U.S. DEPARTMENT OF ENERGY
Office of Electricity Delivery & Energy Reliability

SAND2018-0368C

Role of DOE Energy Storage Program

Babu Chalamala

Sandia National Laboratories

for Dr. Imre Gyuk, Program Director, DOE Energy Storage Program

January 18, 2018

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology and Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International, Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525. SAND No:

ES Program: Where We Are – Where We Are Going

PAST	PRESENT	FUTURE
Grants and Cost Shared Projects	Research and Development	Resilient, Secure Power Grid
Energy Independence and Security Act (2007)	Demonstration	Enable Flexible Grid of the Future
The Recovery Act (2009)	Market Enablement	Support Grid-at-the-Edge Paradigm

Energy Storage Vision

Added storage at generation to ease issues of supply intermittency or load ramping.

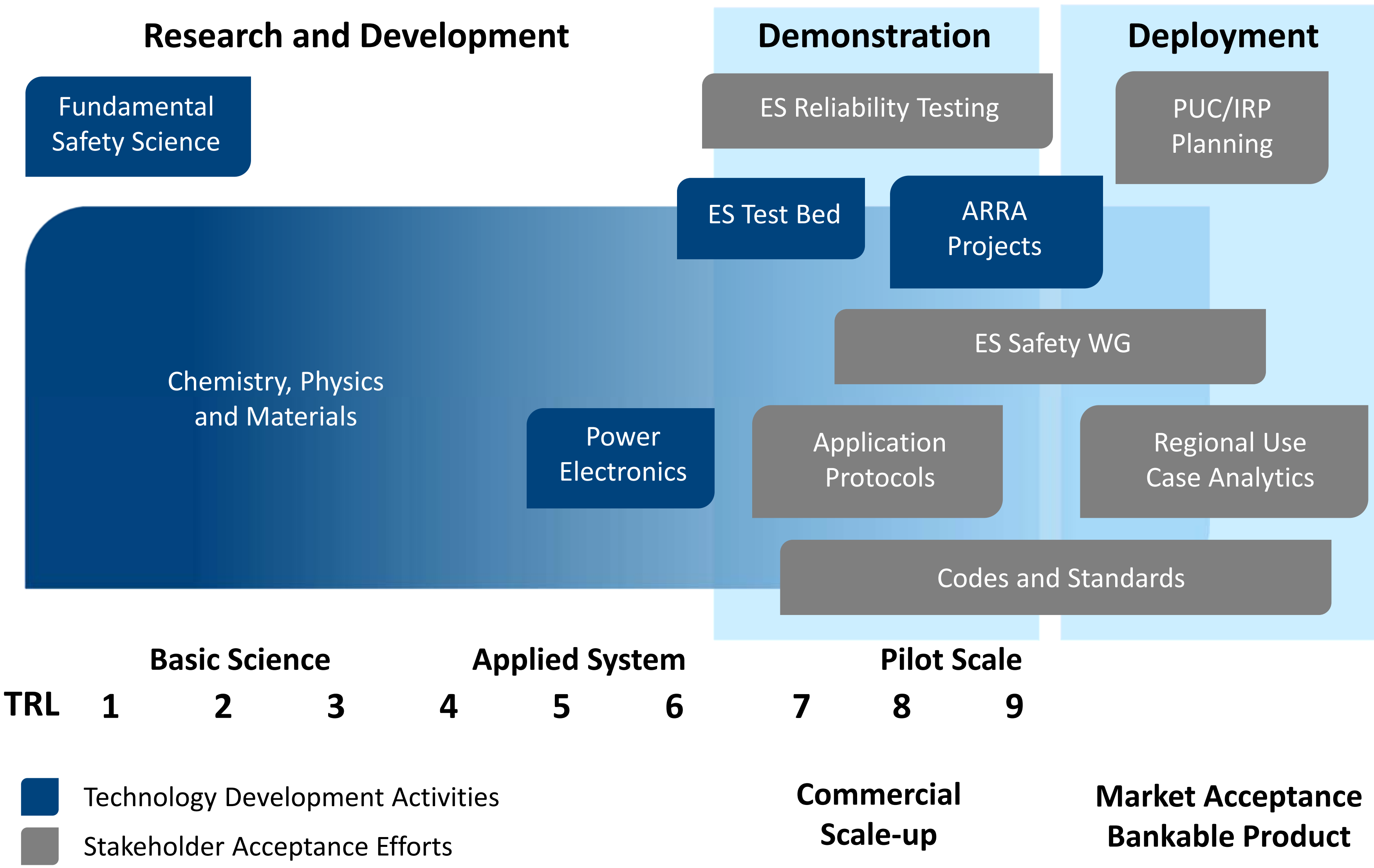
Strategically located storage across the transmission and distribution lines to improve reliability, efficiency, ramping, and resilience.

Storage at Load to support distributed resources and add redundancy to improve resilience

Energy Storage Program Objectives

Program Areas	Goals	Objective
Cost Competitive Technology	Capability and cost to meet industry requirements.	• Materials and chemistry • Systems and manufacturing • Cost reduction • Expanded applications
Reliability & Safety	Increase user confidence	• Lab testing • Codes and standards • Guidebooks • R&D Improvements
Regulatory Environment	Barriers and requirements equal or comparable to other grid resources	• Policy analysis • Valuation methods • Resolution of benefits
Industry Acceptance through Demonstrations	Develop locational value and technical use cases	• Stakeholder engagement • Proving success • Seamless integration • Consumer benefits

Technology Deployment



Cost Competitive Technologies

Program Areas	Goals	Objective
Cost Competitive Technology	Capability and cost to meet industry requirements.	• Materials and chemistry • Systems and manufacturing • Cost reduction • Expanded applications

Mission:

- Develop improvements in materials and chemistries that can significantly reduce the capital and operational costs of energy storage technologies

Current Targets:

- V/V Redox Flow: Demonstrate < $300/kWhr system cost.
- Organic Flow Batteries: 50% reduction in cost over V/V systems.
- $Zn\text{-}MnO_2$: Bring material cost for system < $60/kWhr
- Na-Metal Systems: Achieve lifetimes exceeding current Na-S system with reduced cost structure.
- Power Electronics: <$0.05/W
- Polymeric Membranes: 10x reduction in cost compared to Nafion

Reliability & Safety

Program Areas	Goals	Objective
Reliability & Safety	Increase user confidence	• Lab testing • Codes and standards • Guidebooks • R&D Improvements

Mission:

Validate and improve the safety and reliability of energy storage systems to decrease human and financial risk while accelerating acceptance of new storage:

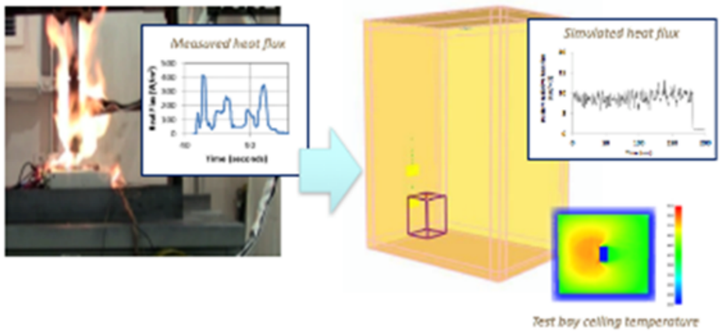
Current Efforts:

Energy Storage Safety Working Group (ESSWG) with industry stakeholders
Energy Storage Reliability Workshop.
Safety Codes and Standards Documentation.
Development of safer materials.

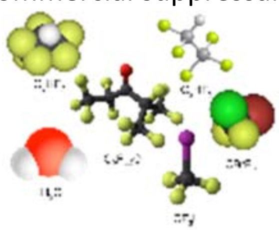
Greater Commercial and Societal Acceptance of Energy Storage requires significant advance in Safety and Reliability R&D and the field validation of system performance.

ESS Safety tied into industry to effect maximum impact

Thermal runaway experiment and modeling

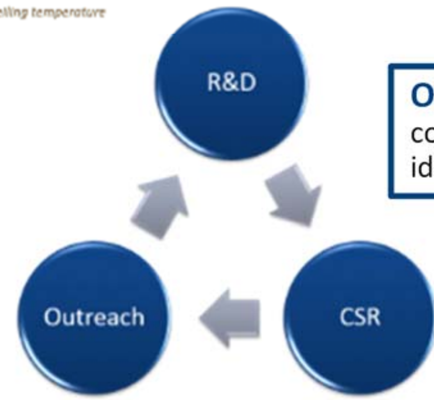


Commercial suppressants



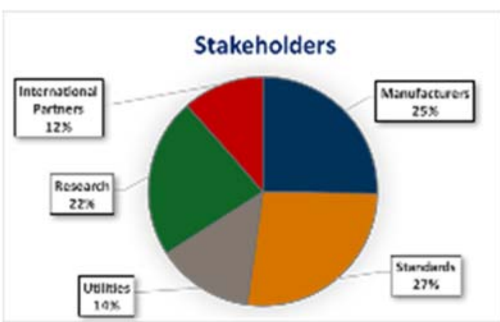
Objective: ESS safety R&D dictated by industry priorities solicited through our diverse working group.

- **Fire Suppression testing** and analysis
- **Thermal runaway** research
- **System scale burn test**
- **Commodity classification** development
- **Fire and vent gas modeling** and analysis

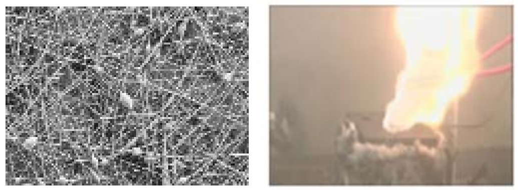


Objective: Distill codes and regulations, providing common sense feedback to code bodies while identifying gaps to facilitate safe and efficient adoption.

Objective: Provide awareness to first responders and authorities with jurisdiction; metering perception of risks with reality.



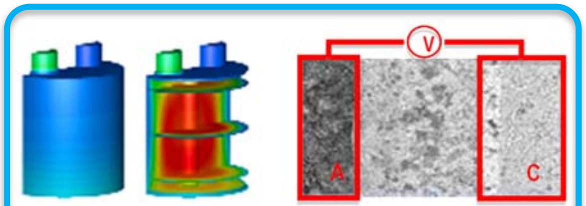
ESS Safety: R&D for Making Systems Safe and Reliable



Materials R&D to date:
- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials

Materials R&D needs:
- Viable flow batteries
- Aqueous electrolyte batteries
- High specific heat suppressants
- Vent gas composition

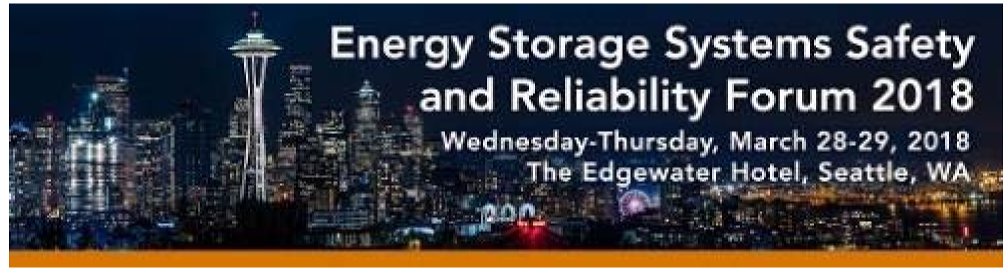
Testing
- Electrical, thermal, mechanical abuse testing
- Failure propagation testing on batteries/systems
- Suppressants and delivery with systems and environments
- Large scale thermal and fire testing (TTC)

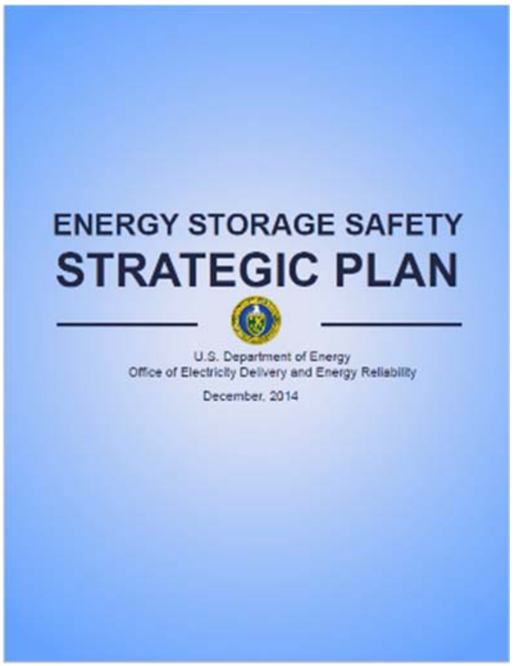


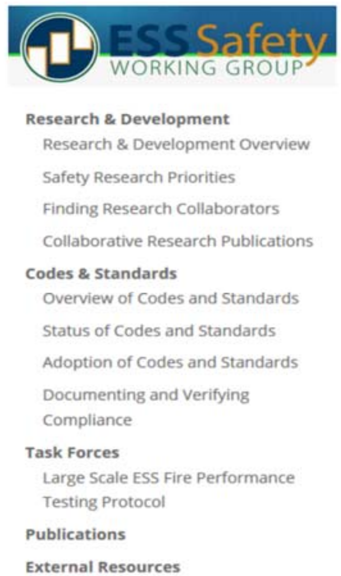
Simulations and Modeling
- Multi-scale models for understanding thermal runaway
- Validating failure propagation models
- Fire Dynamic Simulations (FDS) to predict the size, scope, and consequences of battery fires

Procedures, Policy, and Regulation
- UL 1973-13 Batteries for Use in Stationary Applications
- ANSI/UL 9540-P (ESS Safety)
- UL 1974 (Repurposing)
- IEEE 1635-12 (Ventilation and thermal management)

Energy Storage Safety and Reliability







For more information on the Energy Storage Safety Working Group (ESSWG) visit our website

*The goal of the energy storage safety working group is to **"Foster confidence in the safety and reliability of energy storage systems."***

http://www.sandia.gov/energystoragesafety/

Pacific Northwest NATIONAL LABORATORY | Sandia National Laboratories

DOE OE Energy Storage Systems Safety Roadmap

Regulatory Environment

Program Areas	Goals	Objective
Regulatory Environment	Barriers and requirements equal or comparable to other grid resources	• Policy analysis • Valuation methods • Resolution of benefits

Mission: Reducing institutional and regulatory across federal, state and municipal entities.

Current Efforts:

- Workshops on energy storage with commissioners and staff
- Provide information on valuation of energy storage assets
- Support technical assistance on energy storage
- Pilot projects and deeper relationships established with:

Outreach to PUCs

2016 Southwestern Public Utilities Commission (SW PUC) Energy Storage Workshop | May 3, 2016

Energy Storage Technology Advancement Partnership (ESTAP)

Energy Storage State Policy Update

Pacific Northwest Regulatory Workshop: Drivers

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

US DOE and PNNL hosted Northwest utility regulatory commissioners and staff on July 22-23, 2015 at the Laboratory main campus in Richland, Washington.

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

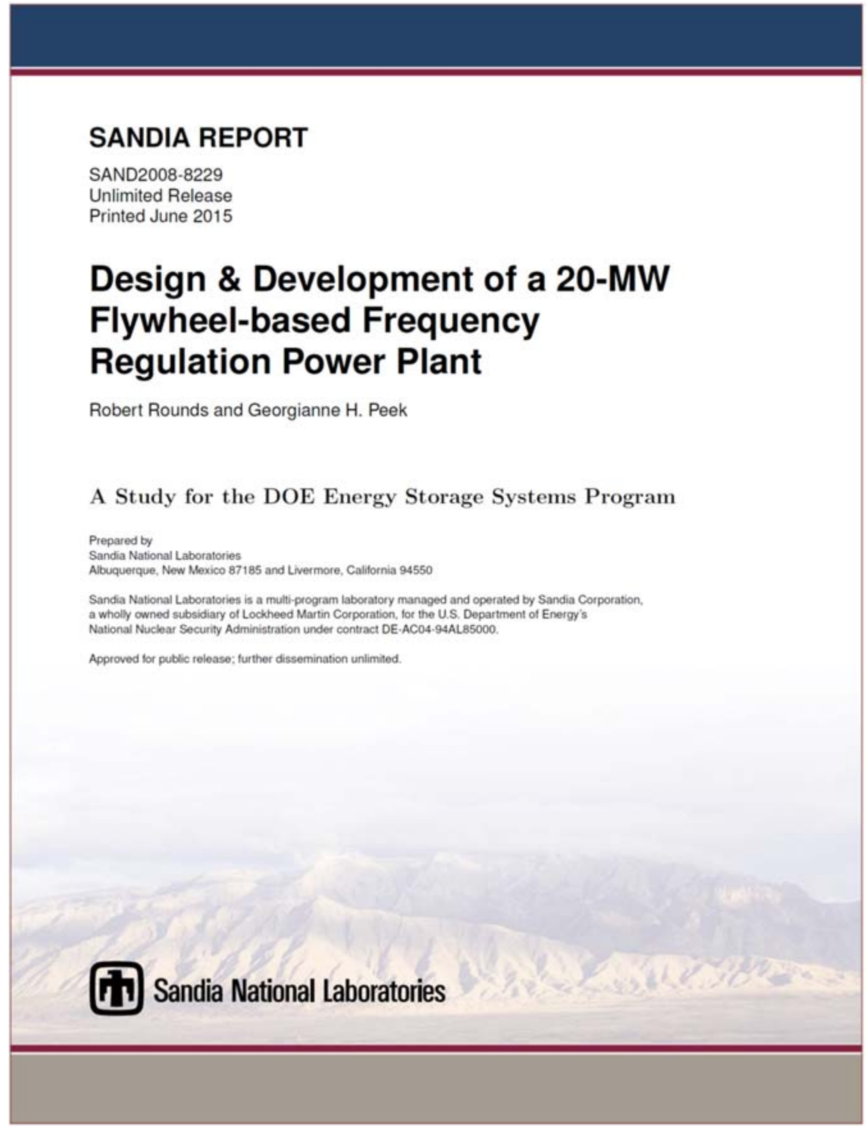
Energy Storage Seminar

Western State Regulatory Commission Staff

November 6, 2017
Western Electricity Coordinating Council offices
155 North 400 West, Suite 200, Salt Lake City, Utah

Example Impact: FERC 755

- 2008 OE/Sandia sponsored study showed that flywheel energy storage could provide 2-4X more regulation service per MW than conventional resource, yet was paid the same.
- FERC Order 755, enacted in 2011, increased the pay for "fast" responding sources like batteries or flywheels that are bidding into frequency regulation service markets.
- First enacted by PJM
- 2/3 of US energy storage now deployed in PJM to provide frequency regulation services.



SANDIA REPORT

SAND2008-8229
Unlimited Release
Printed June 2015

Design & Development of a 20-MW Flywheel-based Frequency Regulation Power Plant

Robert Rounds and Georgianne H. Peek

A Study for the DOE Energy Storage Systems Program

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

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Approved for public release; further dissemination unlimited.

Sandia National Laboratories

Industry Acceptance through Demonstration

Program Areas	Goals	Objective
Industry Acceptance through Demonstrations	Develop locational value and technical use cases	• Stakeholder engagement • Proving success • Seamless integration • Consumer benefits

Mission: The development, deployment, and operation of energy storage through controlled testing and field validation of prototype commercial storage technologies is critical for industrial acceptance.

Current Efforts:

- Identify applications
- Develop use case analysis and provide cost-benefit analysis
- Deliver technical assistance on procurement, siting, and commissioning.
- Establish control architecture
- Capture real-world successes

Industrial Acceptance

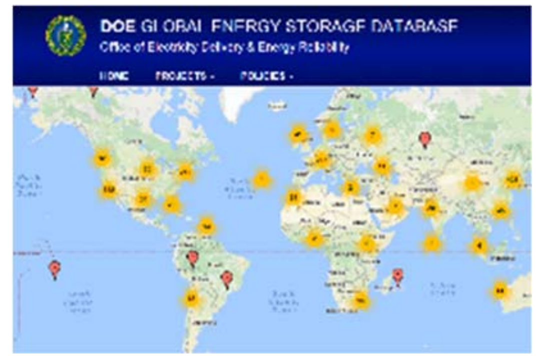
Where we have been

ARRA - Initial evaluation of grid connected ES projects

Where we are today

Additional projects to enable applications in renewables, resiliency, and critical infrastructure

Where we are going



World wide adaption of ES based on our work

PAST → **PRESENT** → **FUTURE**

Storage Economics and Policy Implementation

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

Energy Storage Device
25-40%

Power Electronics
20-25%

Balance of Plant
20-25%

Economics of Storage

Analysis of energy storage value streams is location dependent

- Market area
- Vertically integrated utility

Often there is a technical performance component

- Stability analysis
- Transient response from a generator drop
- Ramp rate limiting for renewable integration

Until policy and regulations catch up, storage owners are not compensated for some potential services

- Carbon reduction
- Synthetic inertia
- Voltage support

J. Eyer and G. Corey, “Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide”, Sandia National Laboratories, SAND2010-0815, February 2010.

Market Area Results

CAISO

– Frequency regulation is the optimum policy. DA/RT energy arbitrage has potential

ERCOT

– Frequency regulation is the optimum policy. Location does not matter

PJM

– Frequency regulation is the optimum policy.

ISO NE

– Frequency regulation. Forward Capacity Market (FCM) payment reduction
– Regional Network Services (RNS) payment reduction

MISO

– Frequency regulation is the optimum policy

[1] R. H. Byrne, and C. A. Silva-Monroy, *Estimating the Maximum Potential Revenue for Grid Connected Electricity Storage: Arbitrage and Regulation,* SAND2012-3863, Sandia National Laboratories, Albuquerque, NM 87185, 2012.
[2] R. H. Byrne, and C. A. Silva-Monroy, "Potential Revenue from Electrical Energy Storage in the Electricity Reliability Council of Texas (ERCOT)," in IEEE Power and Energy Society (PES) General Meeting, Washington, DC, 2014.
[3] R. H. Byrne and C. A. Silva-Monroy, Potential revenue from electrical energy storage in ERCOT: The impact of location and recent trends," in Proceedings of the 2015 IEEE Power and Energy Society (PES) General Meeting, Denver, CO, July 2015, pp. 1-5.
[4] R. H. Byrne, R. Concepcion, and C. A. Silva-Monroy, "Estimating potential revenue from electrical energy storage in PJM," Proceedings of the 2016 IEEE Power and Energy Society (PES) General Meeting, Boston, MA, July 2016, pp.1-5.
[5] R. H. Byrne, S. Hamilton, D. R. Borneo, T. Olinsky-Paul, I. Gyuk, "The Value Proposition for Energy Storage at the Sterling Municipal Light Department," Proceedings of the 2017 IEEE Power and Energy Society (PES) General Meeting, Chicago, July 2017, pp.1-5.
[6] T. A. Nguyen, R. H. Byrne, R. J. Concepcion, I. Gyuk, "Maximizing Revenue from Electrical Energy Storage in MISO Energy & Frequency Regulation Markets," Proceedings of the 2017 IEEE Power and Energy Society (PES) General Meeting, Chicago, July 2017, pp.1-5.
[7] R. H. Byrne, Tu A. Nguyen, D. A. Copp, R. J. Concepcion, B. R. Chalamala, I. Gyuk "Opportunities for Energy Storage in CAISO: Day-Ahead and Real-Time Market Arbitrage," submitted to the IEEE Speedam 2018 conference, June 2018.

Reports available at: http://www.sandia.gov/ess/

Vertically Integrated Utilities

Cost savings are typically the primary benefit of energy storage

- Production cost modelling analysis
  - Improved operation of traditional generators
  - Reduced curtailment of renewables
  - Reduced reserve requirements (e.g., turn off must-run generators)
- Transmission and Distribution (T&D) deferral
  - Can be a very large savings
  - Very location specific
  - Often there are competing alternatives (e.g., demand response, conservation, etc.)
- Distribution level
  - Voltage support
  - Renewable integration
  - Grid resiliency

Recent case studies

- Nevada Energy, Southern Co, Maui Electric Co, Hawaiian Electric Co

Following reports on these studies are available at: Reports available at: http://www.sandia.gov/ess/
SAND2013-4902 (2013); SAND2013-2251 (2013) SAND2012-10314 (2012)
J. Ellison, L. Rashkin, J. Serio, R. Byrne, "The Benefits of Grid-Scale Storage on Oahu," Journal of Energy Storage, 2018.

Economics of Energy Storage

Different approaches for estimating value streams

- Market areas
- Vertically integrated utilities

Analysis is typically very location dependent

- Technical requirements
- Policy & regulations

Once applications and value streams have been modelled and quantified – selecting the appropriate technology is the next step

- Return-on-investment can vary significantly by energy storage technology

The efficacy of algorithms to operate the system should be evaluated – potential impact on revenue / grid benefits

ES Optimization & Evaluation Tools

What is it?

- Open-source unified tool set for energy storage stake holders:
  - Analyze value of energy storage across the country
  - Optimal sizing and placement
  - Optimal microgrid management
  - Technology selection

Why use it?

- No other unified tools are available.
- Our tool is general, free, open-source, and easy-to-use.
- Interfaces with other Sandia software tools such as Prescient (Production Cost Model Tool), Microgrid Design Tool (R&D 100 winner!)

When is it available?

- Release Date: July 1, 2018

Energy Storage Optimization & Evaluation Tool

Select an ISO to place the energy storage device in.

ISOs (Independent System Operator) have different market structures, resulting in different opportunities for generating revenue.

PJM | ERCOT | MISO

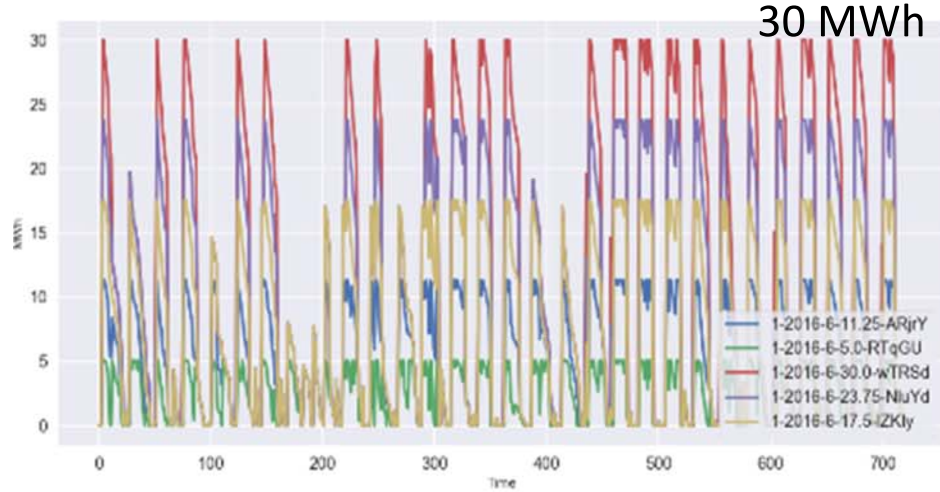
CAISO | ISO NE

Parameters

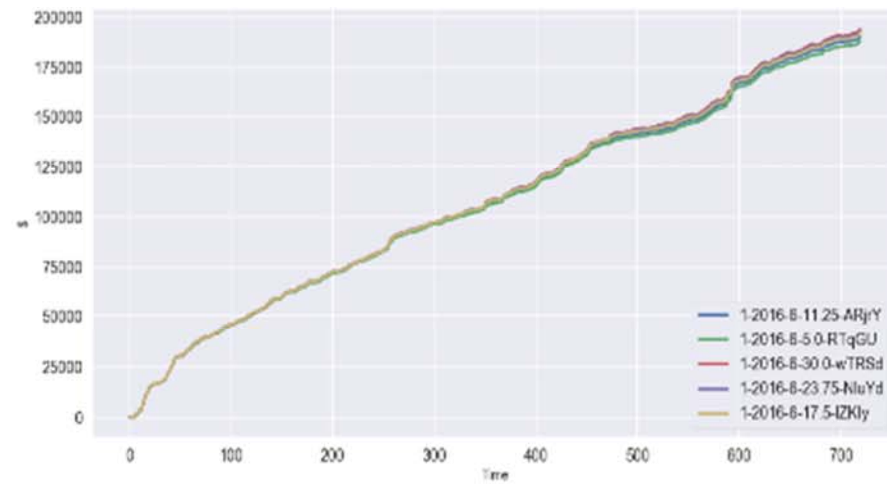
storage efficiency	0.88
conversion efficiency	0.85
minimum state of charge (MWh)	0.00
maximum state of charge (MWh)	32.00
maximum power charge (MW)	5.00
maximum power discharge (MW)	5.00

State of Charge [MWh]

30 MWh



Revenue [$]



Program Outreach Tools

DOE/EPRI One-stop shop for Current ES Technologies and Applications, Life Cycle System Cost Methodology, 10000+ Downloads in 2017

PUC Workshops

DOE Global Energy Storage Database: 1600+ Projects; 2.2Million page visits

Technical Conferences

Sample Partnerships

Major Universities

UNIVERSITY of WASHINGTON

CUNY The City University of New York

COLORADO SCHOOL OF MINES
EARTH • ENERGY • ENVIRONMENT

IOWA STATE UNIVERSITY

HARVARD
VE RI TAS

CASE WESTERN RESERVE UNIVERSITY EST. 1826

MICHIGAN STATE UNIVERSITY

Oregon State UNIVERSITY

West Virginia University

ASU Arizona State University

UNIVERSITY OF MARYLAND

PennState

UNIVERSITY OF TEXAS ARLINGTON

Drexel UNIVERSITY

NC STATE UNIVERSITY

SUNY The State University of New York

UC San Diego

UCLA

Illinois Institute of Technology

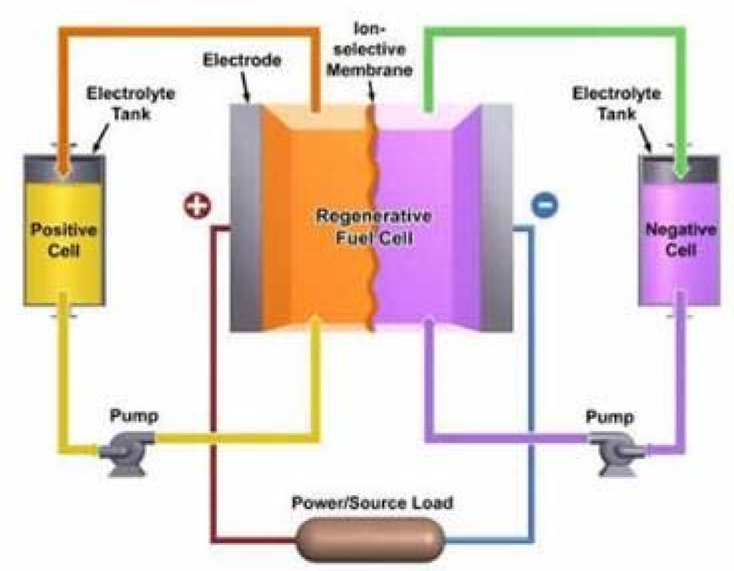
Stanford University

NM STATE

DOE State Initiatives

Washington State Clean Energy Fund selected projects with UET vanadium flow battery:

- Avista, PNNL, Washington State University
- Snohomish, PNNL, University of Washington



Vermont Public Service Department, DOE, Green Mountain Power:

- Contributes to an economic development effort
- 7,700 solar panels can generate 2 MW, backed up by a 4-MW battery storage system
- System can be islanded to provide resilient microgrid

Stafford Hill Solar Farm. Photo credit: Eric Hudiburg

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

DOE/State Demos

Sterling, MA:

$1.5M grant from MA-DOER under Community Clean Energy Resiliency Initiative

- Part of the Commonwealth's broader climate adaptation and mitigation efforts
- Grant program focused on municipal resilience
- Uses clean energy technology solutions to protect communities from interruptions in energy services due to severe climate events

Cordova, AK:

Existing run-of-the-river hydro-diesel islanded microgrid

- No water storage
- Peak loads supplemented by diesel
- Storage and demand managed loads
- Storage: frequency regulation and spinning reserve
- Demand management: increase hydropower utilization (electro-thermal storage)

Eugene, OR:

Joint solicitation with Oregon DOE for storage deployments

- Provide "resilient backup power" in case of grid outage to support critical facilities that provide electricity, water and communication services
- Also includes electric vehicle charging stations and a community solar installation
- Solar operation enables EWEB customers to buy into a PV system and receive a share of the electricity cost savings

On the Horizon

R&D prototyping new aqueous soluble organic flow battery chemistries for 2X reduction in cost

Expand Safety Forum to include national and international community for adoption of codes and standards

Expand regional workshops to engage utility regulatory commissions

Expand technical assistance to states on demonstrations with 8MW+ of energy storage assets

Program Philosophy and Leadership

Dr. Imre Gyuk

Energy Storage Program Director, OE

Imre.Gyuk@hq.doe.gov

Dr. Babu Chalamala

Program Manager, Sandia National Laboratories

bchalam@sandia.gov

Dr. Vincent Sprenkle

Program Manager, Pacific Northwest National Laboratory

Imre.Gyuk@hq.doe.gov

Dr. Michael Starke

Program Manager, Oak Ridge National Laboratory

starkemr@ornl.gov