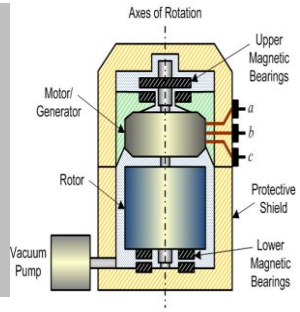
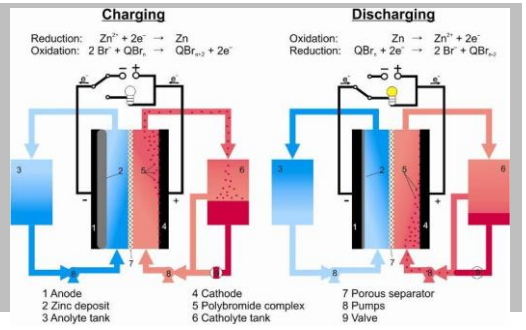
SAND2014-17533 PE

http://fsr-encyclopedia.eui.eu/wp-content/uploads/2013/03/logo_ekipedia_20_trasparent.png





Sandia National Laboratories

Exceptional service in the national interest

Energy Storage Technical Partnerships

Preparing the Demonstration, Testing & Analysis Projects for Business at the Edge of the Grid

DOE/OE Energy Storage:

2014 Program Peer Review

Renaissance Hotel, Washington D.C.

September 2014

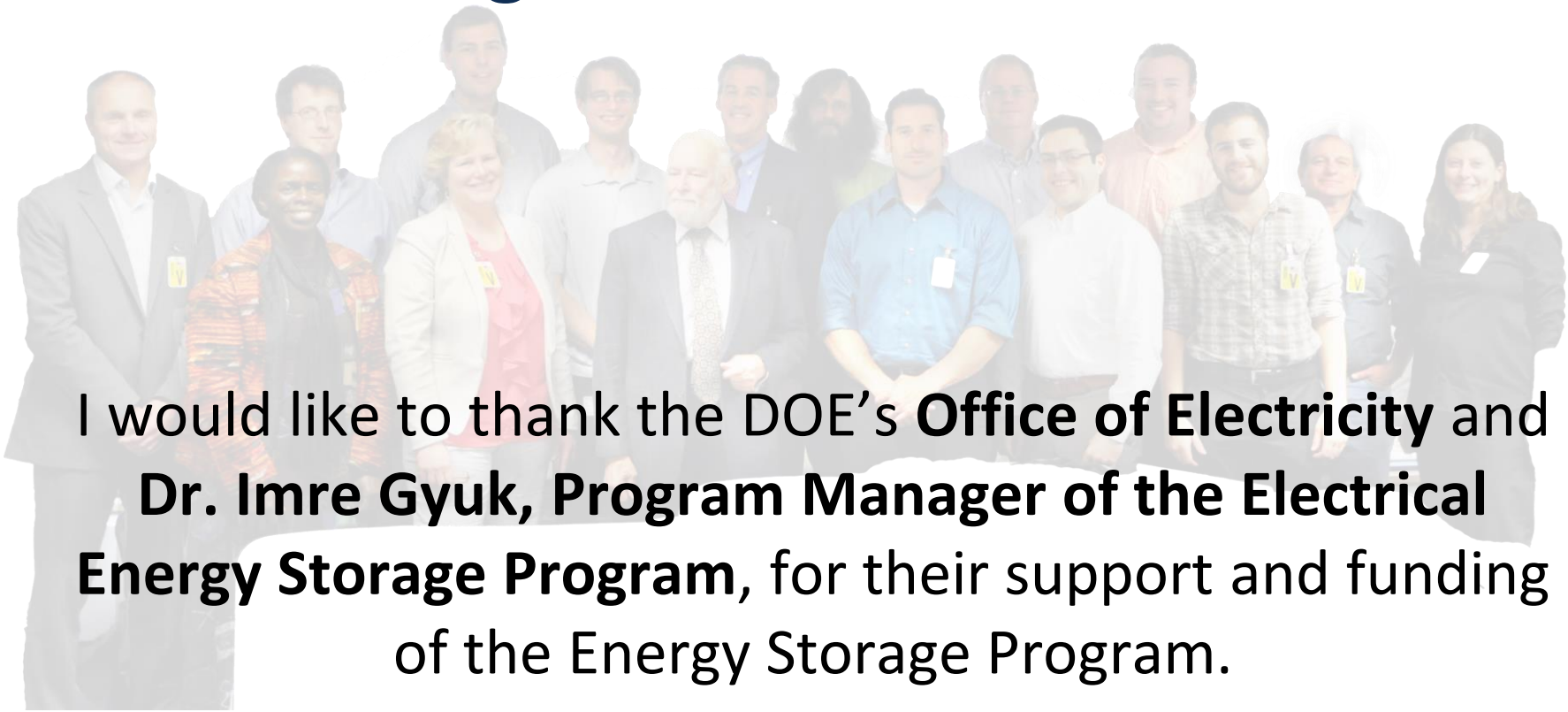
Jacquelynne Hernández

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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. SAND NO. 2011-XXXXP

Acknowledgements



I would like to thank the DOE's **Office of Electricity** and **Dr. Imre Gyuk, Program Manager of the Electrical Energy Storage Program**, for their support and funding of the Energy Storage Program.

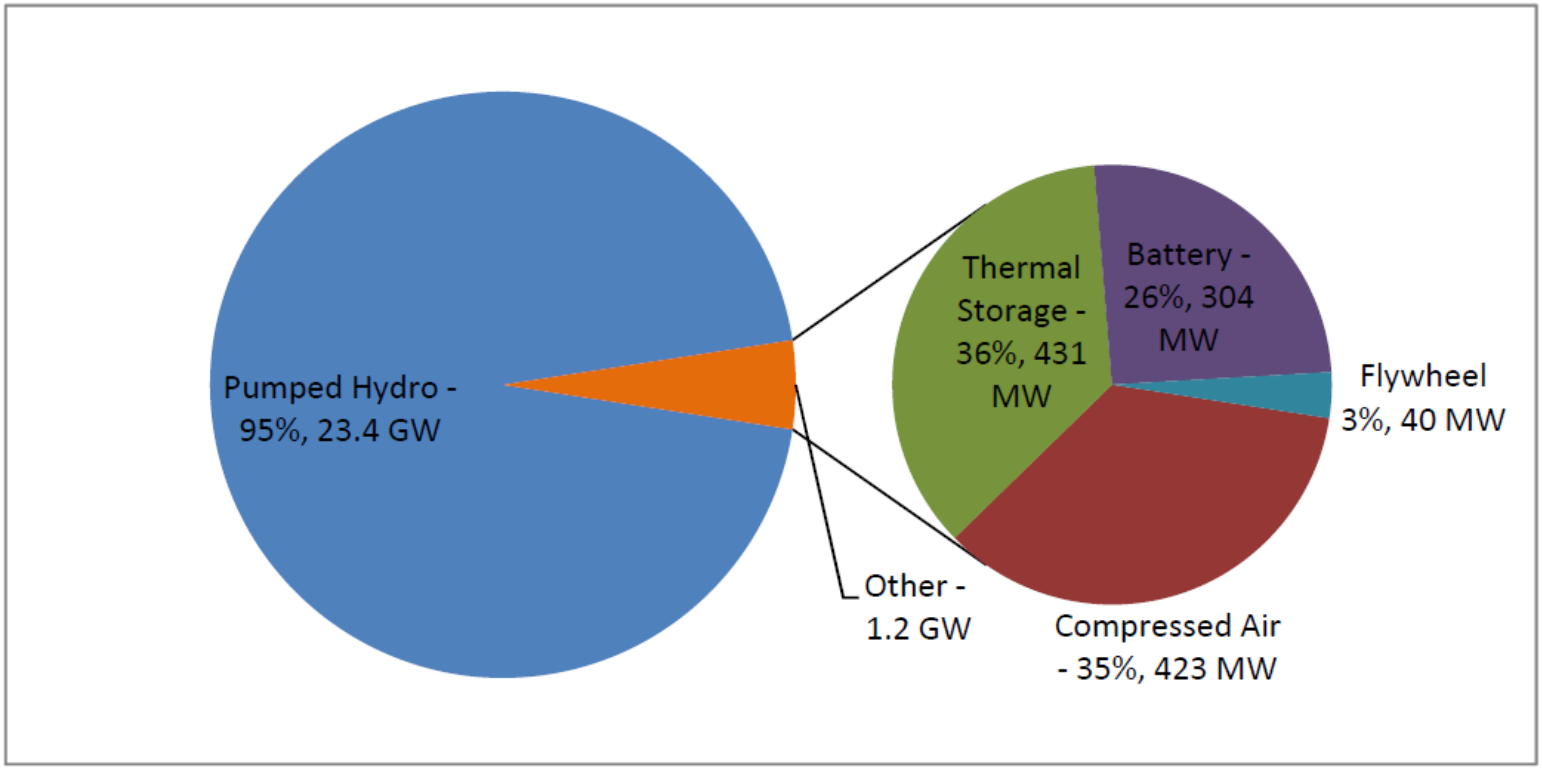
Summary of U.S. DER Storage

August 2013

Current mix of U.S. DER storage technologies

202 U.S. storage system deployments

24.6 GW Cumulative operational capability



NOTE:

DER or Distributed Energy Resources can be aggregated to provide power needed to meet regular demand. Electric utilities and grid operators count on DER such as storage to help in the transition to a smarter electricity grid.

DOE Global Storage Database, 2013
http://www.energystorageexchange.org/

ES Demo, Testing & Analysis DER/Grid-Edge Industry Partnerships

Annual Operating Plan (AOP) Goals	Partnerships, Collaborations, Technology Transfer
Devices and Systems Development	Helix Power
Industrial Engagement	NAATBatt
Modeling and Analysis	E&I Consulting
Applied Materials Testing and Field Evaluation	Ktech Corporation

AOP Goal: Energy Storage Devices & Systems Development

- **Innovation**

  HPSF serves as a power management device that significantly improves power quality

- Product/Service provided to DOE/SNL

  Conceptual design to store or deliver 1 MW of power

  for 90 seconds using flywheel energy storage system with objective to achieve greater than 80% round trip (ES) efficiency and steady state power losses less than 1 % of rated power

- Company Description (Helix Power)

  Developer of next generation power management hardware for utility scale applications

Helix HPSF Flywheel for Short Duration, High Cycle Applications

Advanced architecture

- High Power
  Short duration
  Fast response
- 1MW module rating
- 90 second discharge
- 200 msec response
- High duty factor
- High efficiency
- Low Loss
- High cycle life

Applications

- Industrial and rail applications
- Uninterruptible power supplies
- Microgrids
- Grid connected applications

Parameter space where flywheels compete best

- Several seconds to several hundred
- > 100 kW
- High cycle life

- Longer duration: Batteries are more cost effective
- Shorter duration: Capacitors are more cost effective
- Lower Power: Balance of system costs are prohibitive

High value applications in multiple sectors

Helix Challenge – Underserved Flywheel Applications

HPSF electric energy storage system addresses energy storage applications that are underserved by other flywheel developers and existing competing electrical energy storage technologies like those cited in the chart below.

ES Resource Service	Industry Applications
Frequency Response	Transmission Reliability
Remote Microgrids	Forward Operating Bases
Load Shaping & Peak Shaving	Renewable Resources Load & Interconnect Mismatch
Uninterruptible Power Supply	Critical Electrical Loads Multiple Synchronous Engines

Helix Power:

ES Devices & Systems Development

- Problem(s) Addressed
  - No trade-off of performance w/ efficiency, product life, or O&M expenses
  - Controls power ramps for grid-connected systems OR isolated systems while simultaneously improving power quality
  - Response time in milliseconds
  - Applications suited for installations that require high power, short duration, cyclic demands
- Path Forward
  - Move toward commercialization
  - Build, test, deploy HPSF flywheels over next 12 months

AOP Goal: Energy Storage Industrial Engagement

- **Innovation**

  Identification and ranking of new drivers and applications of DES/DER including preferred technology, deployment locations, barriers from utility owners

- Product/ Service provided to DOE/SNL

  Survey of electric utilities, vendors, other stakeholders about optimal use of Distributed Energy Sources technology and related barriers to deployment

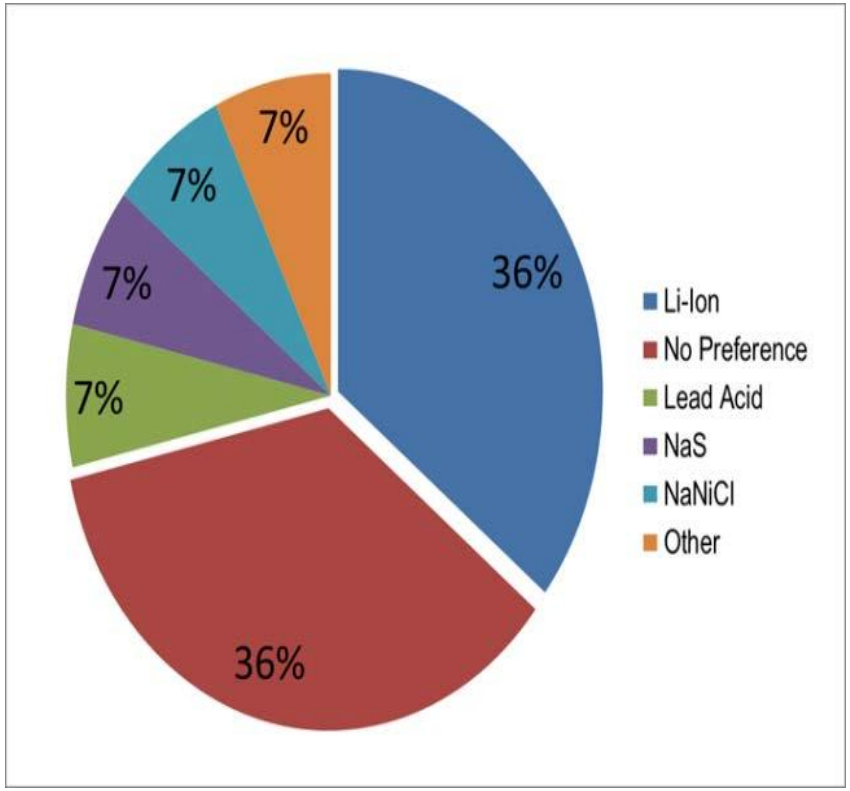
- Company Description (NAATBatt)

  Not-for-profit trade association of corporations, associations, research institutions focused on large format advanced batteries for transportation and ES applications

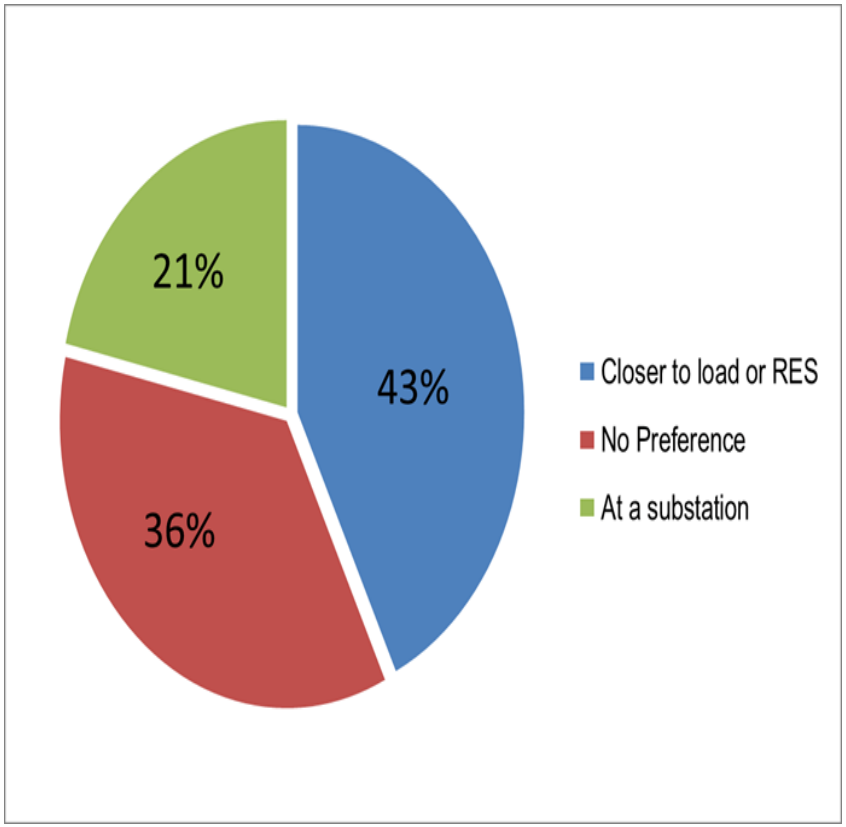
NAATBatt Survey Respondents

18 Utilities 22 Respondents	11 Vendors (11 respondents)	8 Consultants / Analysts (8 respondents)	2 Others
AEP (2)	1EnergySystems, Inc.	Customized Energy Solutions, LLC	Kentucky PSC
AES Energy Storage	ABB, Inc.	EPRI	UL, LLC
ComEd	Amperex Technology, Ltd.	G Nicholas and Associates, LLC	
Con Edison of New York	Becket Energy Systems	Good Company Associates, Inc.	
CPS Energy	EaglePicher Technologies, LLC	Navigant Consulting, Inc.	
DTE Energy	Enerdel, Inc.	Renewable Energy Ventures, LLC	
Duke Energy (2)	GE	Strategen Consulting, LLC (CESA)	
FirstEnergy Service Company	Kokam, LLC	Technology Insights, LLC	
HECO	S&C Electric Company, Inc.		
National Grid	Saft America, Inc.		
North East Utilities	UniEnergy Technologies, LLC		
Orange and Rockland Utilities			
PNM (2)			
SCE (2)			
SDGE			
Snohomish PUD			
Tri-State G&T			
Xcel Energy			

NAATBatt Survey Results

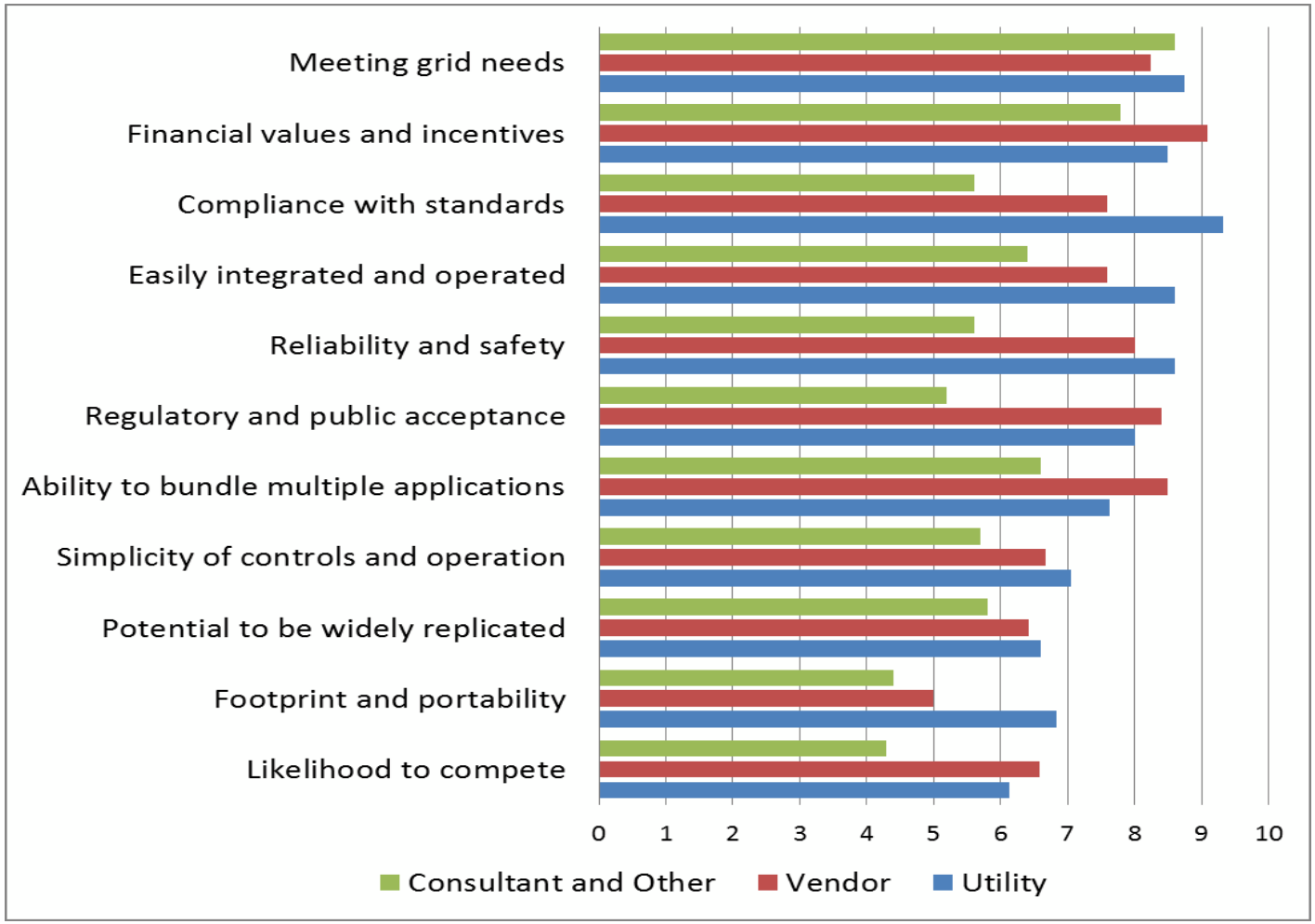


Preferred ES Technologies



Preferred ES Deployment Locations

NAATBatt DES Drivers Ranked



NAATBatt DES Barriers Summary

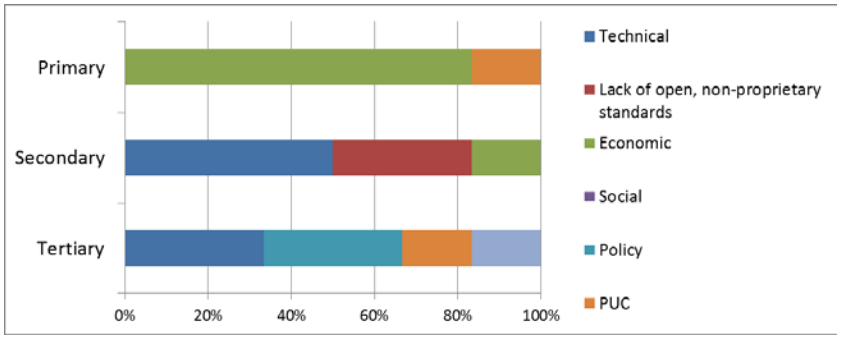


Figure 10 - Utilities Barriers Ranking

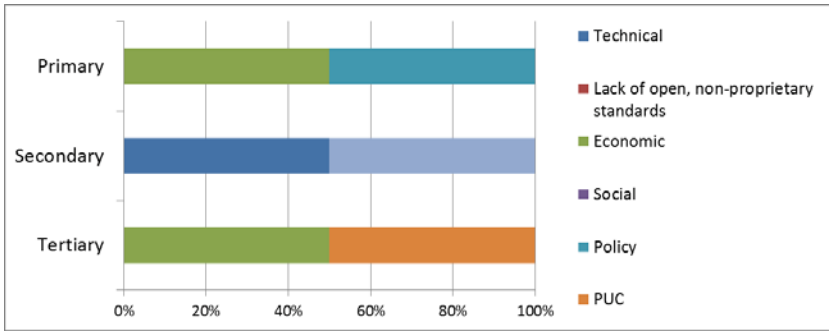


Figure 12 - Consultants and Others Barriers Ranking

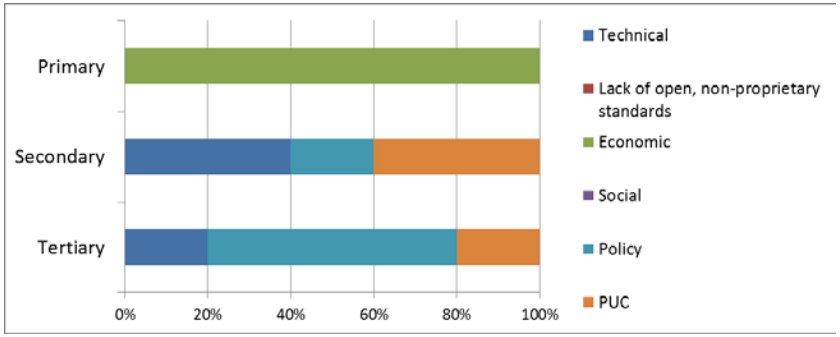


Figure 11 - Vendors Barriers Ranking

NOTES:

1. These are graphs from the final NAATBatt Report, available on the SNL ESS website October 15, 2014.
2. The author uses the term “economic” to indicate return on investment (ROI).

Innovative DES Projects Deployed

Snohomish PUD Projects

Project Name	TBD - Li-ion	TBD - Flow battery
Commission Date	2014	2015
Location	Substation	Substation
Ratings	1-2MW/2-4MWh	2-4MW/4-6MWh
Intended function(s)	Wind integration/peak shifting	Wind integration/peak shifting

PNM Project

Project Name	Prosperity Energy Storage Project
Commission Date	Initial 9/2011 full 2/2012
Location	Albuquerque
Ratings	0.5MW/.1 MWH
Intended function(s)	Smooth and shift PV

Kokam Projects

Project Name	Duke Marshall	KCP&L	CES – AEP, DTE, Duke, SDG&E	Del Lago	DTE PV demonstration
Commission Date	~Q4 2011	~Q4 2011	~Q1 – Q2 2013	~Q4 2013	~Q4 2013
Location	Charlottesville, NC	Kansas City, MO	Detroit, Columbus, North Carolina, San Diego	San Diego, CA	Detroit, MI
Ratings	1 MW/750 kWh	1 MW/1 MWh	Units of 25 kW/25 kWh	200 kWh	500 kWh Provided cells only
Intended Function(s)	Time shifting	Smart Grid, including islanding	Reliability, PV mitigation, Peak shaving	Reliability, PV mitigation, Peak shaving	PV mitigation

Innovative DES Projects Deployed

SCE Projects

Project Name	TSP	ISGD	ISGD	Distribution Energy Storage Integration (DESI)	PLS
Commission Date	2014	2013	2013	2015	2014
Location	Monolith, CA (sub station)	Irvine, CA, CES	Several residential units	Not chosen yet	Customer site
Ratings	8MW/32MWh	25kW/50kWh	14 units @ 4kW/10kWh ea	~ 2MW/4MWh	100kW/500kWh
Intended function(s)	Grid support & market	Load leveling, voltage support	Back-up power, utility control, customer energy management	Grid support	Permanent Load Shifting technology demo

Duke Energy Projects

Project Name	Notrees	McAlpine	Rankin	Marshall	Clay Terrace
Commission Date	2012	2012	2011	2012	2012
Location	Wind farm	Substation	Substation	Substation	Behind the meter
Rating	36 MW / 24 MWh	200 kW / 500 kWh	482 kW / 282 kWh	250 kW / 750 kWh	75 kW / 42 kWh
Intended Function(s)	Frequency Regulation	Renewable smoothing / energy shifting / utility microgrid	Circuit smoothing	Renewable smoothing / Energy Shifting	Renewable smoothing / Energy shifting / Demand side management

California Energy Storage Targets

Energy Storage Procurement Targets (in MW)

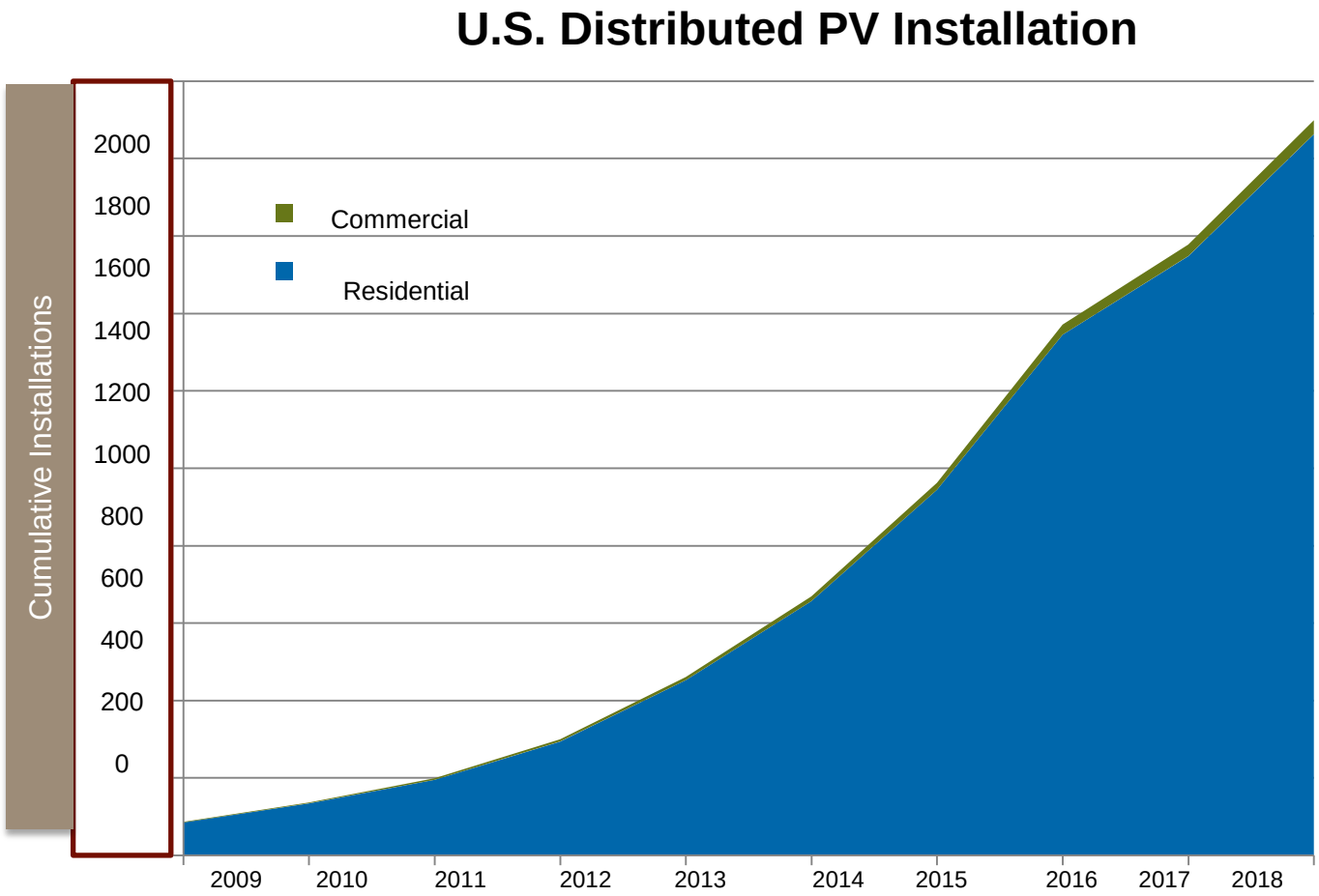
Storage Grid Domain (Point of Interconnection)	2014	2016	2018	2020	Total
Southern California Edison					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal SCE	**90**	**120**	**160**	**210**	**580**
Pacific Gas and Electric					
Transmission	50	65	85	110	310
Distribution	30	40	50	65	185
Customer	10	15	25	35	85
Subtotal PG&E	**90**	**120**	**160**	**210**	**580**
San Diego Gas & Electric					
Transmission	10	15	22	33	80
Distribution	7	10	15	23	55
Customer	3	5	8	14	30
Subtotal SDG&E	**20**	**30**	**45**	**70**	**165**
Total - all 3 utilities	**200**	**270**	**365**	**490**	**1,325**

Source: CPUC 2013 Final Decision

Projected DER Response To California Targets

*** Over 1.8 million DPV systems by 2018**

*** 96% are residential systems**



NOTE: In response to the California clean energy objectives, it is anticipated that most systems will be residential, with pressure on net metering programs.

Source: Historical: SEIA | Projections

NAATBatt:
Industrial Engagement

- Problem(s) Addressed
  - Primary barriers that prevent widespread deployment of DES technology at the substation level
  - Master list of projects to advance grid-scale demonstration and deployment of DES work that addresses industry and market challenges
- Path Forward
  - UL – Verification and review of safety standards for systems closer to the user
  - GS Battery – Evaluation of ES for emergency response applications for critical loads; Volt/VAR support schemes

AOP Goal: Energy Storage Modeling and Analysis

- **Innovation**

Application of approach called "market segmentation" for ES

- Product/Service provided to DOE/SNL

  High level characterization of the array of energy storage uses and benefits for electricity infrastructure and market place strategies

- Company Background Information (E&I Consulting)

  E&I completed the SAND Report SAND2010-0815

  "Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide"

ES Market Segmentation*

Physics ↓ Finance

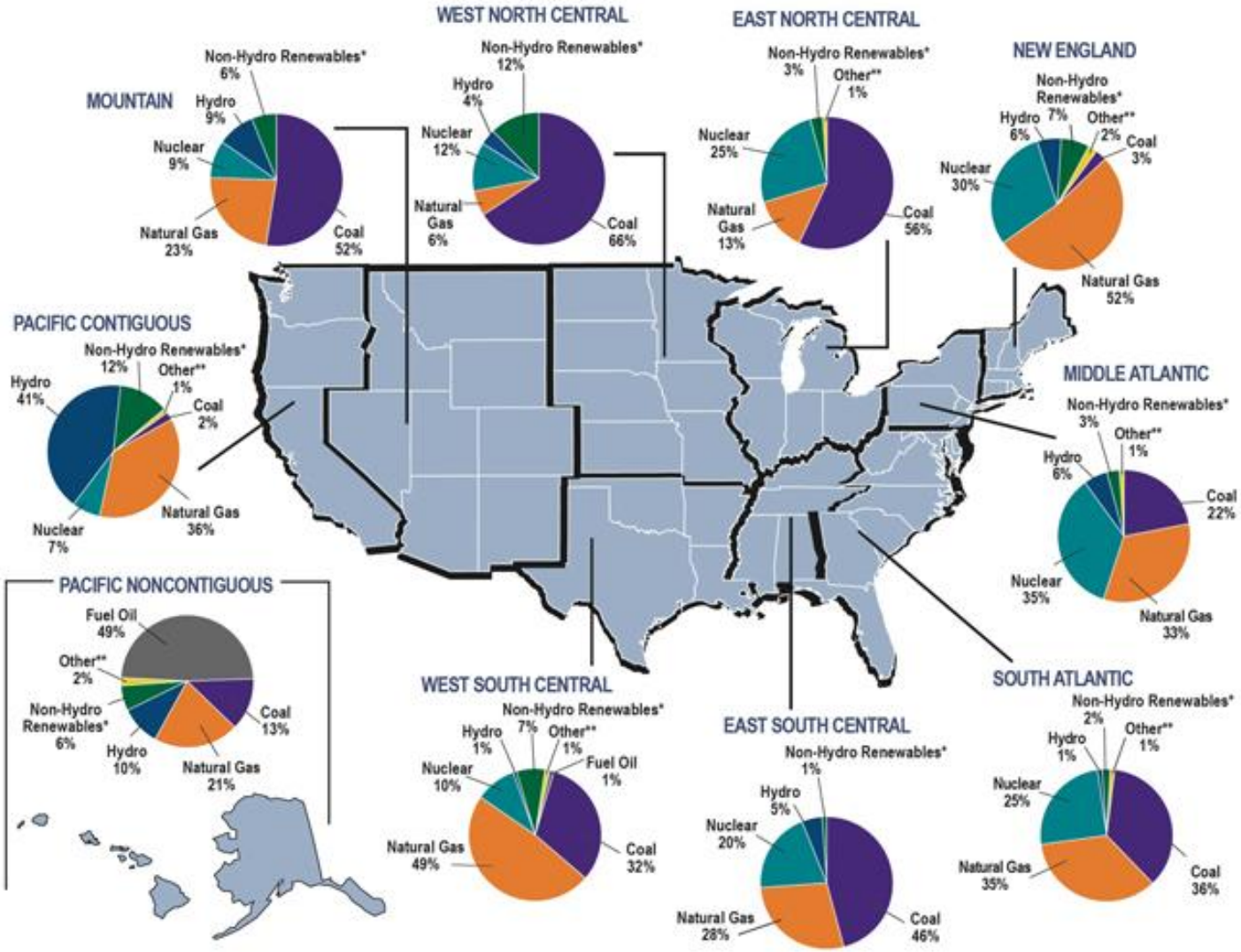
Energy	Power
Work (accomplished or potential)	*Capacity* to accomplish Work
Amount or *Quantity* (generated, transferred, utilized)	*Rate* (of energy generation, transfer, utilization)
Temporal (over time)	*Instantaneous*
Can be stored.	*Cannot* be stored.
Fuel and Variable Maintenance	Infrastructure (Equipment, Land)
Operating *Expense* (OPEX)	*Investment*, Capital Expentiture (CAPEX)
Variable Cost	Fixed Cost
Fuel purchased mostly *when/as* needed.	Capacity is added in "lumps,"* *before* it is needed.
Purchased using recent *revenue*.	Purchased with *capital* (equity and debt or just debt)
Utilities "pass-through" *expenses* (to their customers) without any mark up (without profit).	Source of *financial returns* (for bond interest and for investor-owned utility stock dividends)
Shorter term commitment	*Longer term* commitment
Relatively *less risky*	Relatively *more risky*
Common Units: Joules, kiloWatt-hours (kWh), MegaWatt-hours (MWh), British thermal units (Btus), horse power hours.	Common Units: Watts (W), kiloWatts (kW), MegaWatts (MW), Btus per hour, horse power.
End-user cost based on 1. *total amount* used and 2. volumetric pricing ($/kWh used)	End-user cost based on 1. *maximum rate* and 2. fixed pricing ($/kW$_{max}$) for each "demand period"

*In most cases capacity cannot be added in small increments.

☞ **Most utility storage benefits are *capacity*-related.**

*Summary offered by E& I Consulting

EPA 111D/ Clean Power Plan



http://cdn0.vox-cdn.com/assets/4524217/111d-key-challenges-brief-figure-2.png

E&I Assessment Guide

Options

- Continue Study
- Ignore
- Engage Industry & Others in New Markets, Different Structures
- Transform

E&I Consulting: Modeling and Analysis

- Problem(s) Addressed
  - ES Market Targeting Schemes
  - Development of DER/ES Business Model

- Path Forward

  Use of real-time data to monitor and analyze functionality and business model for ES for a variety of electricity consumers (residential, multi-unit dwelling, small and medium commercial outlets, and MUST-RUN mission critical load entities)

AOP Goal: Energy Storage Applied Materials; Testing and Field Evaluation

- **Innovation**

  Improvements to the RK30 Zinc-Bromine prototype and its components that impact manufacturability

- Product/Service provided to DOE/SNL

  Analysis of the performance, safety, and testing requirements derived from applicable regulations as well as commercial and military standards that apply to a prototype flow battery energy storage system

- Company Description

  Provider of technical services and products for government and commercial clients, and laboratories in the United States. Its work includes engineering design and drafting, hardware prototyping and assembling, testing, and fielding of electrical and mechanical complex systems, along with data acquisition, monitoring and control systems.

Ktech Compliance Matrix

RK30 Zinc-Bromine Battery ESS

Standard, Requirement, or Specification	Application (Requirement, Limitation, or Guidance) for Flow Battery Energy Storage System
29 CFR Part 1910, Occupational Safety and Health Standards	OSHA Permissible Exposure Limit (Bromine, 29 CFR 1910.1000, Table Z-1). The OSHA permissible exposure limit for bromine exposure to workers is an airborne concentration of 0.1 ppm, 0.7 mg/m^3 (8-hour time-weighted average). This applies during manufacture, and it must also be anticipated for installation and customer use and maintenance. Limits on other flow battery electrolytes may vary.
49 CFR Part 172, Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, Training Requirements, and Security Plans	Department of Transportation classifications in the §172.101 Hazardous Materials Table and associated requirements for transportation of hazardous materials. Bromine is categorized in the Hazardous Materials Table as follows: • Identification number: UN1744, Bromine or Bromine solutions • Hazard Class 8 (Corrosive) • Packing Group I • §172.102 Special Provisions 1, B9, B64, B85, N34, N43, T22, TP2, TP10, TP12, and TP13 • Bromine may transported only in cargo aircraft and railcars, not in passenger-carrying aircraft or railcars Requirements and limits on other flow battery electrolytes may vary.
47 CFR Part 15, Radio Frequency Devices	Electromagnetic Interference. FCC Part 15 regulations apply to unintentional emissions of electromagnetic energy to ensure electromagnetic interference is minimized. A flow battery system for commercial, industrial, or business (non-residential) applications would be considered a Class A device, and subject to less restrictive limitations than Class B devices, which are those marketed to the general public for use in residential environments.
UL 1741, Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources	UL 1741 is applicable to the inverter of the ESS. It includes requirements for construction, safety, output power characteristics, rating, marking, manufacturing and production tests, and performance standards including maximum voltage, temperature, dialectic voltage withstand tests, output power characteristics, abnormal tests, grounding impedance, overcurrent protection calibration, strain relief, overvoltage, stability, static load, compression, and rain and sprinkler tests, among others. For utility-interactive equipment, these requirements are intended to supplement and be used in conjunction with IEEE 1547, Standard for Interconnecting Distributed Resources With Electric Power Systems, and in associated test procedures in IEEE 1547.1, Standard for Conformance Test Procedures for Equipment Interconnecting Distributed Resources with Electric Power Systems.
UL 1973, Batteries for Use in Light Electric Rail (LER) Applications and Stationary Applications	The UL 1973 standard covers energy storage for use as energy storage for stationary applications such as for photovoltaic, wind turbine storage, or for uninterrupted power supply applications (as well as similar systems for use in light electric rail power supplies). Its test requirements include electrical tests (e.g., for overcharge, short circuit, overdischarge protection, temperature and operating limits, imbalanced charging, dielectric voltage withstand, continuity, failure of cooling and thermal stability, working voltage, and tests of electrical components), mechanical tests (e.g., static force, impact, drop impact, mold stress, pressure release, and start-to-discharge tests) and environmental tests (thermal cycling, resistance to moisture, salt fog, and fire exposure tests). In addition, it contains appendices addressing specific requirements for particular battery technologies, including an appendix providing requirements specific to flowing electrolyte batteries.

Ktech Compliance Matrix
RK30 Zinc-Bromine Battery ESS

IEEE 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems	**IEEE 1547 is applicable to the inverter of the ESS. The standard includes eight sections that provide guidance for safe connection to utility grids, namely the islanding aspect for inverter applications. UL 1741 is intended to be harmonized with IEEE 1547.**
SR-3580, NEBS™ Criteria Levels	Telecommunications industry requirement. SR-3580 groups requirements of NEBS GR-63 and GR-1089 into three functional levels (I, II, or III). Grouping the criteria into levels helps clarify the impact of nonconformance and allows the broad range of NEBS requirements to be judiciously applied to equipment, based on the equipment's application and impact on the operation of the network. "NEBS Level 3" means the equipment meets all of the requirements of GR-63 for physical protection and GR-1089 for electromagnetic compatibility and electrical safety. NEBS Level 3 has strict specifications for fire suppression, thermal margin testing, vibration resistance (earthquakes), airflow patterns, acoustic limits, failover and partial operational requirements, failure severity levels, radio-frequency emissions and tolerances, and testing/certification requirements.
NEBS GR-63-CORE, NEBS™ Requirements: Physical Protection	Telecommunications industry requirement. NEBS GR-63 identifies the minimum spatial and environmental criteria used for new telecommunications equipment for new telecommunications equipment to be used in a carrier central office (as such, most requirements may not be directly applicable to an offsite ESS; however, these requirements are considered on a graded basis by NEBS SR-3580, as described above). The environmental criteria include temperature, humidity, altitude, fire resistance, equipment handling earthquake, office vibration, transportation vibration, airborne contaminants, and acoustic noise.
NEBS GR-1089-CORE, Electromagnetic Compatibility (EMC) and Electrical Safety	Telecommunications industry requirement. The electromagnetic compatibility and electrical safety requirements of GR-1089 address system-level electrostatic discharge and electrical fast transient; electromagnetic interference; lightning and power fault; steady-state power induction; electrical and optical safety criteria; corrosion; bonding and grounding; and criteria for DC power port of telecommunications load equipment.
NEBS GR-3108, Generic Requirements for Network Equipment in the Outside Plant (OSP)	Telecommunications industry requirement. GR-3108 defines environmental, mechanical and electrical testing criteria and provides design and performance requirements to help ensure that electronic equipment located in outside plant facilities will operate reliably over its expected lifetime. GR-3108 addresses environmental criteria such as operating temperatures, humidity, particulate contamination, pollution exposure, and heat dissipation; mechanical criteria such as structural requirements, packaging, and susceptibility to vibration, earthquake, and handling; electrical protection and safety including protection from threats of lightning surges, AC power induction and faults, electromagnetic interference, and DC power influences; and closure considerations.
NEBS GR-513, Power Requirements in Telecommunications Plant	Telecommunications industry requirement. GR-513 addresses power system requirements including ESSs; monitoring, control, and alarms; outside plant sites; reporting and listing requirements; reliability, quality and documentation requirements; and functional requirements.
MIL-STD-810G, Environmental Engineering Considerations and Laboratory Tests	Environmental analysis, design analysis, and laboratory testing. Testing may be required for military procurement. Testing protocols described are: temperature shock; contamination by fluids; solar radiation (sunshine); rain; humidity; fungus; salt fog; sand and dust; explosive atmosphere; immersion; acceleration; vibration; acoustic noise; shock; pyroshock; acidic atmosphere; gunfire shock; temperature, humidity, vibration, and altitude; icing/freezing rain; ballistic shock; vibro-acoustic/temperature; freeze-thaw; time waveform replication; rail impact; multi-exciter testing; and mechanical vibrations of shipboard materiel.

Ktech ZBM Flow Battery ESS Bill of Materials

	Description	Lead Time	Estimated Cost Summary
Battery	ZBM battery (including battery controller)	4–6 weeks	$8000
Battery Venting	Hydrogen venting	2 weeks	$1000
Battery Safety	Secondary containment of flow battery	2 weeks	$175
Electrical Hardware	Connectors, distribution blocks, fuses, lugs, wire, bus bars	3–4 weeks	$7500
Electrical Components	Power supplies, inverters, contactors, breakers	4–6 weeks	$28500
Mechanical Enclosure	Tricon	3–4 weeks	$5800
Mechanical Hardware	Nuts, bolts, backplates, cable trays	2 weeks	$500
Mechanical Structure	Internal frame, mechanical structure	4–6 weeks	$3500
Safety	Gas sensors, interlocks, smoke detector	4–6 weeks	$1000
SCADA/communication	Controller, data converters, Ethernet switch, modem, antenna, display	3–4 weeks	$3400

Ktech : Energy Storage

Applied Materials; Testing and Field Evaluation

- Problem(s) Addressed

  Analysis of flow battery (RK30 that was analyzed, evaluated at Sandia's Energy Storage Technology Pad - ESTP) to develop cost-effective, large scale manufacture of ESS that can provide power to remote off-grid locations, reduce grid power at peak, provide for power shortages after natural disasters, offer battery back-up

- Path Forward
  - Development of prototype with attention to costs that depend on materials, components, testing and certification for quality and reliability consistent with regulatory, industry, military standards
  - Develop ESS that incorporates multiple means of storage

Regulated States, DER,FOBs, ESSs, Rule 111D & Georgia Power's Solar Evolution: An Interesting Example

2003 4000 customers subscribed to program
Georgia Power buys solar and landfill gas (solar at 17 cents per kWh)

2011 50 MWs of large scale solar / 20 year PPA

2012 210 MWs Distributed Generation and Utility Scale
procured over 2 year timeframe (2013 & 2014)
13 cents per kWh (20 year PPA) **first time** that a
distribution benefit has been added to pricing

2013 PSC expanded the ASI Program by 525 MW
100 MW DG (50 MW 2015 & 50 MW 2016)
425 MW Utility Scale

2014 PSC approves GP putting 3 30MW projects on military bases

Material presented by T. Echols, GPUC at EUCI DER Conference August 2014

SNL ES Demo & Testing Partnerships - Meeting DOE AOP Goals

The Energy Storage Program supports the Secretary's Goal of *Energy: Build a competitive, low-carbon economy and secure America's Energy Future.* The program is designed to develop and demonstrate new and advanced energy storage technologies that will enable the stability and surety of the future electric utility grid as it transforms into a Smart Grid, and additional deployment of variable renewable energy resources such as wind and solar power generation. The OE Energy Storage Program focuses on **accelerating the development and deployment of energy storage in the electric system through technology development that improves the affordability and performance of energy storage, and enables a robust suite of competitive options for various grid services**.

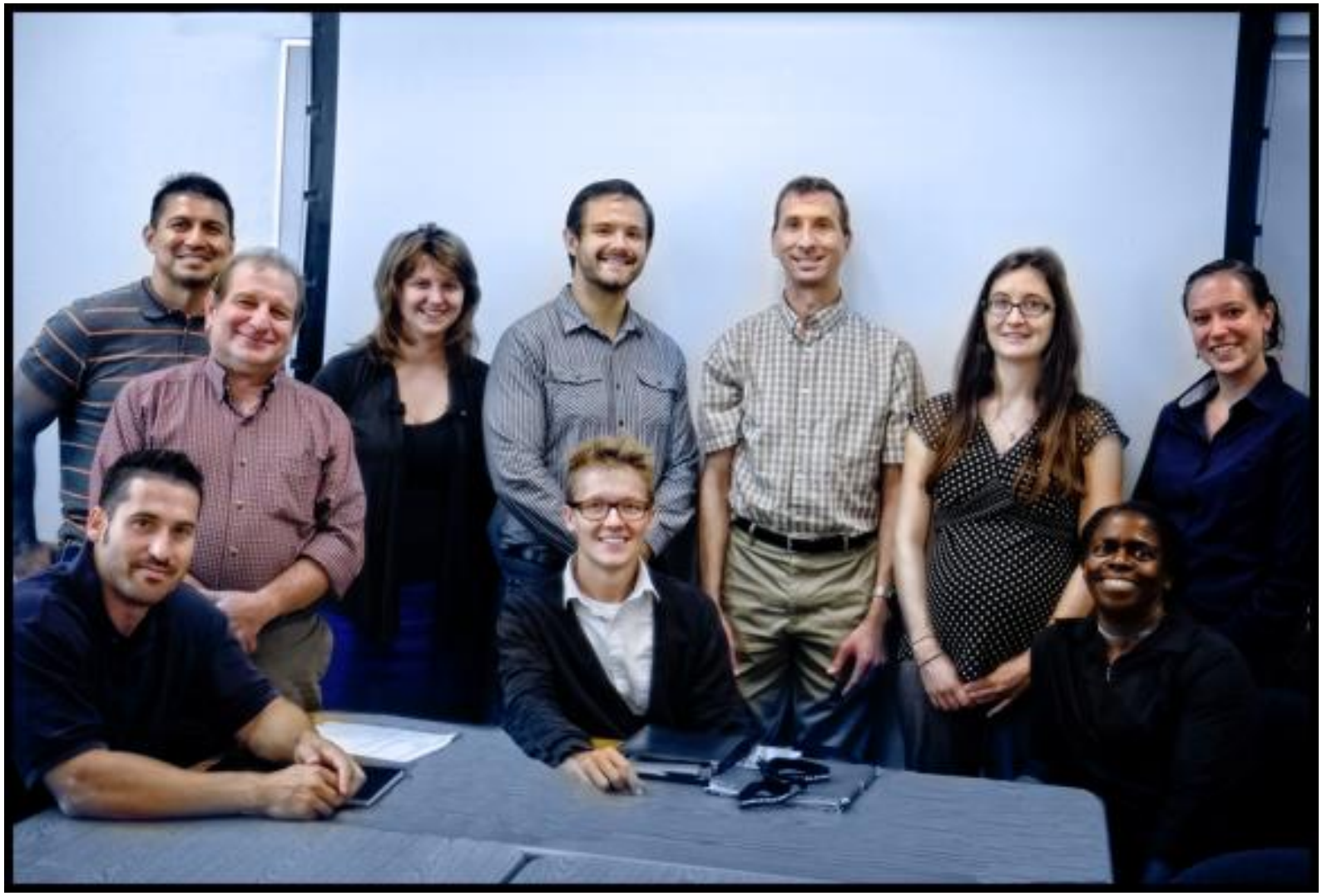
The program develops a portfolio of technologies such as advanced batteries, flow batteries, ultracapacitors, flywheels, and compressed air energy storage (CAES). Each of these technologies has **potential for reduced cost, higher energy density, increased safety, and/or improved manufacturability.** Primary grid application areas include frequency regulation, ramping support, energy management for peak shifting and load leveling, smoothing and integration of renewables.

The program activities include 1) applied storage materials development 2) devices and systems development, 3) testing and field evaluation, 4) modeling and analysis, and 5) industrial engagement.

Kickoff Meeting in Vermont

Workshop in Oregon

SNL ES Demo, Testing, Analysis Team



Summary/Conclusions

Each of these partnerships are important elements at the distribution part of the electricity delivery system and can aid in the development of electrical energy storage devices, equipment and systems, and policy, regulations, standards, and business models that help the industry to properly integrate ES resources that are now being located “at the edge of the grid” into the existing grid while avoiding negative impacts on the system as a whole with respect to innovative approaches, cost, reliability, and safety.

Questions?

Principal Investigator Contact Information:

J. Hernández/ JHERNAN@SANDIA.GOV