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Energy Storage and Integration

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Program Manager, SNL OE Energy Storage Program

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Energy Storage is Key to Future Electric Grid

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Grid 1.0

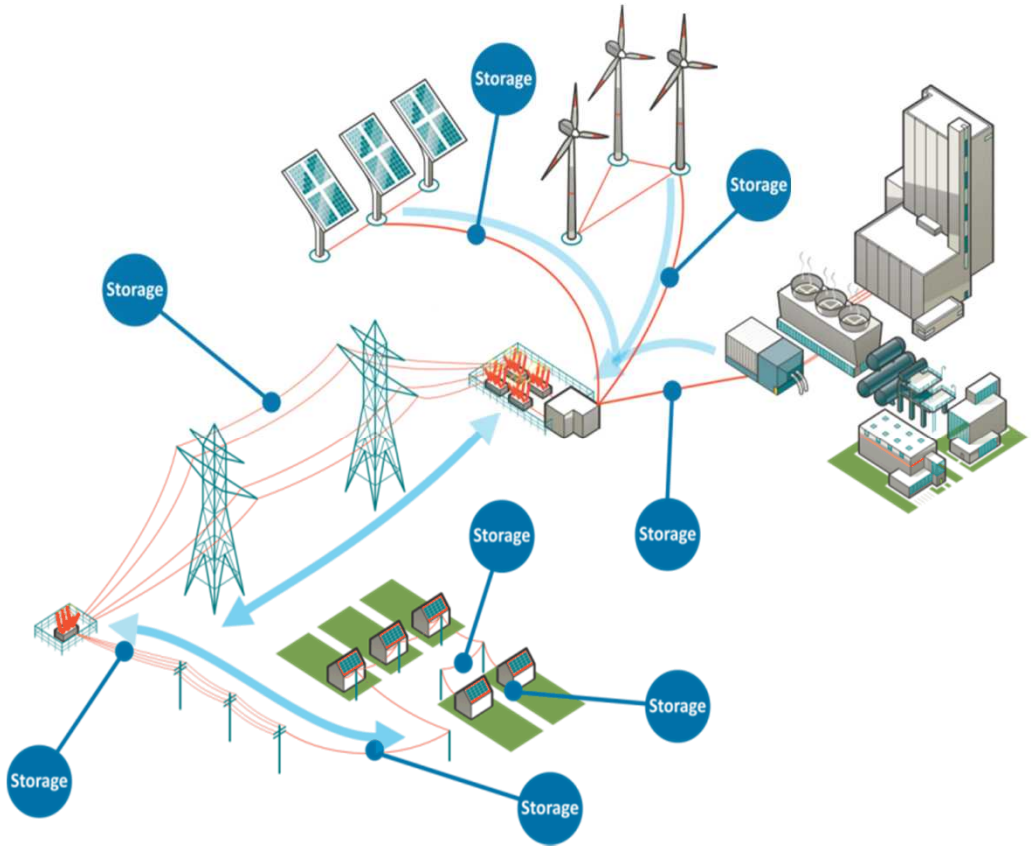
- One way energy flow
- Little/no renewable energy

Grid 2.0

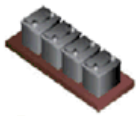
- Integration of renewables and distributed generation beginning to take off
- Minimal tools to manage grid instabilities

Future Grid

- Distributed generation and two-way energy flows
- Energy Storage is key for grid stability and large scale renewable integration

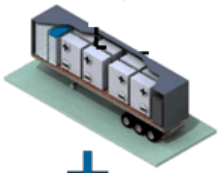


Cost Structure of Storage System in 2016



Storage Racks+BMS

+



Product Integration

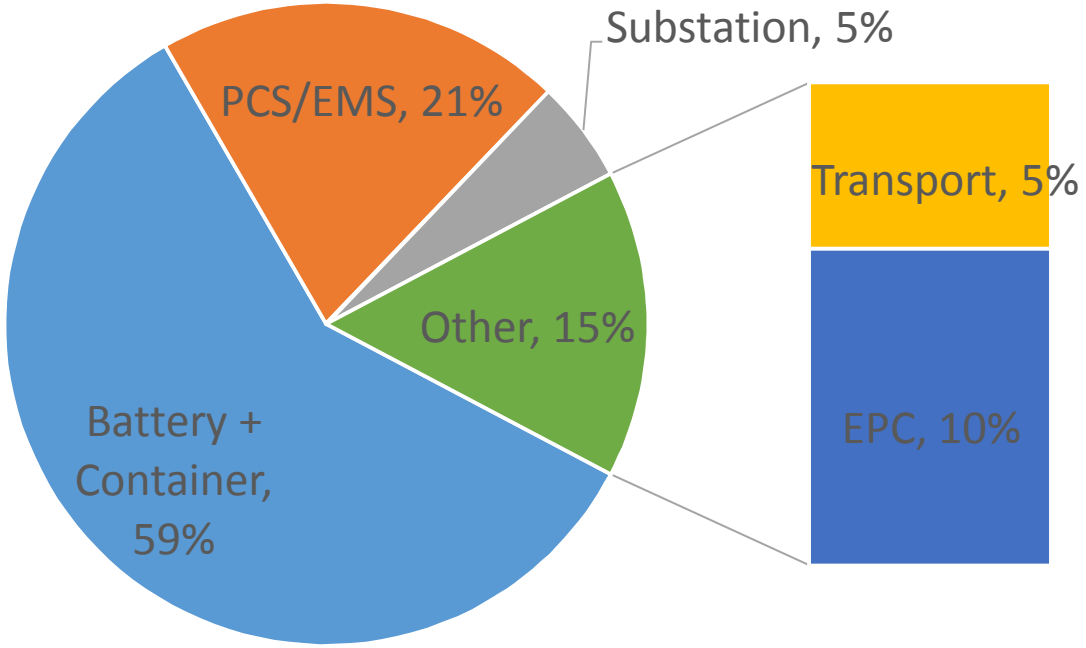
+

Power Conditioning (PCS)

+

Field EPC Grid Integration

Based on Commercial Li-Ion Storage



Over 40% of Energy Storage System cost is outside the Battery

Data: Multiple industry sources

R&D Focus Areas

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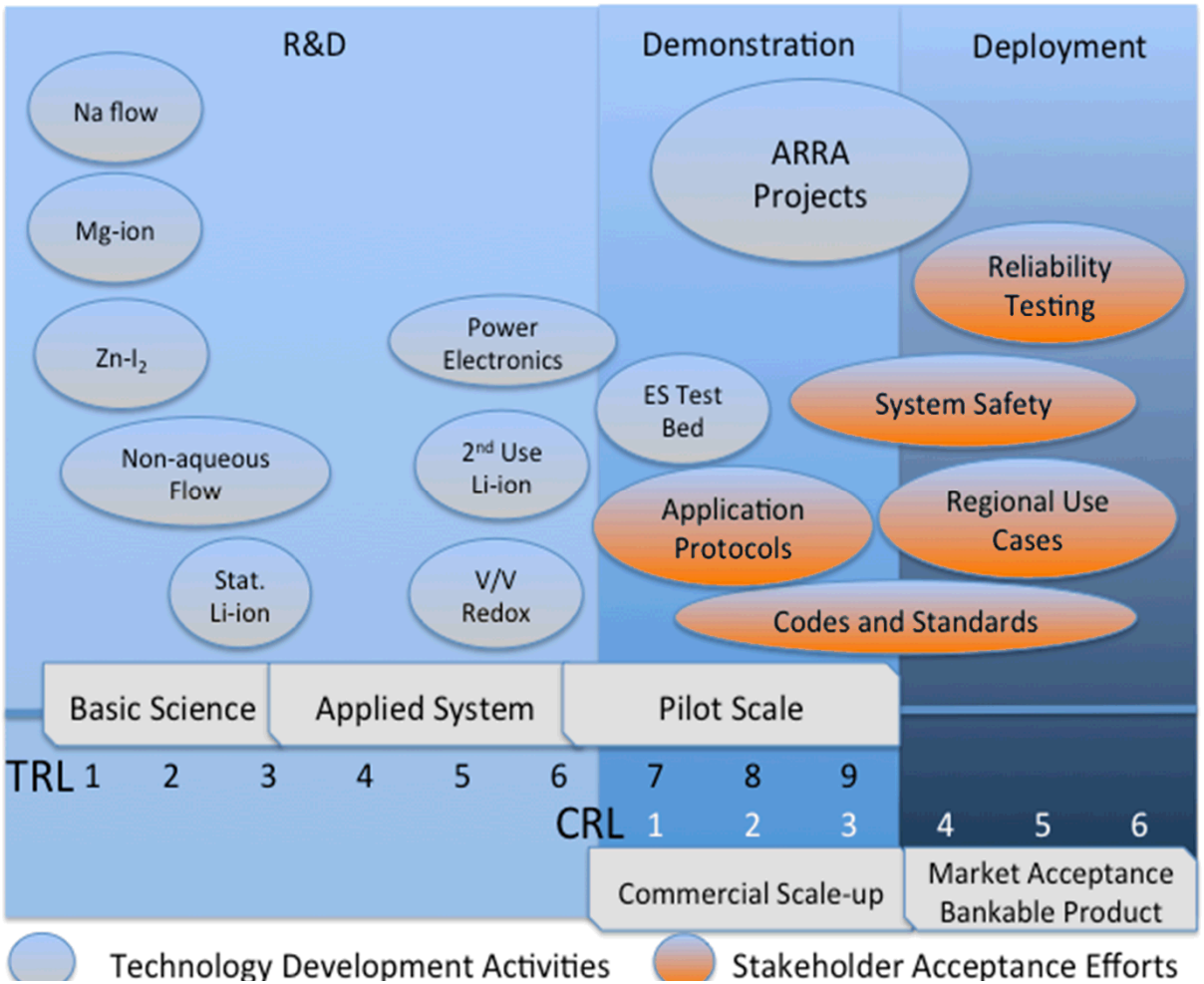
Our R&D program is focused on solving critical problems to make energy storage safe, reliable, and cost effective across all markets. Main thrusts are:

- Lowering the cost of energy storage at the materials and device level
- Improving the reliability and safety of energy storage systems
- Developing industry standards, protocols, and regulations
- Enabling storage deployment through field demonstrations, analysis and verification, industry outreach and education

Energy Storage and Integration R&D



We are working across the entire technology development cycle, in partnership with universities, other labs, and many companies

Energy Storage is a Major Crosscut

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Hydrogen Storage

Hydrogen and Fuel Cells program is developing technologies to accelerate large-scale deployment of hydrogen storage.

Thermal Storage

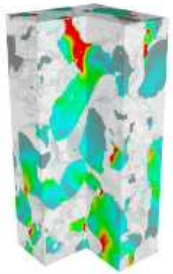
Sandia's Concentrating Solar Power (CSP) program is developing molten salt thermal storage systems for grid-scale energy storage.

Battery Materials

Sandia has a large portfolio of R&D projects related to advanced materials to support the development of lower cost energy storage technologies including new battery chemistries, electrolyte materials, and membranes.

Systems Modeling

Sandia is performing research in a number of areas on the reliability and safety of energy storage systems including simulation, modeling, and analysis, from cell components to fully integrated systems.



Systems Analysis

Sandia has extensive infrastructure to evaluate megawatt-hour class energy storage systems in a grid-tied environment to enable industry acceptance of new energy storage technologies.

Cell & Module Level Safety

Sandia has exceptional capabilities to evaluate fundamental safety mechanisms from cell to module level for applications ranging from electric vehicles to military systems.

Power Conversion Systems

Leveraging exceptional strengths in power electronics, Sandia has unique capabilities to characterize the reliability of power electronics and power conversion systems.

Grid Analytics

Analytical and multi-physics models to understand risk and safety of complex systems, optimization, and efficient utilization of energy storage systems in the field.

Wide ranging R&D covering energy storage technologies with applications in the grid, transportation, and stationary storage

Involves Multiple R&D Depts and Partners

Sandia National Laboratories

Participating Departments in the DOE OE Energy Storage Program

Energy Storage Systems	Nanoscale Science	Advanced Materials Lab
Power Systems	Thermal, Fluid & Aero Sciences	Electronic, Optical, & Nano Materials
Solar Energy	Electrical Science & Experiments	Materials Aging & Reliability
Power Sources Technology	System Readiness & Sustainment	Microsystems Process

Industrial Partners

Transpower
Raytheon/Ktech
UET
SunPower
Aquion Energy
Gridtential
Helix
Arkansas Power Electronics
GeneSic Semi
United SiC
Princeton Power
DRS Research
HRL
Sigma Technologies
Hawaiian Electric Co
Maui Electric Co
Sprint
Transpower
Aquion Energy
Kodiak Electric Assoc
Milspray
Duke Energy
PNM, NEDO, MDS
East Penn
CPUC

University Collaborations

CO School of Mines
University of Maryland
Oregon State
Iowa State University
UC San Diego
UC Davis
Case Western
Stonybrook
Univ. of New Mexico
Arizona State
Iowa State
Drexel University
NC State

Standards, Policy, and Regulatory

UL, IEC
IEEE 2030.2, 1547
NFPA, NIBS, IFC, MESA

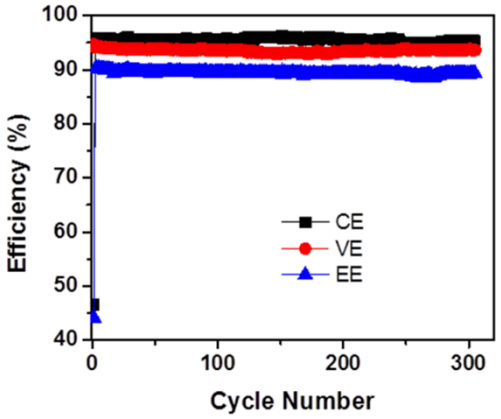
CEC, CPUC
EPRI, ESA, CESA

Advanced Membranes for Flow Batteries

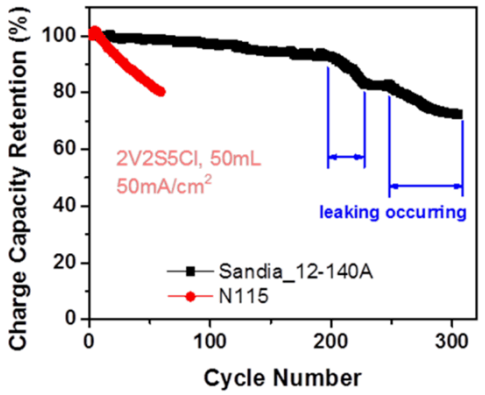
Sandia National Laboratories

Collaboration with PNNL and ORNL

- **Project Goals:** Develop and commercialize a new class of polymeric membranes that are superior to commercial membranes like Nafion in cost (10x lower) and performance.
- **Present Status:**. Developed membranes with enhanced ion selectivity and durability. Testing has shown improved performance over current state of the art.
- **Commercialization:** Secured patent protection for materials synthesis and membrane application in flow batteries, fuel cells and electrolyzers. 1 issued patent and 4 pending applications. Commercialization through spin off.



New membranes are stable (300 cycles, 4 months), higher energy efficiency (90%) compared to state of the art (80%).



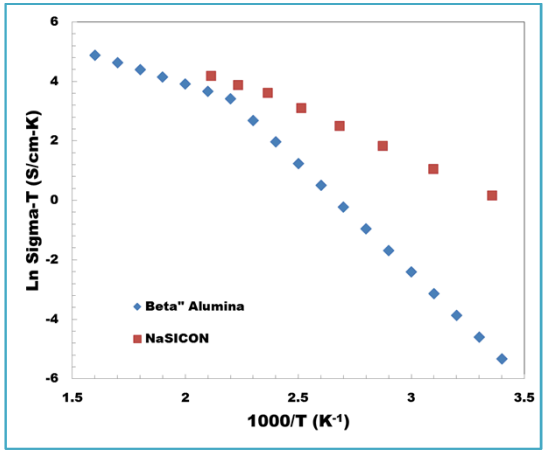
New membranes retains higher energy capacity for over 200 cycles. Longer term testing is in progress.

Sodium Ion Battery Development

Sandia National Laboratories

Collaboration with Ceramatec (CoorsTek)

- **Project Goals:** Develop and demonstrate low cost sodium batteries operating at lower temperature (< 200°C) than state of the art NaS batteries. Technology based material innovations in NaSICON ceramic membranes (collaboration with Ceramatec/CoorsTek).
- **Present Status:** Successfully demonstrated cells using Na-Ni(Fe)Cl2 as well as novel Na-I battery chemistries. 100 Ah cells demonstrated stable performance during 1+ year of operation. 250 Ah cells under test.
- **Project Milestone**: Demonstrate a 10 kWh battery module in a grid application (Q2, FY`18).



NaSICON is 10 × more conductive than β''-Al_2O_3 @ room temperature

Prototype Na-ion cells

CERAMATEC TOMORROW'S CERAMIC SYSTEMS

CoorsTek Amazing Solutions

Nanocomposite Materials for Flywheels

Sandia National Laboratories

Research done at Advanced Materials Laboratory on UNM Campus

Collaboration with Cobhum and PowerThru

We developed nano composite materials that increase the strength of flywheels by 30%

- New materials light weight and allow for faster spin rates
- Pilot scale production of materials at Kg level and built prototypes

Scaled production process for nano composite synthesis to Kg levels

Finished flywheel rim assemblies containing nano composite carbon fiber

Power Electronics - Leveraging world class capabilities in Wide Bandgap Materials

Sandia National Laboratories

R&D 100 53 Years of Invention

2015 R&D100 Winner

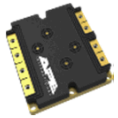
WORLD'S FIRST FIBER OPTIC ELECTRICAL TRANSDUCER TO PASS MILITARY VIBRATION AND SHOCK CERTIFICATION
Exceeds 30Mhz
Capable of Operating up to 34.5kV without additional Insulation, Isolation, or Cooling

WORLD'S FIRST HIGH TEMPERATURE SIC SINGLE-PHASE INVERTER
3 kW (1200 V/150 A peak)
250 ° C Junction Temperature
Integrated Gate Driver

WORLD'S FIRST HIGH TEMPERATURE SIC POWER MODULE
50 kW (1200 V/150 A peak)
250 ° C Junction Temperature
Integrated HTSOI Gate Driver

WORLD'S FIRST COMMERICALLY AVAILABLE ULTRA-HIGH-VOLTAGE SIC THYRISTOR
Rating exceed 6.5kV, 200kHz, 80A
> 200° C junction temperature

WORLD'S FIRST HIGH VOLTAGE, HIGH TEMPERATURE, REWORKABLE SIC HALF-BRIDGE POWER MODULE
> 15 kV / 100 A, > 200 ° C
Reworkable
Wire Bond Free, Low Parasitic Design
Device Neutral
HV Isolated Gate Driver



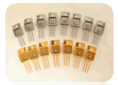
WORLD'S HIGHEST VOLTAGE NORMALLY OFF SIC JFET
6.5 kV, 20kHz, 60A
200° C Junction Temperature

2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015

WORLD'S FIRST VOLTAGE CONTROLLED 4500V/400A TURN-OFF THYRISTOR
4500V and 400A rated
Integrated Si MOSFET and GTO
Embedded Current Sensing Capability

WORLD'S FIRST HIGHLY ACCELERATED LIFETIME TESTING (HALT) OF HIGH VOLTAGE SIC MODULES
Dramatically Accelerates Design Cycle
-100 ° C to 250 ° C (1.7 ° C/s Ramp)
48 in × 48 in Table Size
6 axis 75 gRMS Vibration

WORLD'S FIRST MONOLITHICALLY INTEGRATED SINGLE CHIP TRANSISTOR
Integrated SJT/Diode Chip at 1200V



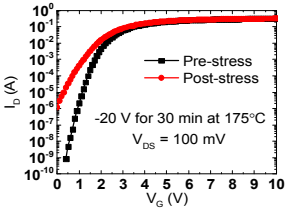
WORLD'S FIRST HIGH FREQUENCY, HIGH TEMPERATURE, SIC HALF-BRIDGE POWER MODULE
15 kV/100 A, 20 kHz, 200C
Reworkable
Low Parasitic Design
Device Neutral
HV Isolated Gate Driver

Power Electronics – Expertise and Facilities

Sandia National Laboratories

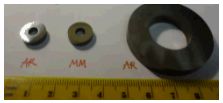
WBG Reliability Characterization

- Static and dynamic reliability characterization of SiC and GaN semiconductor devices under stress conditions
- 10 kV/50A/600C wafer-level device measurement capability
- 3kV/50A package-level device measurement capability
- Double-pulse switching testing capability
- Impedance spectroscopy

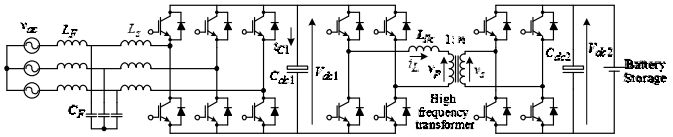


Advanced Magnetics

- Electron microscope for raw magnetic powder characterization
- Quantum design magnetic property measurement system

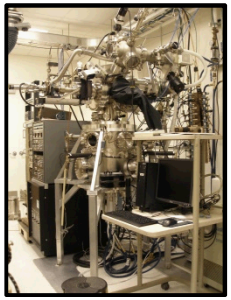


γ'-Fe_4N toroidal inductive cores

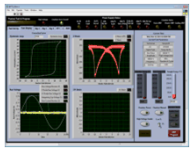


Advanced Gate Oxide for WBG Devices

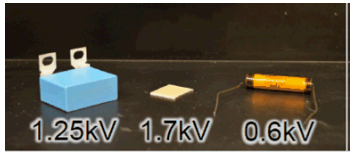
- Unique oxide molecular-beam eptiaxy instrument (1 of ~30 such instruments in the US)
- Grows MgO, CaO, La_2O_3, and Gd_2O_3 gate and passivation dielectrics on GaN, AlGaN, and SiC power semiconductors
- Comprehensive dielectric characterization tools
- 5 Hz to 26 GHz, -100C to 300C capabilities



Advanced Capacitors



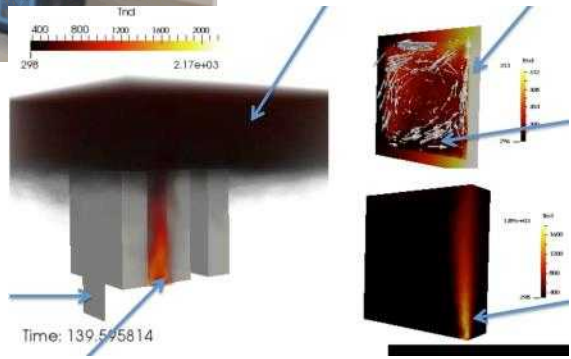
- Test voltages as high as +/-10kV, with kA transients with HV diagnostics from mHz-MHz capability
- Impedance bridges and polarization-hysteresis looper allows full dielectric characterization
- Temperature dependent insulation resistance characterization capability



Safety and Reliability is a Major Thrust

Sandia National Laboratories

- Focus on developing a fundamental understanding of safety and reliability through R&D in four areas:
  - Materials origin of safety and reliability
  - Device level failures
  - Cascading failures
  - Software's role as a critical safety system
- Extensive laboratory infrastructure at Energy Storage Test Pad (ESTP) and BATlab
- Advanced simulation and modeling of energy storage systems



Energy Storage Safety Protocols

As an increasing number of energy storage systems are deployed, the risk of safety incidents increases.

Damage to Facilities

2012 Battery Room Fire at Kahuku Wind-Energy Storage Farm (15 MW, 10 MWh)

- There were two fires in a year at the Kahuku Wind Farm
- There was significant damage to the facility
- Capacitors in the power electronics are reported to be associated with the failure.

Impact to First Responders

2013 Storage Battery Fire, The Landing Mall, Port Angeles WA (75kW, 50kWh)

- First responders were not aware of the best way to extinguish the fire,
- It reignited a week after it was thought to be extinguished.

ESS Safety Activities Timeline

Sandia National Laboratories

Pacific Northwest NATIONAL LABORATORY

DOE OE Workshop for Grid Energy Storage Safety
- Attended by 70 thought leaders from stakeholder groups across the energy storage industry

Inventory of Safety Related Codes and Standards Published

Energy Storage Technology Advancement Partnership (ESTAP) Webinar
- Introduced the strategic plan and next steps

ESA Annual Conference Workshop
technical and procedural aspects associated with documenting and verifying ESS safety

2014 | FEB | AUG | SEP | DEC | 2015 | JAN | MAR | APR | MAY

Overview of Development and Deployment of Codes, Standards, and Regulations Affecting ESS Safety Published

Grid Energy Storage Safety Strategic Plan Published
- Based upon outcomes of the DOE OE Workshop for Grid Energy Storage Safety
- Outlines a path forward for ESS safety initiatives

Energy Storage Safety Preliminary Team Web Meetings
- Identified and prioritized safety gaps related to energy storage:
  - safety validation and risk assessment R&D,
  - codes and standards, and
  - safety outreach and incident response

Field Demonstrations

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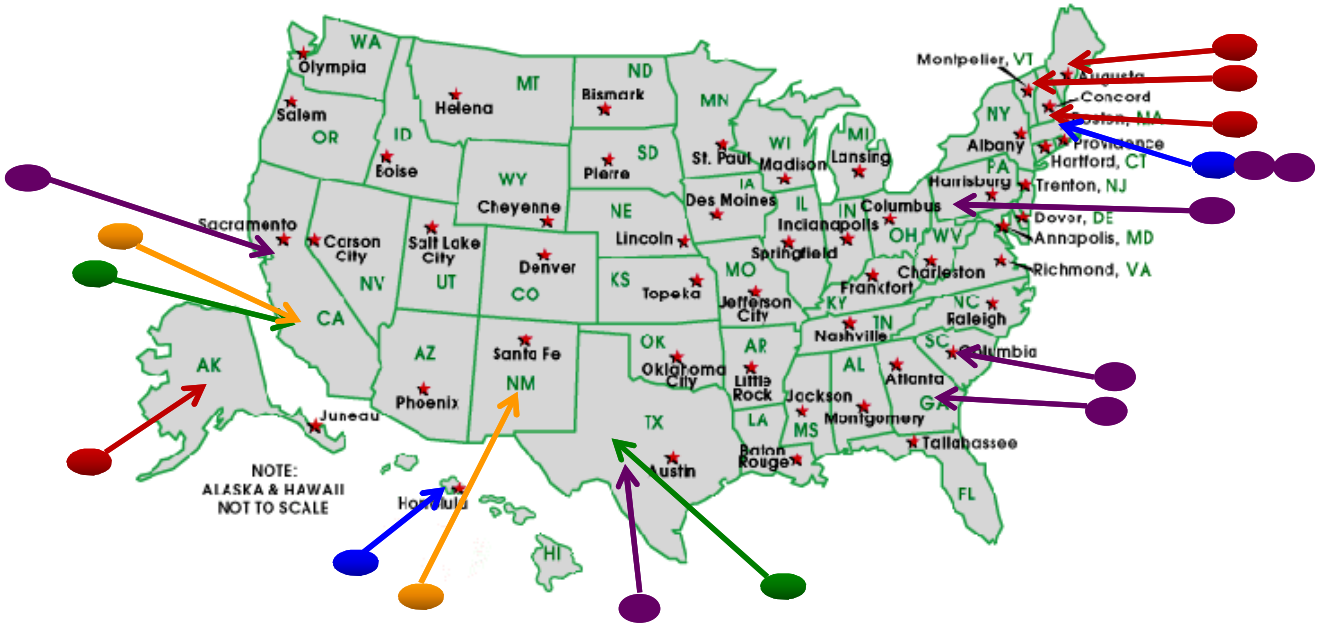
To assistance regulators and utilities in determining how to utilize storage systems to maximize return on investment (ROI). Field demonstrations and pilot projects help to ensure ROI and facilitate adoption via improving confidence in safety, reliability, performance and cost effectiveness.



Legend:

DoD

Commercial End User

State

Academia

Industry

Energy Storage Deployment in NM

SNL energy storage team played a critical role in deployment and commissioning of energy storage systems across a number of states. In NM,

- Critical role in the deployment and commissioning of 250 KW/ 1 MWh Ultrabattery installation with PNM
- Currently working with Los Alamos country to optimize storage utilization on Circuit 6.
- Hosting a workshop for Southwest PUCs in April, 2016
- Storage and Smart Grid – Working with UNM and NMSU in developing Smartgrid R&D projects with storage

PNM 500 KW solar plant with 250 kW/ 1 MWh Energy Storage

Los Alamos County 1.8MW/ 8.3 MWh of battery storage Installation. SNL is analyzing various options to achieve 100% renewables in Circuit 16 (pending DOE funding)

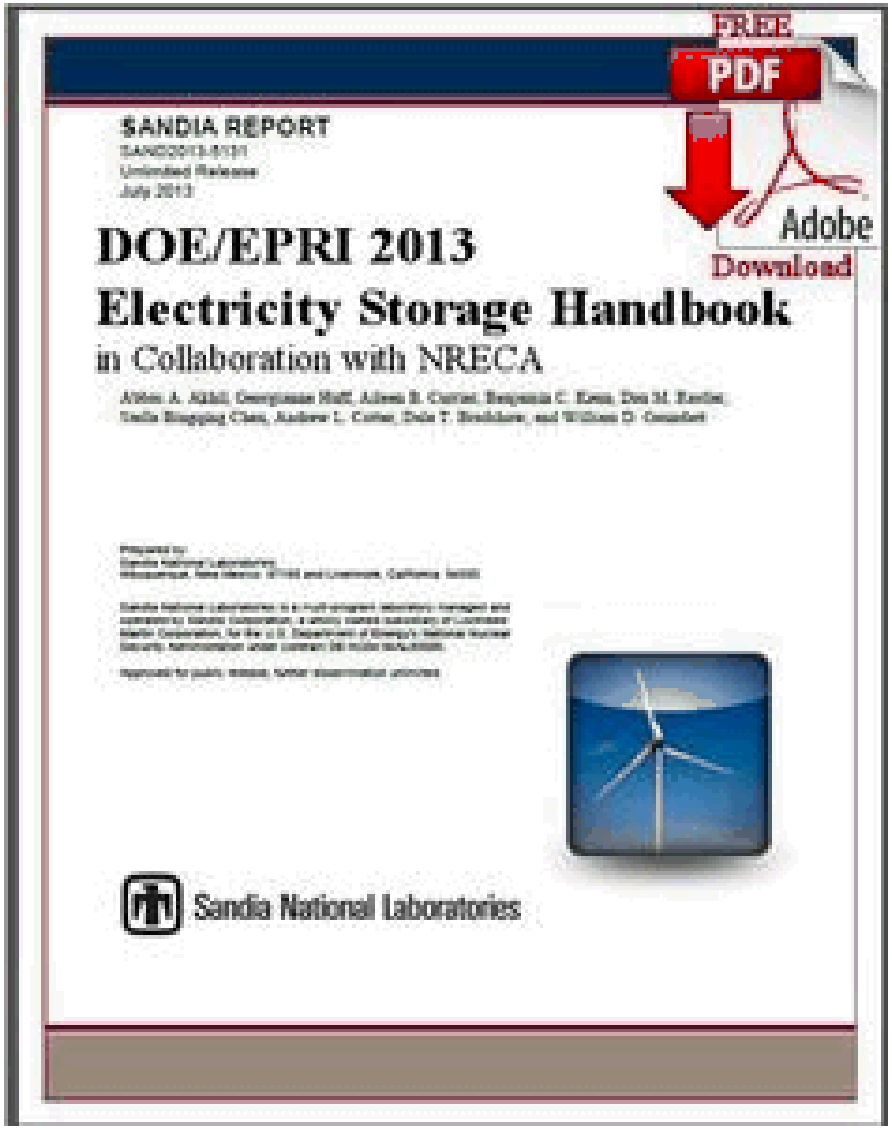
Outreach and Industry Tools

Sandia National Laboratories

- ***DOE/EPRI Electricity Storage Handbook*** is a how-to guide for utility and rural cooperative engineers, planners, and decision makers to plan and implement energy storage projects safety in communities
- ***DOE Global Energy Storage Database*** provides free, up-to-date information on grid-connected energy storage projects and relevant state and federal policies.
- ***DOE Performance Protocol*** focuses on developing uniform methods of measuring ESS performance for specific applications.

DOE/EPRI Energy Storage Handbook

- Fills an industry-wide need
- Establishes single-point resource for making decisions and stakeholders
- Handy reference on current and emerging technologies and applications
- Describes the services and applications of energy storage
  - in/on the grid
  - commercial status
  - system costs
  - performance metrics



DOE Energy Storage Database

Sandia maintains a comprehensive online resource of energy storage projects and policies.