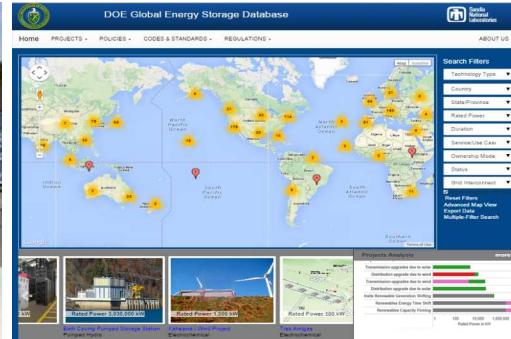


*Exceptional service in the national interest*



# SNL OE-ES Overview

Babu Chalamala

**SNL thanks Dr. Imre Gyuk for his decades of support of the SNL Energy Storage Program**



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.

# Sandia Team and Industry/University Partners

## Energy Storage Systems

Babu Chalamala  
Stan Atcitty  
Ray Byrne  
Dan Borneo  
Jaci Hernandez  
Georgianne Huff  
David Rosewater  
Ana Beare

## Nanoscale Science

Carlos Gutierrez  
Todd Monson  
Nancy Missert

## Advanced Materials Lab

James Miller  
Kevin Zavadil  
Tim Boyle

## 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

## Grid Modernization & Renewable Energy

Carol Adkins  
Charlie Hanley  
Dave Schoenwald  
Subhash Shinde  
Tony Martino  
Tim Lambert

## Electrical Science & Experiments

Steve Glover  
Lee Rashkin

## Materials Aging & Reliability

Doug Wall  
Cy Fujimoto

## Power Source Technology

David Ingersoll  
Thomas Wunsch  
Kyle Fenton  
Christopher Orendorff  
Christopher Applett  
Travis Anderson  
Summer Ferreira  
Josh Lamb

## System Readiness & Sustainment

Bruce Thompson  
Mark Smith

## Business Support

Allyson Beck  
Gina Fresquez  
Miles Hall  
Carissima Heise  
Dan Johns  
Sharon Ruiz  
Amanda Spinney  
Irene Trujillo

## Microsystems Process

David Hughart

## Standards, Policy, and Regulatory

UL, IEC  
IEEE 2030.2, 1547  
NFPA, NIBS, IFC, MESA  
CEC, CPUC  
EPRI, ESA, CESA

# FY15 Sandia Thrust Structure

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- **Cost Competitive Energy Storage Technologies**
  - Materials and Systems Thrust
  - Power Electronics Thrust
- **Validated Reliability and Safety**
  - Grid Energy Storage Safety Initiative
  - Documenting and Verifying Safety through Codes and Standards
- **Equitable Regulatory Environment**
  - Energy Storage Selection and Grid Integration Modeling
  - State Energy Storage Deployments
- **Industry Acceptance**
  - Field Demonstrations and Outreach
  - Reliable, Independent, Third Party Analysis and Verification

# FY15 Accomplishments

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- **Key Highlights**
  - **New membrane materials for flow batteries**
  - **Demonstration of 100 Ah Na-ion cells**
  - **Scalable production process for  $\text{TiO}_2$  nanoscale fibers**
  - **Energy Storage Safety Working Group established**
  - **Engagement with Singapore Energy Market Authority**
- **Patents:** 1 issued patent and 4 patent applications
- **Publications:** 10 journal publications, a number of papers in conference proceedings, and 3 SAND reports
- **Deepening Industry Engagement**

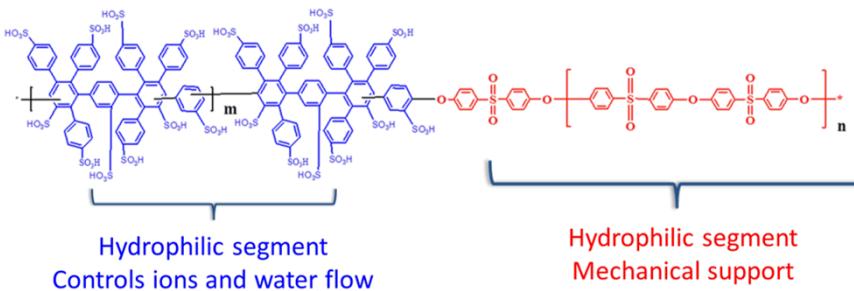
# Cost Competitive Energy Storage Membranes for Flow Batteries



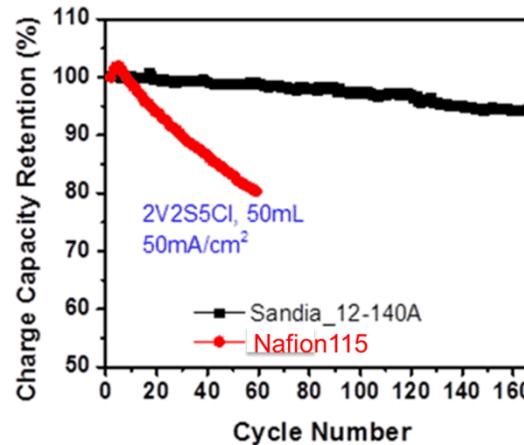
Cy Fujimoto  
Peer Review  
Presentation  
Thursday, 9/24  
8:45 am



High cost of Nafion membranes has been a critical bottleneck in flow battery commercialization. We have developed a new class of materials with electrochemical properties superior to Nafion, along with a significantly lower cost. Test and validation are ongoing at PNNL and ORNL.



New separator IP (US Patent Application 62/075,693), promising VRFB performance. Materials have broad application, interest from EERE for fuel cells use



PNNL's  
mixed acid  
 $\text{HCl-H}_2\text{SO}_4$   
2M  
Vanadium

## FY16-17 Accomplishments

- Developed new chemical structures to further improve oxidative stability – additional patents are preparation
- Exploratory discussions with several companies on the use these materials use in fuel cells and electrochemical hydrogen production
- Expected to be significantly lower cost than Nafion, preliminary estimates are two order

## FY16-17 Plans

- With the family of IP developed in this program, SNL is in the early stages of commercializing the technology. Exploratory discussions on licensing and potential spin off
- Develop detailed cost model in volume production
- Plans for scaling the chemistry for larger batch processes

# Cost Competitive Energy Storage

## Nanocomposite Materials for Flywheels



Tim Boyle  
Peer Review  
Presentation  
Tuesday, 9/24  
4:30 pm



To increase energy storage capacity in flywheels, materials that allow for faster spin speeds are needed. We developed an inexpensive nano composite that requires low loading levels (<5% by weight) and have shown increased flywheel strength by 30%.



*Scaled production process for nano composite synthesis to Kg levels. Started working with Cobham to roll carbon fiber impregnated hubs with nano particles.*



*Finished flywheel rim assemblies containing nano composite carbon fiber*

### FY15 Accomplishments

- Scaled process for synthesis of TiO<sub>2</sub> nano particles to Kg level batch process
- Developed tooling to machine rim parts and built a press process tool
- Completed the assembly of 4 flywheels

### FY16-17 Plans

- Evaluation of flywheels by PowerThru (balancing)
- Test for breakdown of newly fabricated flywheels to >3 GPa
- Partner with industry to begin implementation of nano composite for future flywheel designs

# Cost Competitive Energy Storage

## Sodium-based Battery Chemistries



Dave Ingersoll  
Peer Review  
Presentation  
Thursday, 9/24  
10:15 am



Our goal is to develop low cost ( $\leq \$100/\text{kWh}$ ), low temp ( $\leq 150^\circ\text{C}$ ), safe, nonflammable alternatives to Na-S and Li-ion batteries. Based on Na-based battery chemistries.

- High energy per unit weight and volume – **Smaller devices**
- Abundant supply domestic Na reserves
- Na-ion conducting separators (Nasicon) commercially available (Ceramatec, CoorsTek) **Low production cost**
- Various low cost, safe cathode material couples
- -  $120^\circ\text{C}$  Na-I/ $\text{AlCl}_3$  (fully inorganic),  $25^\circ\text{C}$  Na-air (aqueous)

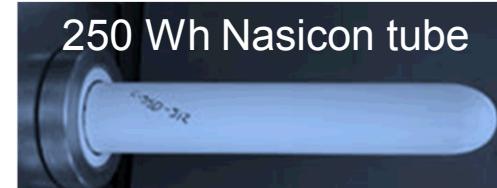
### FY15 Accomplishments:

- 100 W-h sodium-ion cell long-term cycling
- >200 cycles of large sodium-ion cell with 87.5% efficiency
- Developed cost basis analysis tool for large scale battery and performed sensitivity analysis for Na-I vs. Na-Br
- 2 papers published, 4 sodium battery patent applications
- Demonstrated bulk and thin film NaSICON separators
- Developed water-compatible NaSICON separators with improved alkaline stability (enables Na-air batteries)
- Safety testing protocol established for sodium batteries

100 Wh,  $120^\circ\text{C}$   
NaI/ $\text{AlCl}_3$  battery



250 Wh Nasicon tube



Proposed 10 kWh Na module:  
40x250Wh Ceramatec cells



### FY16-17 Plans:

- Demonstration of 10 kW-h sodium battery (with Ceramatec: 180 Wh/l,  $\$150/\text{kWh}$ , 2.8V, 40 cells)
- Scale-up of cell size to 250 Wh sodium-ion cells
- Demonstrated low cost  $\$100-200/\text{kWh}$
- Head to head safety basis analysis (Li vs. Na etc.)
- Quantified safety advantage of all-inorganic sodium chemistry relative to Li ion

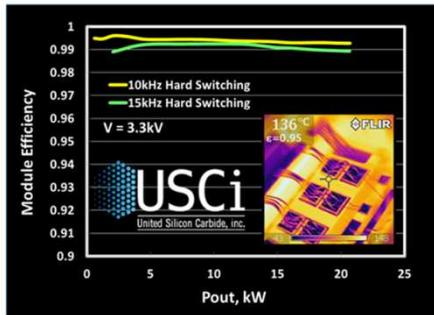
# Cost Competitive Energy Storage Power Electronics



Stan Atcity  
Peer Review  
Presentation  
Thursday, 9/24  
10:30 am



Using wide bandgap semiconductor devices, advanced topologies, and controls to significantly reduce installed cost and footprint, improve control capability, and increase reliability



6.5kV 60A SiC JFET Half-Bridge Module

## Recognition

- Four R&D100 Awards
- Four U.S. Patents, two pending
- Over 40 technical publications
- Stan Atcity received Presidential Early Career Award for Scientists and Engineers
- Power Electronics for Renewable & Distributed Energy Systems book



## FY15 Accomplishments

- Demonstrated continuous operation of world's first 6.5kV JFET HV power module at 15-20kHz
- Demonstrated world's first 15kV SiC-based power module at ultra-fast switching (80kV/us)
- Fabricated toroidal Fe4N cores for >20kHz high frequency converters for ES
- Developed design for a 75kW, 480V, 3-phase GaN-based DC-DC converter for ES

## FY16-17 Plans

- Begin reliability assessment and expand commercialization efforts of 6.5kV JFET module
- Transition the SiC-based HV power module into a manufactured product for ES and commercialize
- Optimize synthesis of Fe4N cores and performance characterization for high frequency ES converters
- Develop a low cost, high performance GaN-based power module rated at 650V and >100A for ES

# Validated Safety and Reliability Grid Energy Storage Safety Initiative

Stan Atcitty  
Peer Review  
Presentation  
Thursday, 9/24  
10:30 am



## Motivation:

- In conjunction with stakeholders, DOE-OE identified Validated Safety as a critical need for the successful adoption of grid energy storage.
- Energy Storage Safety involves wide range of stakeholders including: developers, utilities, regulatory officials, certification agencies, insurance and first responders



February 2014 Safety Workshop  
Albuquerque, NM

Strategic Safety Plan  
December 2014

Energy Storage Safety  
Strategic Plan

U.S. Department of Energy  
Office of Electricity Delivery and Energy Reliability  
December 2014

## FY14-15 Accomplishments:

- DOE OE Strategic Plan on Energy Storage Safety, December 2014  
<http://energy.gov/oe/downloads/energy-storage-safety-strategic-plan-december-2014>
- DOE OE Webinar on Strategic Plan on Energy Storage Safety – January 2015
- DOE OE forms ES Safety Working Group – March 2015
- Developed interactive webpage to foster community engagement and provide current information.  
<http://www.sandia.gov/ess/safety.html>

## FY16-17 Plans:

- Initiate research and development on science of materials safety and cascading component failures
- Expand and lead quarterly ES Safety Forum focused on safety R&D, CSR, and Education
- Expand ES Safety WG activities to include international involvement

# Equitable Regulatory Environment

## BPA Wide Area Damping Control

D. Schoenwald  
Peer Review  
Presentation  
Wed, 9/24  
2:45 pm

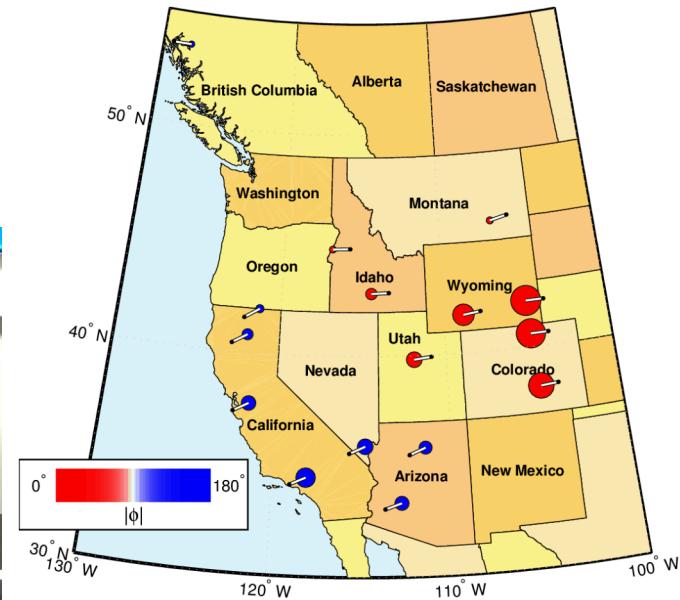


### Motivation:

- Low frequency (0.2-1Hz) inter-area oscillations are present in all large power systems
- The 1996 blackout in the western U.S. was partially attributed to un-damped inter-area oscillations
- This project is a collaboration between the Bonneville Power Administration (BPA) Technology Innovation Program (TIP), the DOE Transmission Reliability Program, and the DOE Energy Storage Program

### FY15 Accomplishments:

- Developed a prototype damping control system for energy storage or PDCI modulation
- Delivered the prototype control system to the BPA synchrophasor laboratory
- Have been successfully collecting test data since October 2014
- Developed an optimal fixed structure controller algorithm for distributed energy storage



### FY16-17 Plans:

- Develop optimal sizing and placement algorithms for energy storage wide area damping control
- Quantify the benefits of distributed versus centralized storage for wide area damping

# Industry Acceptance Vermont – Green Mountain Power

Dan Borneo  
Peer Review  
Presentation  
Wednesday, 9/23  
1:15 pm



## Motivation:

- Collaboration between Green Mountain Power, Vermont Public Service and OE Energy Storage program
- Integration of 2 MW Stafford Solar Farm with 4MW/3.4 MWh of energy storage
- Focused on improving resiliency and safety in communities

## FY15 Accomplishments:

- Installed 2MW PV and 4MW/3.4MWh Li-ion and Lead acid Hybrid ES system.
- Integrated DER and ES and performed commissioning

## FY16-17 Plans:

- Monitor ES operation
- Perform a technical and economic evaluation of system performance
- Project review and lessons learned



**Stafford Solar Farm Kickoff Ceremony**  
Green Mountain Power CEO Mary Powell, Rutland Mayor Chris Louras, Governor Peter Shumlin and DOE OE Program Manager Imre Gyuk



Solar Panel Installation Stafford Solar Farm  
September 2014.

# Industry Acceptance DOE Outreach/Industrial Tools

Cedric Christensen  
Peer Review Presentation  
Thursday, 9/24  
2:00 pm



## Motivation:

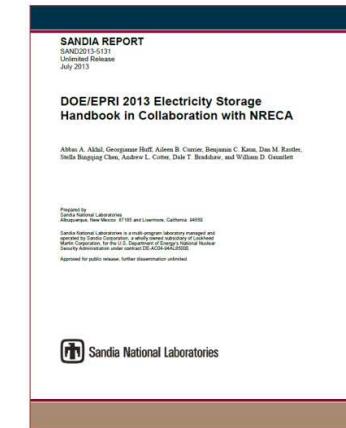
- The DOE Global Energy Storage Database provides free, up-to-date information on grid-connected energy storage projects and relevant state and federal policies.
- The DOE/EPRI Electricity Storage Handbook is a how-to guide for utility and rural cooperative engineers, planners, and decision makers to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

## FY15 Accomplishments:

- DOE Database (since 2012)
- 1,300 Projects and Policies
- Over a million page views, users from 189 countries
- 50+ Energy Storage Technologies
- Data Visualization Tools
- DOE/EPRI Handbook
- Continually updated in conjunction with EPRI, NRECA and feedback from industry
- Performance Protocol
- Developed (4) new protocols for m-grids and PV smoothing, load leveling, and frequency regulation



DOE Energy Storage Database  
[www.energystorageexchange.org](http://www.energystorageexchange.org)



DOE/EPRI Handbook  
<http://www.sandia.gov/ess/publications/SAND2013-5131.pdf>

## FY16-17 Plans:

- **DOE Database**
  - Build out Policy Section
  - Expand Database to include Safety Codes and Standards
  - Develop international partnerships
- **DOE/EPRI Handbook**
  - Expand technology base including sections on Thermal Storage, Power Electronics, Storage Safety, Systems Modelling, and Analytics.
  - Integrate content from ESIC (EPRI)
  - Develop valuation and cost estimate process



DOE OE Performance Protocol

## Performance Protocols

- Update previous protocols, select new protocols for development

# FY16 – Goals and Direction

## Major R&D Goals

- Improve the breakdown strength of nanocomposite materials for flywheels to >3 GPa, and line up an industrial partner for commercialization
- Complete the scale of Na-I2 cell technology and demonstrate 250 Wh cells
- Scale up high performance poly(phenylene) separator technology and refine cost models for manufacturing
- Develop a low cost, high performance GaN-based power module rated at 650V and >50A for energy storage applications
- **Stationary Energy Storage Safety and Reliability Center** – as a focal point to coordinate research, development, and validation of technologies
- **Establish a Quarterly Energy Storage Safety Forum**
- **New state Engagements in OR, AK, NY, MA, HI**
- **Energy Storage Handbook – major revisions**
- **Regulatory Modeling** - Initiate collaborative development with FERC, NARUC, and NCSL to address the roles and economic opportunities for energy storage services
- **Expanded effort on the development, publication, and dissemination of value assessments**