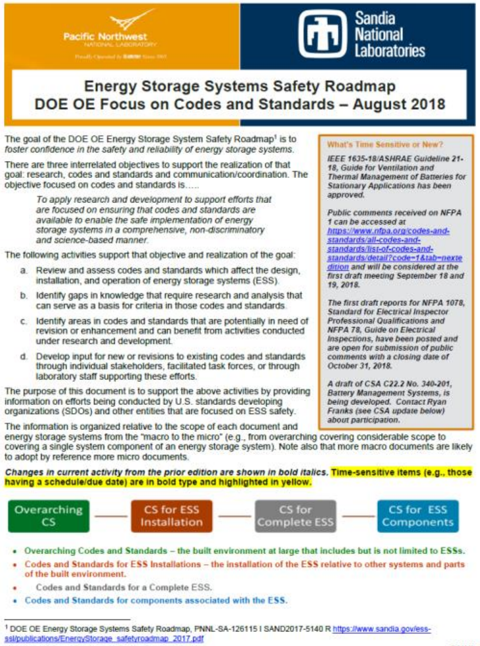
> 100 individuals and organizations involved in various safety workgroups

Research



Modeling of fire propagation in ESS

Codes and Standards



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Sandia National Laboratories

Energy Storage Systems Safety Roadmap
DOE OE Focus on Codes and Standards – August 2018

The goal of the DOE OE Energy Storage System Safety Roadmap[1] is to *foster confidence in the safety and reliability of energy storage systems.*

There are three interrelated objectives to support the realization of that goal: research, codes and standards and communication/coordination. The objective focused on codes and standards is.....

To apply research and development to support efforts that are focused on ensuring that codes and standards are available to enable the safe implementation of energy storage systems in a comprehensive, non-discriminatory and science-based manner.

The following activities support that objective and realization of the goal:

a. Review and assess codes and standards which affect the design, installation, and operation of energy storage systems (ESS).
b. Identify gaps in knowledge that require research and analysis that can serve as a basis for criteria in those codes and standards.
c. Identify areas in codes and standards that are potentially in need of revision or enhancement and can benefit from activities conducted under research and development.
d. Develop input for new or revisions to existing codes and standards through individual stakeholders, facilitated task forces, or through laboratory staff supporting these efforts.

The purpose of this document is to support the above activities by providing information on efforts being conducted by U.S. standards developing organizations (SDOs) and other entities that are focused on ESS safety.

The information is organized relative to the scope of each document and energy storage systems from the "macro to the micro" (e.g., from overarching covering considerable scope to covering a single system component of an energy storage system). Note also that more macro documents are likely to adopt by reference more micro documents.

Changes in current activity from the prior edition are shown in bold italics. **Time-sensitive items (e.g., those having a schedule/due date) are in bold type and highlighted in yellow.**

What's Time Sensitive or New?

IEEE 1635-18/ASHRAE Guideline 21-18, Guide for Ventilation and Thermal Management of Batteries for Stationary Applications has been approved.

Public comments received on NFPA 1 can be accessed at https://www.nfpa.org/codes-and-standards/all-codes-and-standards/list-of-codes-and-standards/detail?code=1&tab=nextedition and will be considered at the first draft meeting September 18 and 19, 2018.

The first draft reports for NFPA 1078, Standard for Electrical Inspector Professional Qualifications and NFPA 78, Guide on Electrical Inspections, have been posted and are open for submission of public comments with a closing date of October 31, 2018.

A draft of CSA C22.2 No. 340-201, Battery Management Systems, is being developed. Contact Ryan Franks (see CSA update below) about participation.

Overarching CS — CS for ESS Installation — CS for Complete ESS — CS for ESS Components

- Overarching Codes and Standards – the built environment at large that includes but is not limited to ESSs.
- Codes and Standards for ESS Installations – the installation of the ESS relative to other systems and parts of the built environment.
- Codes and Standards for a Complete ESS.
- Codes and Standards for components associated with the ESS.

[1] DOE OE Energy Storage Systems Safety Roadmap, PNNL-SA-126115 I SAND2017-5140 R https://www.sandia.gov/ess-ssl/publications/EnergyStorage_safetyroadmap_2017.pdf

Monthly CSR newsletter

Education/Outreach

2018 Energy Storage Systems Safety and Reliability Forum

Energy Storage Reliability

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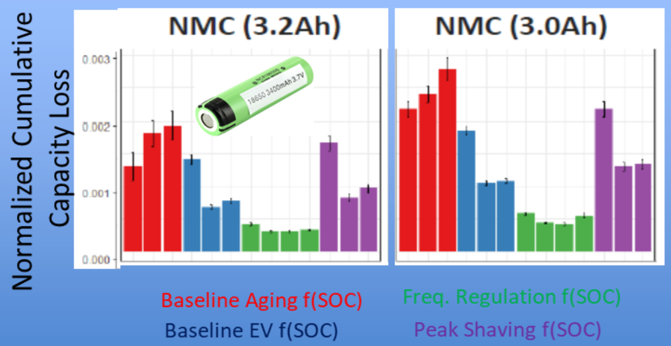
I. Individual cell testing



- Degradation-materials phenomena
- In-situ sensing – improved dispatch

ESS Reliability Needs

1. Want "predictive" understanding of ESS lifetime, performance, and availability under grid duty cycles
2. Independent validation of performance

II. kW module testing

- Reliability Metrics
- Accelerated Testing

II. Supported Field Testing

- Development of Reliability Use Case

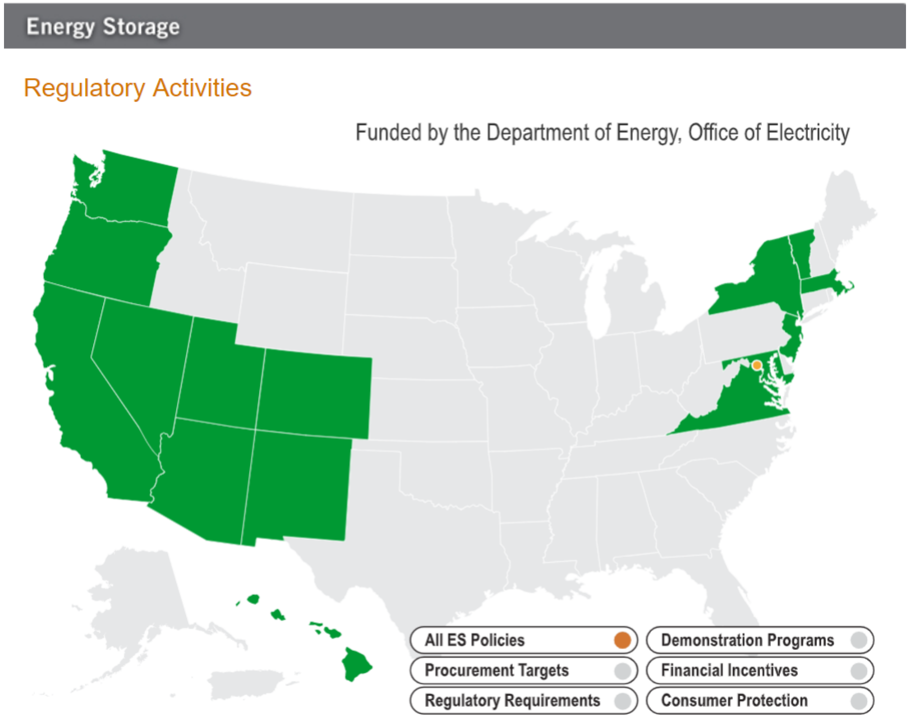
Technical Support for Energy Storage Regulations

Hosted

- 2015 PNW PUC Workshop
- 2016 SW PUC Workshop
- 2017 WECC Seminar

- Providing Technical Support to Commissions in 6 States advancing energy storage.

1-day Energy Storage Seminar for (WECC) and the State PUC's within WECC.



Energy Storage Policy Database

Industrial Acceptance of Energy Storage

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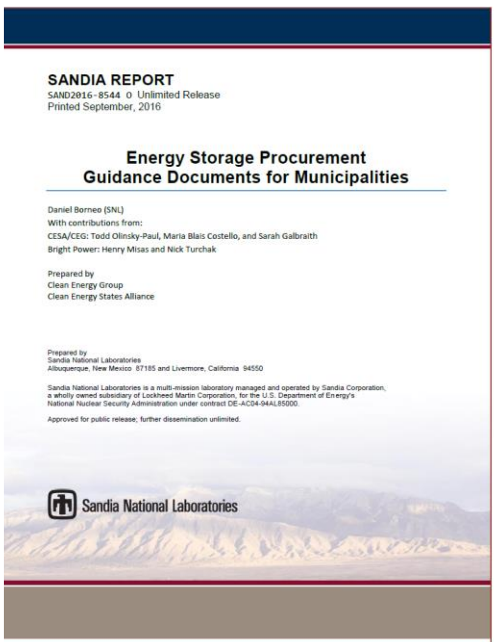
DOE OE Supporting Deployment and Valuation of 45MW – 135 MWh of Energy storage at 22 sites.

1.) Procurement and Commissioning



SANDIA REPORT
SAND2016-8544 O Unlimited Release
Printed September, 2016

Energy Storage Procurement Guidance Documents for Municipalities

Daniel Borneo (SNL)
With contributions from:
CESA/CEG: Todd Olinsky-Paul, Maria Blais Costello, and Sarah Galbraith
Bright Power: Henry Misas and Nick Turchak

Prepared by
Clean Energy Group
Clean Energy States Alliance

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

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Approved for public release; further dissemination unlimited.

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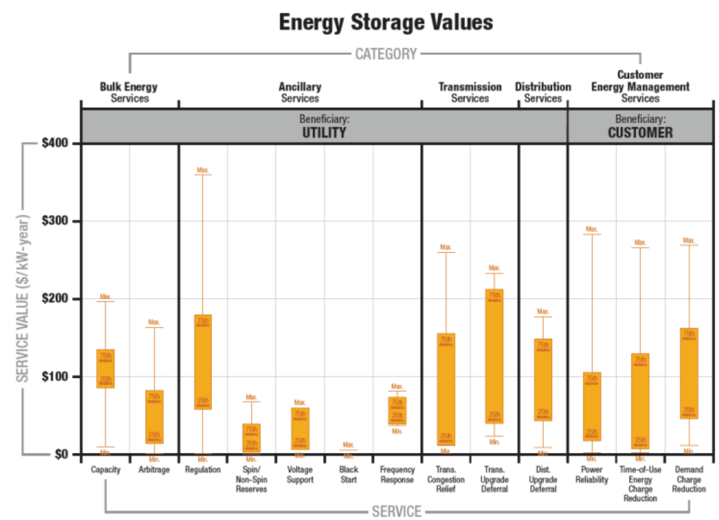
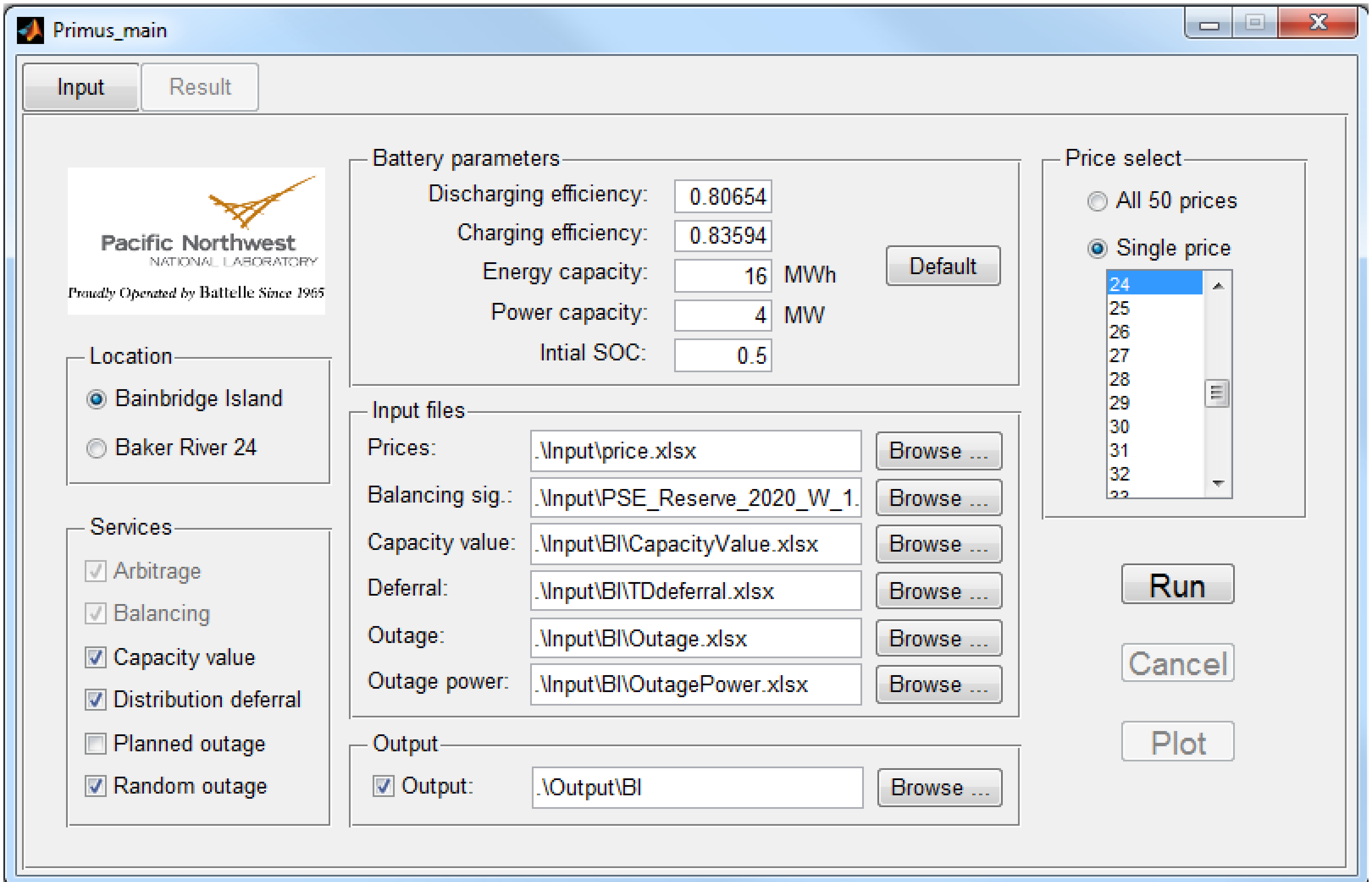
2.) Valuation and Optimization



- Market Optimization
- Avoided Cost Considerations

Energy storage optimization tool



Bundling Storage Services: how to do it optimally?

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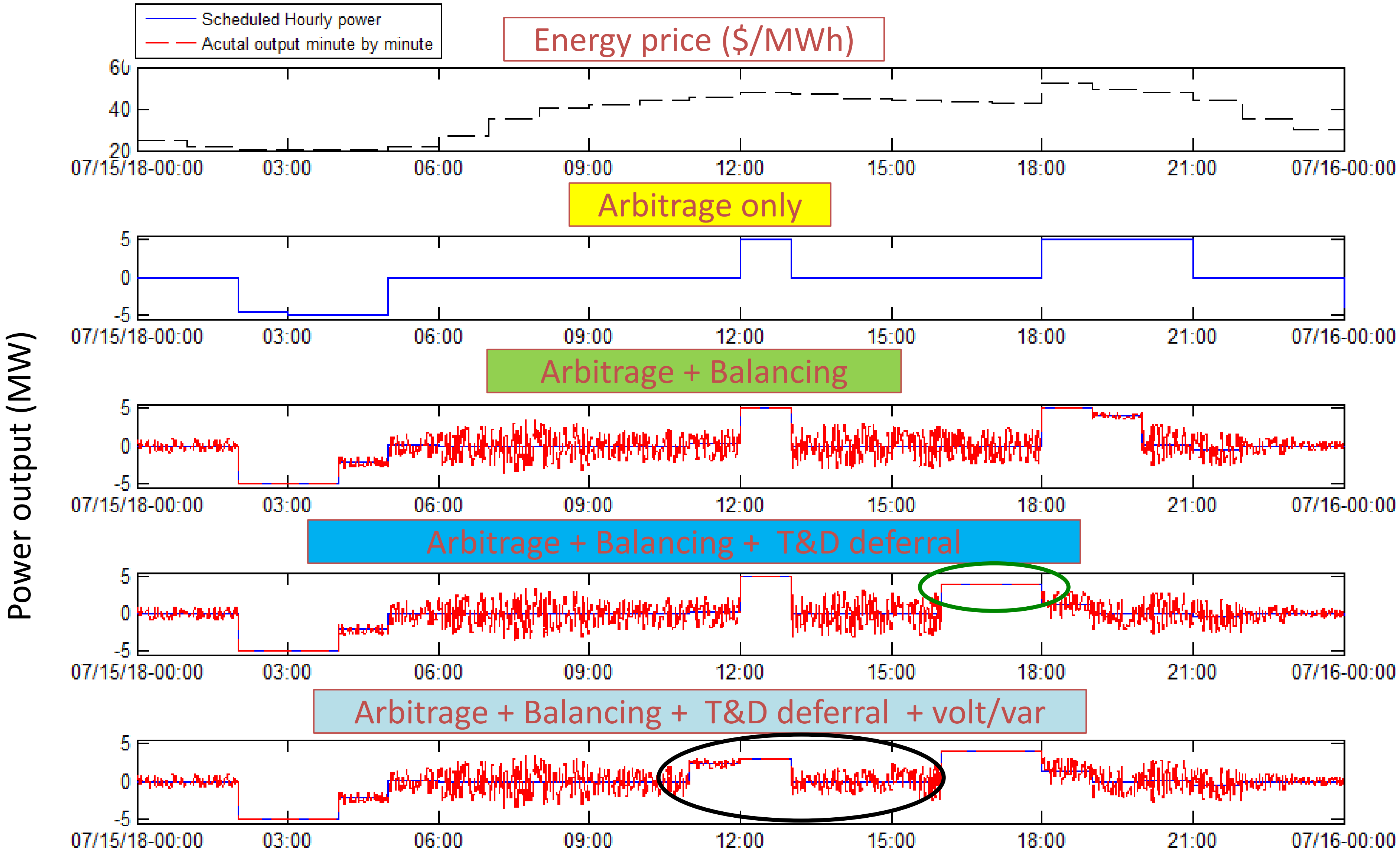
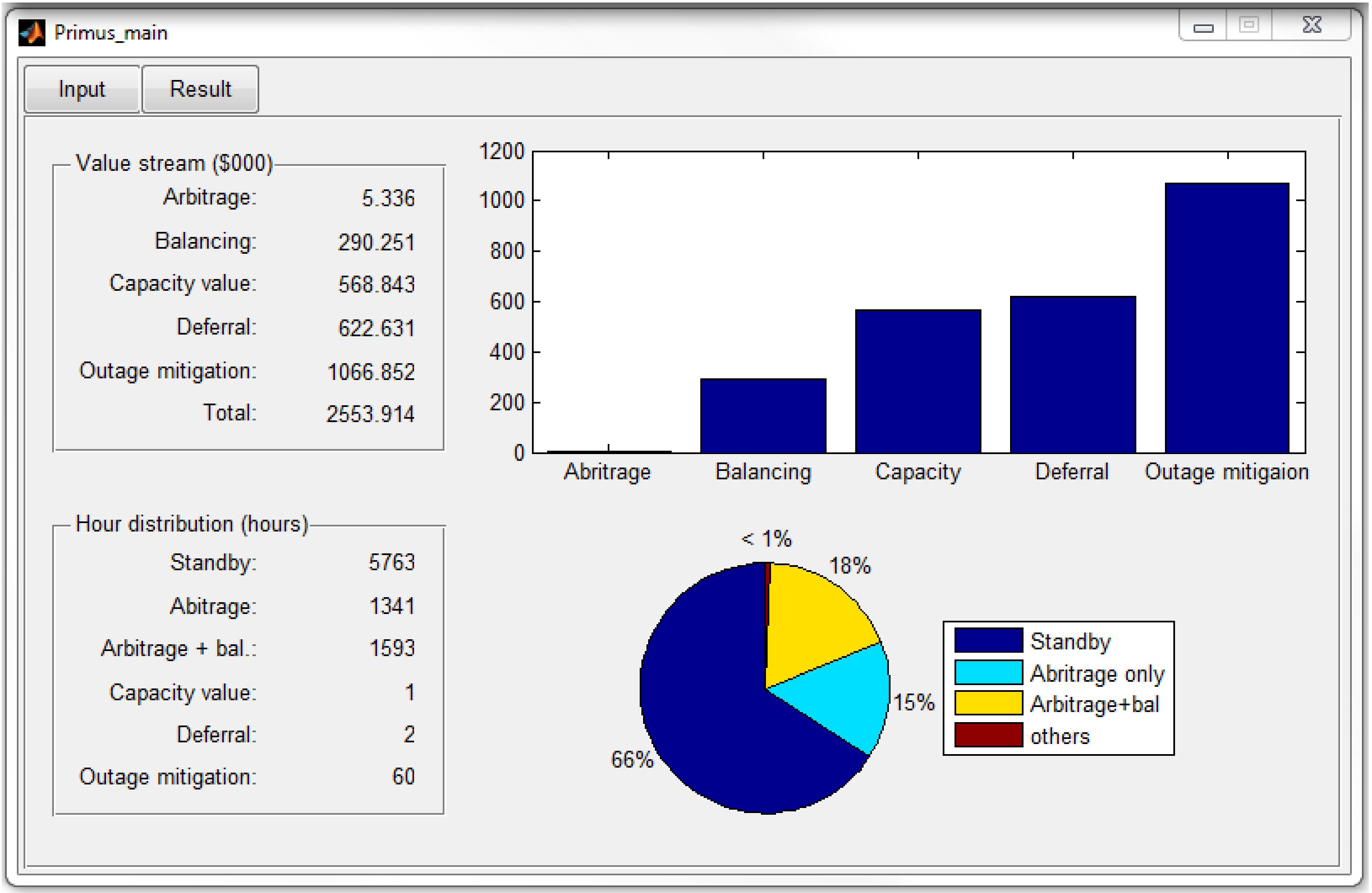


Energy storage optimization tool output



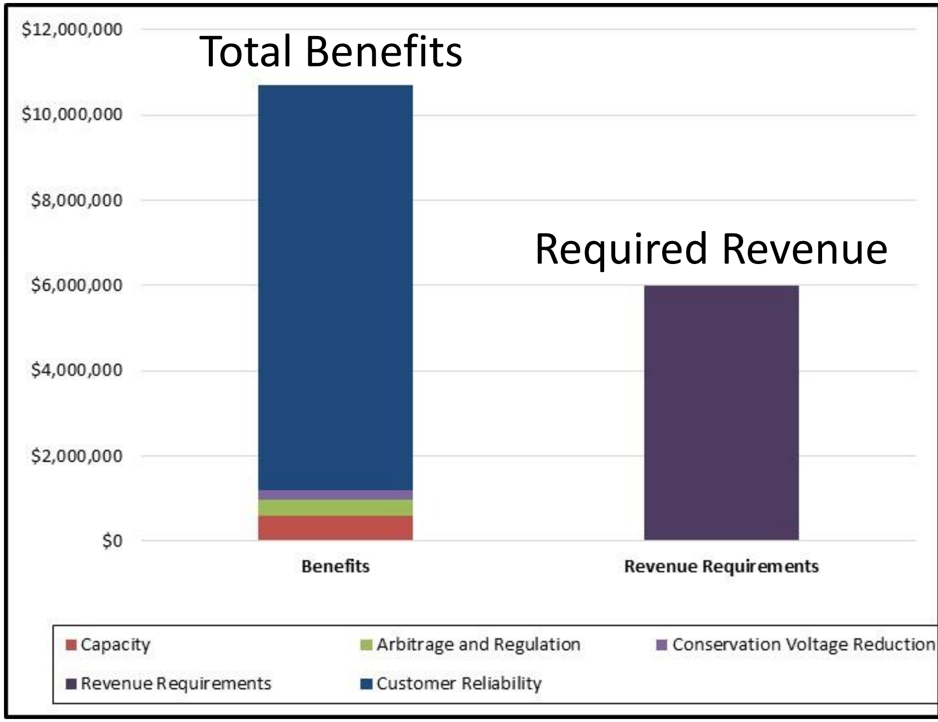
Energy Storage Use Case 1
Manufacturing Reliability

1MW – 3.2 MWh battery at SEL campus

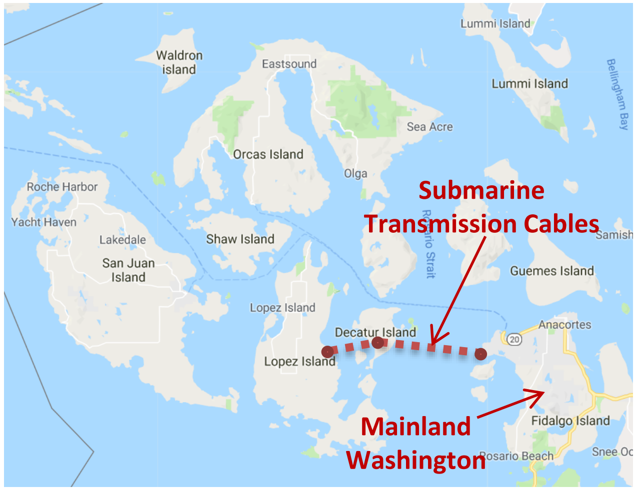
Benefits Evaluated

1. Capacity-resource adequacy
2. Energy arbitrage
3. Regulation up/down
4. Conservation voltage reduction
5. Outage management of critical loads, including addressing voltage sags

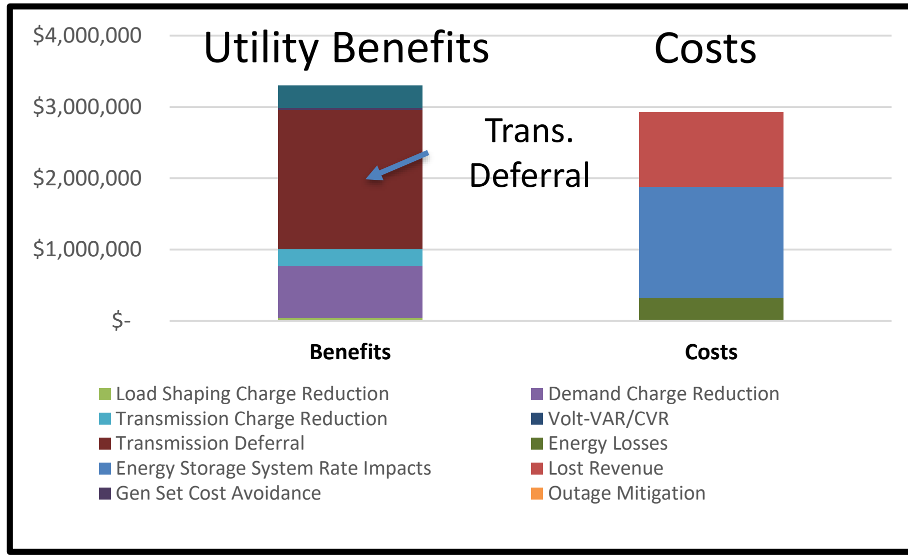
Reliability to SEL generate additional $9.5 million in benefits improving overall benefit-cost ratio to 1.79



Energy Storage Use Case 2
Transmission Upgrade Deferral



Transmission Cable Map from Fidalgo Substation in Anacortes to Decatur and Lopez Islands



0.5 MW / 2 MWh ESS to reduce peak demand on transmission cable. Integrated with 504 kW Community Solar.

Benefits Analyzed

- Demand charge reduction
- Load shaping charge reduction
- Transmission charge reduction
- Transmission cable deferral
- Conservation voltage reduction

- Transmission Deferral for 3.65 years
- ~ $1M in lost revenue from Community Solar calculated into Utility costs.
- Additional $0.4M in outage mitigation to the island ***not*** included in analysis.

Energy Storage Use Case 3
PV + Storage Microgrid ROI

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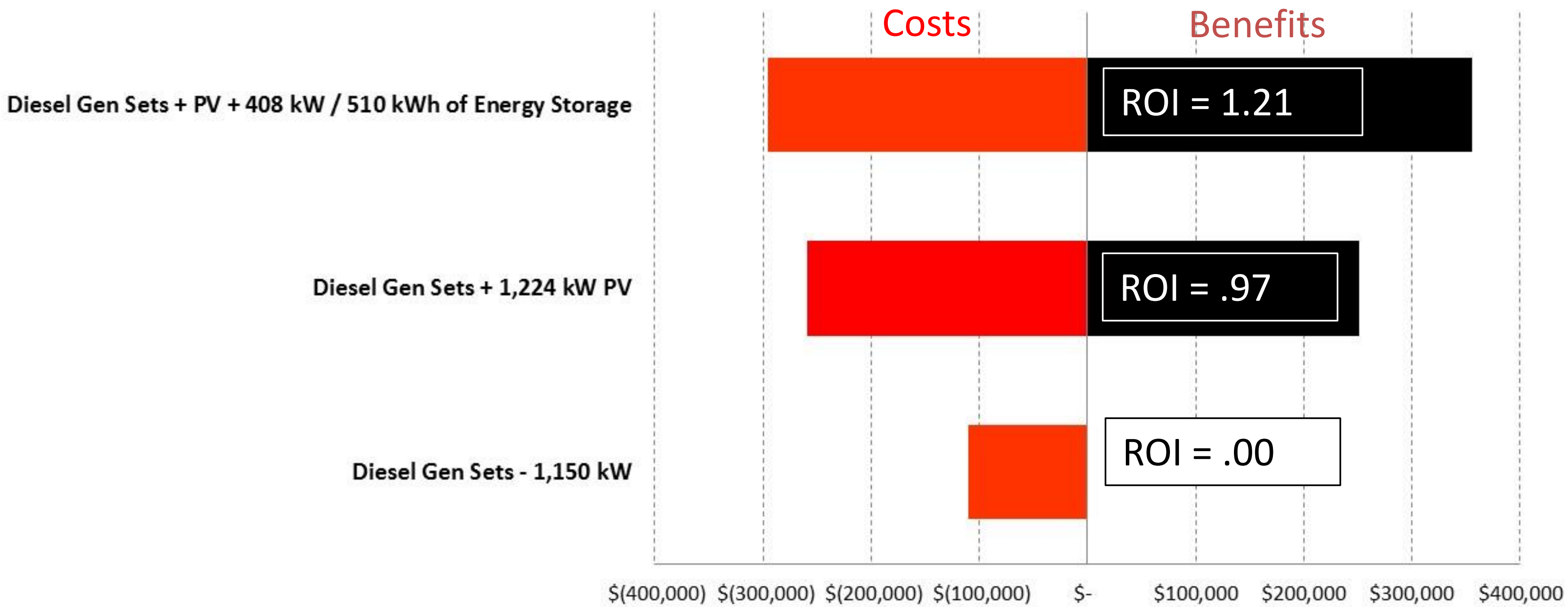

	Diesel Gen Sets - 1,150 kW	Diesel Gen Sets + 1,224 kW PV	Diesel Gen Sets + PV + 408 kW / 510 kWh of Energy Storage
Costs	$(110,120)	$(258,448)	$(294,781)
Benefits		$251,000	$355,618

90% survivability rate for a two-week outage

Thank you

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Acknowledgements

- DOE-OE Energy Storage Program, Dr. Imre Gyuk
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- Stationary Energy Storage Technologies Team at PNNL:

  Patrick Balducci, Wei Wang, David Reed, Rebecca O’Neil, Jeremy Twitchell, Kendall Mongrid, Di Wu, Jan Alam, Charlie Vartanian, David Conover, Ed Thomsen, Zimin Nie, Aaron Hollas, Bin Li, Aaron Hollis, Huilin Pan, Hee Jung Chang, Alasdair Crawford, Jun Liu, Yuyan Shao, Vijay Murugesan, Junhua Song, Xiaochun Lu, Guosheng Li, Hee-Jung Chang, Vish Viswanathan, Daiwon Choi, Xioalin Li, Biwei Xiao, and Litao Yan