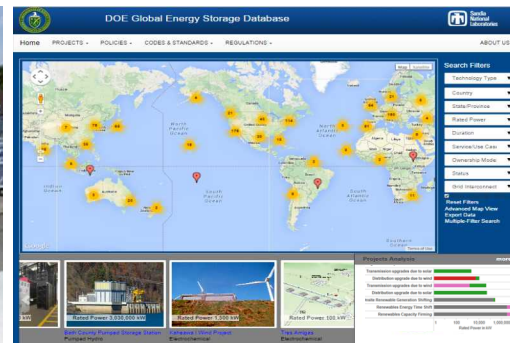


*Exceptional service in the national interest*



# SNL OE-ES Overview

Babu Chalamala

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

# Sandia Team and Industry/University Partners



Energy Storage Systems	Nanoscale Science	Advanced Materials Lab	Industrial Partners	University Collaborations
Babu Chalamala Stan Atcitty Ray Byrne Dan Borneo Jaci Hernandez Georgianne Huff David Rosewater Ana Beare	Carlos Gutierrez Todd Monson Nancy Missert	James Miller Kevin Zavadil Tim Boyle	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	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	Thermal, Fluid & Aero Sciences	Electronic, Optical, & Nano Materials		Standards, Policy, and Regulatory
Carol Adkins Charlie Hanley Dave Schoenwald Subhash Shinde Tony Martino Tim Lambert	Tracie Durbin Harry Moffat Scott Roberts Anthony Geller	Paul Clem Harlan Brown-Shacklee Jon Ihlefeld		UL, IEC IEEE 2030.2, 1547 NFPA, NIBS, IFC, MESA  CEC, CPUC EPRI, ESA, CESA
Power Source Technology	Electrical Science & Experiments	Materials Aging & Reliability		
David Ingersoll Thomas Wunsch Kyle Fenton Christopher Orendorff Christopher Applett Travis Anderson Summer Ferreira Josh Lamb	Steve Glover Lee Rashkin	Doug Wall Cy Fujimoto		
	System Readiness & Sustainment	Business Support		
	Bruce Thompson Mark Smith	Allyson Beck Gina Fresquez Miles Hall Carissima Heise Dan Johns Sharon Ruiz Amanda Spinney Irene Trujillo		
	Microsystems Process			
	David Hughart			

# FY15 Sandia Thrust Structure

- **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

- **Key Highlights**
  - **New membrane materials for flow batteries**
  - **Demonstration of 100 Ah Na-ion cells**
  - **Scalable production process for TiO<sub>2</sub> 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**

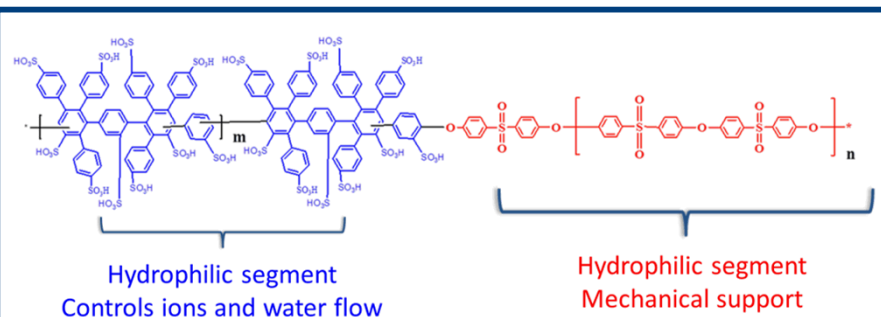
# Cost Competitive Energy Storage Membranes for Flow Batteries



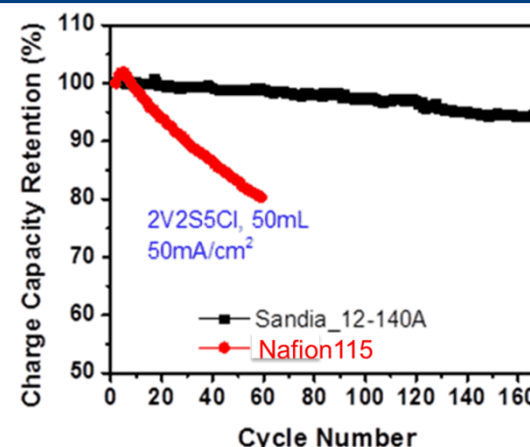
Cy Fujimoto  
Peer Review  
Presentation  
Thursday, 9/24  
8:45 am



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  
HCl-H<sub>2</sub>SO<sub>4</sub>  
2M  
Vanadium**

*Working with PNNL, we have shown a substantial improvement of capacity retention compared to Nafion!*

## 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



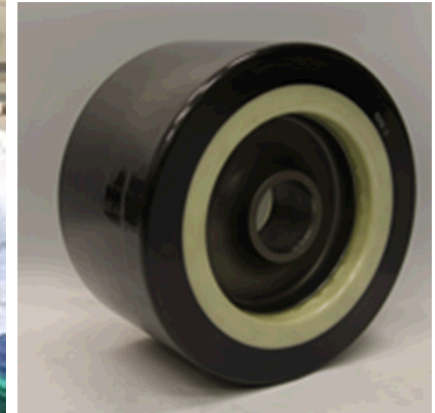
Tim Boyle  
Peer Review  
Presentation  
Tuesday, 9/24  
4:30 pm



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

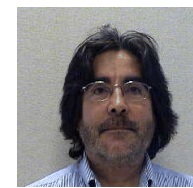
- Scaled process for synthesis of TiO<sub>2</sub> nano particles to Kg level batch process
- Developed tooling to machine rim parts and built a press process tool
- Completed the assembly of 4 flywheels

## 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 (Ceramtec, 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)

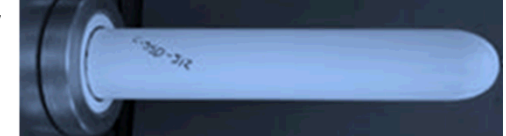
## FY15 Accomplishments:

- 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 Ceramtec cells



## FY16-17 Plans:

- Demonstration of 10 kW-h sodium battery (with Ceramtec: 180 Wh/l,  $\$150/\text{kWh}$ , 2.8V, 40 cells)
- Scale-up of cell size to 250 Wh sodium-ion cells
- Demonstrated low cost  $\$100\text{--}200/\text{kWh}$
- 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 Atcitty  
Peer Review  
Presentation  
Thursday, 9/24  
10:30 am

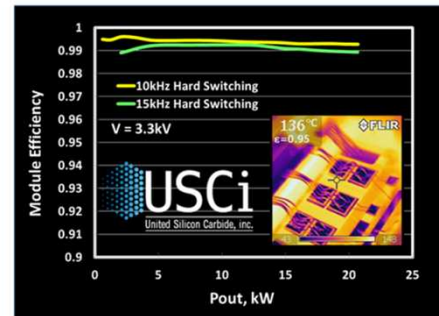


Using wide bandgap semiconductor devices, advanced topologies, and controls to significantly reduce installed cost and footprint, improve control capability, and increase reliability

## *Buck Converter Test Results at 3.3kV hard switching*



**6.5kV 60A SiC JFET Half-Bridge Module**



## Recognition

- Four R&D100 Awards
- Four U.S. Patents, two pending
- Over 40 technical publications
- Stan Atcitty 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

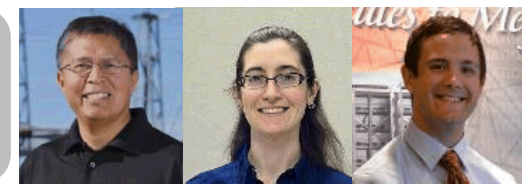
## FY16-17 Plans

- 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

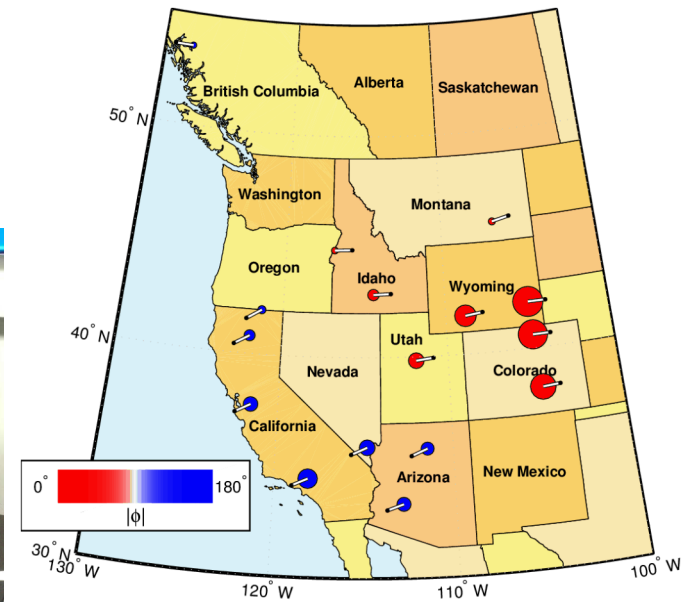


### Motivation:

- 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

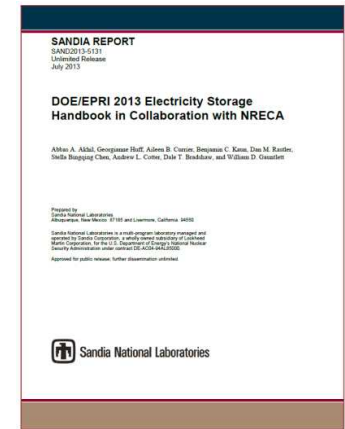


## Motivation:

- 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.



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



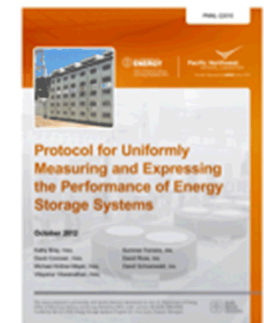
DOE/EPRI Handbook  
<http://www.sandia.gov/ess/publications/SAND2013-5131.pdf>

## 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

## 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



## 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**