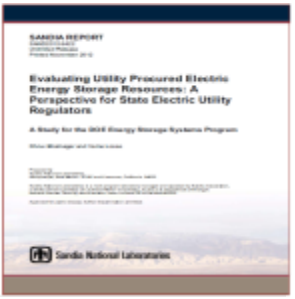

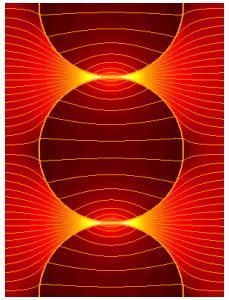

Sandia National Labs Energy Storage Technologies & Systems

Sean J. Hearne

Manager – Grid Storage Program

Sandia National Laboratories

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

Sandia National Laboratories

Exceptional service in the national interest

U.S. DEPARTMENT OF ENERGY

NNSA

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Challenges for Grid Energy Storage

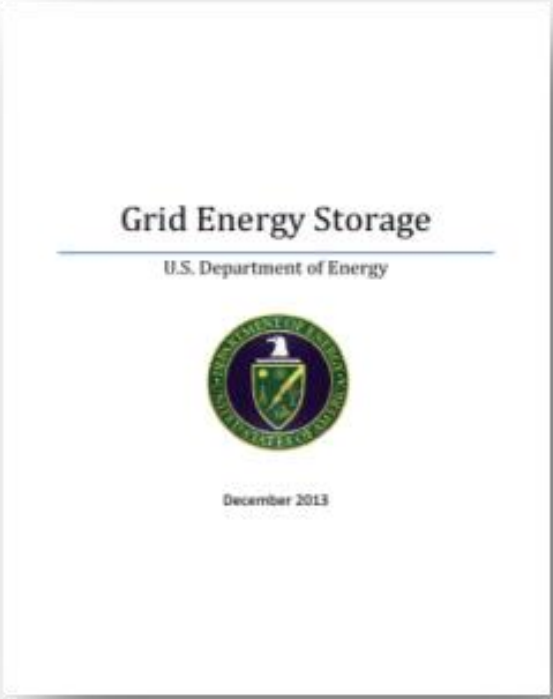
Sandia National Laboratories

During the commissioning hearings of Dr. Moniz to head US DOE, Senator Wyden requested a strategic plan for grid energy storage.

DOE Published the report in December 2013

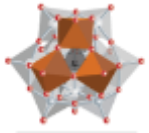
Four Critical Challenges were identified

1. Cost Competitive Energy Storage Technologies
2. Validated Reliability and Safety
3. Equitable Regulatory Environment
4. Industry Acceptance



FY 14 Sandia Thrust Structure

- **Materials and Systems Development**
  - Improving current technology (flow batteries, flywheels, etc.)
  - Leading the development of next-generation technologies
- **Power Electronics**
  - Developing, evaluating and improving new wide-bandgap power-electronic devices
- **Systems Demonstrations and Testing**
  - Laboratory testing and analysis from individual cells to 1MW energy storage systems
  - Field deployments
- **Grid Analytics and Policy**
  - Providing assessments of the impact of storage placement
- **Outreach -** Leading publications and meetings to educate the Grid Energy community



Nanoscopic

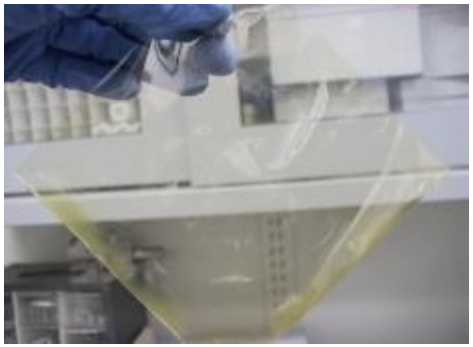
Macroscopic

Materials and Systems Thrust

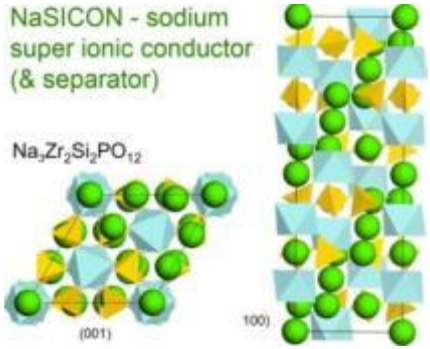
Improving the cost, performance and reliability of energy storage systems.

Near term – Improve existing energy storage technologies:

- Flow Batteries (separators, electrolytes, etc.)
- Flywheels (Carbon composites, new lift magnets)



New low-cost flow battery separator materials



Longer term – Revolutionary new energy storage systems:

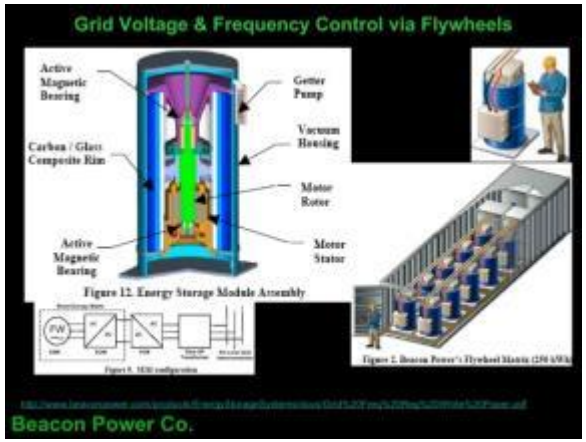
- Sodium metal batteries (low cost)
- Room temperature Na batteries

Near Term Example: Flywheels

Sandia National Laboratories

Purpose:

Improve the overall strength of composite flywheel materials, so they can spin faster.



$$E_k = \frac{1}{2} \bullet I \bullet \omega^2$$

$$s_t = \rho \bullet r^2 \bullet \omega^2$$

Small % changes in the flywheel spin speed leads to magnified energy storage

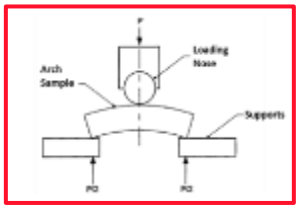
Procedure:

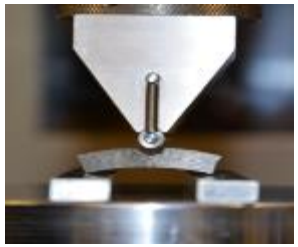
Carbon Fiber/ Nanomaterial Resin Winding

1. Materials Synthesis
2. Composite Fabrication
3. Mechanical Testing

Test Samples

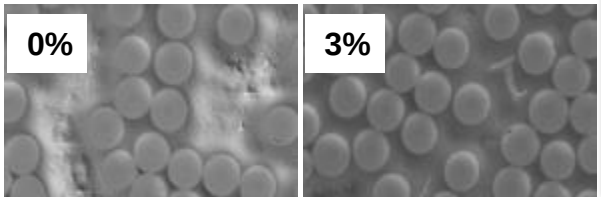
Results:





Ultimate Strength Test

- 20-25% Improvement with 5 wt. % Ceramic loadings in Carbon Fiber/Resin System 1
- 17% improvement with 3 wt. % Graphene loadings in Carbon Fiber/Resin System 2



Cross sectional SEM images

FY14 Accomplishments:

- Improving Flywheel interlaminar strength without changing basic design, processing parameters and cost would allow for faster spin speeds (more energy) to stabilize the AC grid.
- Graphene-based materials and ceramics are both promising materials.
- Currently working with commercial partners to build and test an industry relevant flywheel prototype.

Long Term Example: Sodium-Based Battery

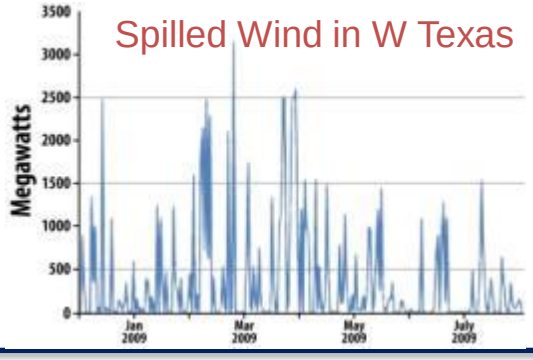
Sandia National Laboratories

Purpose:

Reduce the cost of stored energy to below $100/kWh to allow for enhanced Integration of renewable energy resources and grid modernization.

Energy storage will:

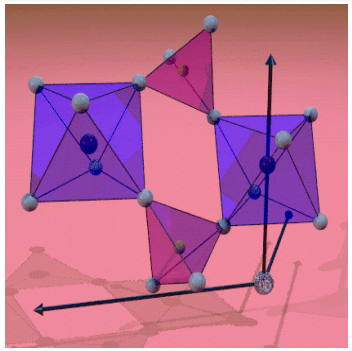
- improve power quality by leveling renewable intermittency
- increase system efficiency by capturing otherwise wasted resources
- allow improved matching of demand to generation



Procedure:

Establish government, national laboratory, industrial, university partnership to develop a sodium-based battery chemistry for large scale storage.

The system under development is predicated on the use of a perm selective solid ceramic separator that is stable against molten sodium.

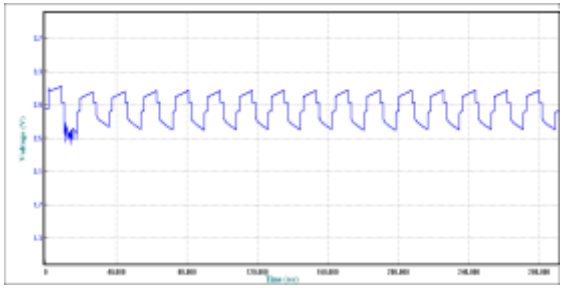


▪NaSICON Structure Sodium (**Na**) **S**uper **I**onic **CON**ductor

Results:

Cell fabricated and under test. Up to 275 cycles so far achieved.

Charge/discharge cycles 93 through 108 at a DOD of 20%

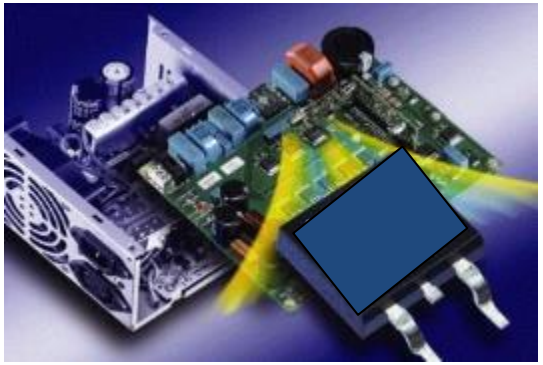


FY14 Accomplishments"

- Na-I_2 battery with tubular NaSICON membranes designed and fabricated
- Demonstrated proof of concept using laboratory prototype
- Cell scale up underway
- Application specific Techno-Economic feasibility analysis has been initiate

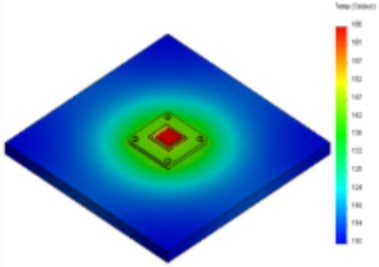
Power Electronics Thrust

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



Arkansas Power Electronics International
15kV Discrete SiC Package

P_{dis} = 200 W, Max Temperature = 166 ˚ C



Recognition

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

FY14 Accomplishments

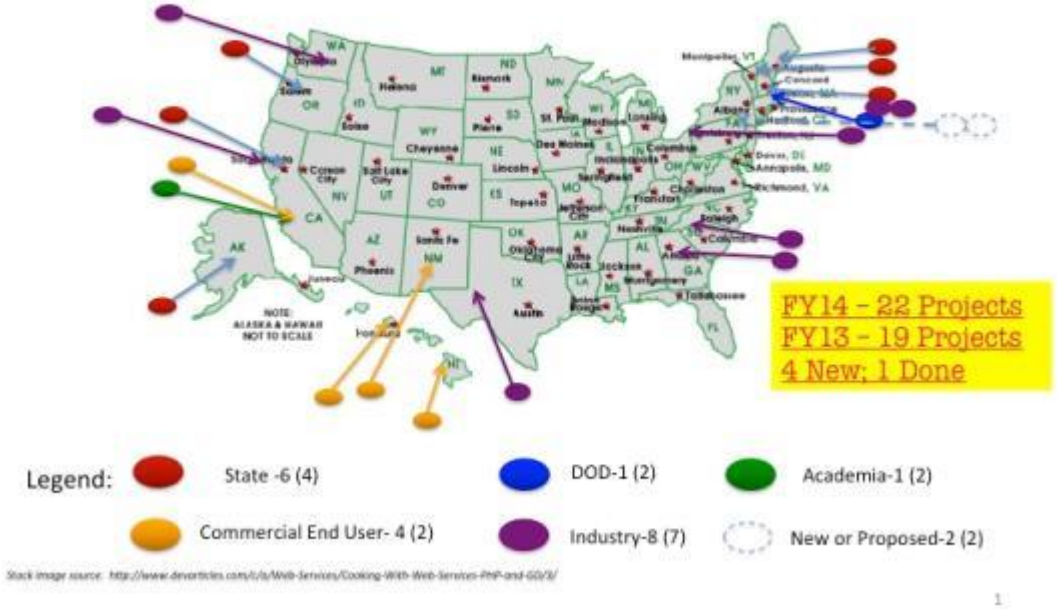
- Developed World's first high voltage (15kV at 100 amps, 200C) SiC multichip module
- Developed world's first normally-off 6.5 SiC Junction Field Effect Transistor (JFET)
- Developed advanced transformer core material for use in high frequency (>20kHz) power conversion system designs

FY15 – FY16 Plans

- Commercialize the high voltage SiC multichip module - Arkansas Power Electronics Co.
- Demonstrate a 6.5kV JFET based H-bridge module at 200C for next generation ESS
- Develop and characterize advanced transformer core materials for high frequency DC-link power conversion system

Demonstrations and Analysis Thrust

States are rapidly discovering the value of energy storage and are acting accordingly through updated policy and regulations. SNL's projects with states increase awareness of value and ROI of energy storage installations.



FY14 Accomplishments

- Began response to California Energy Commission call for 1.2GW of energy storage
- Actively assisting Hawaiian Electric (HECO)
- 2MW ES system under construction at Green Mountain Power in Vermont

FY15-16 Plans

- Work with state and municipal governments to improve grid resilience with energy storage, e.g. NJ, NY, MA
- Optimize and increase safe energy storage deployments and resulting ROI in varying application spaces

ES Analysis and Evaluation

- ***Laboratory analysis from cell to 1MW systems on a 250kW Micorgrid***
- ***Field analysis of storage systems***
- ***Science based development of validation protocols***

GS-Yuasa at ESTP

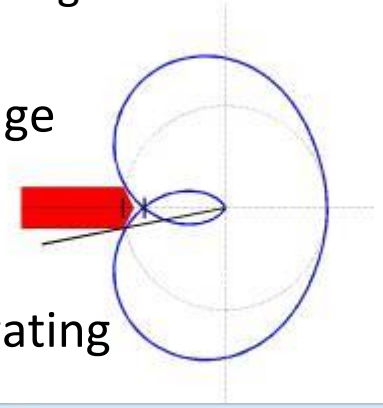
Milspray Deka Battery

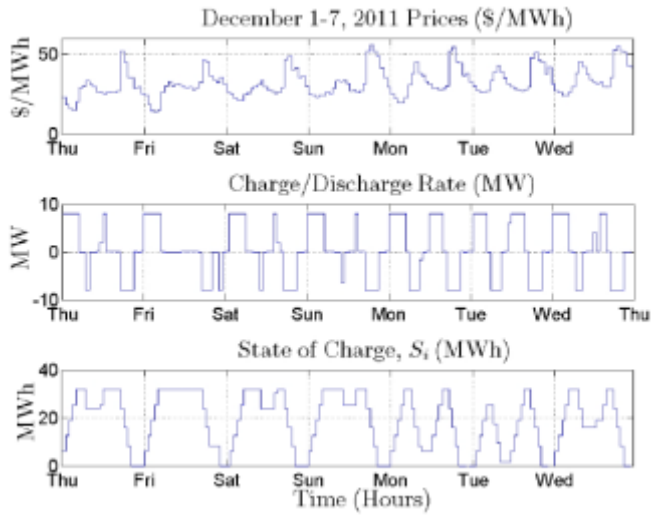
FY 14 Accomplishments

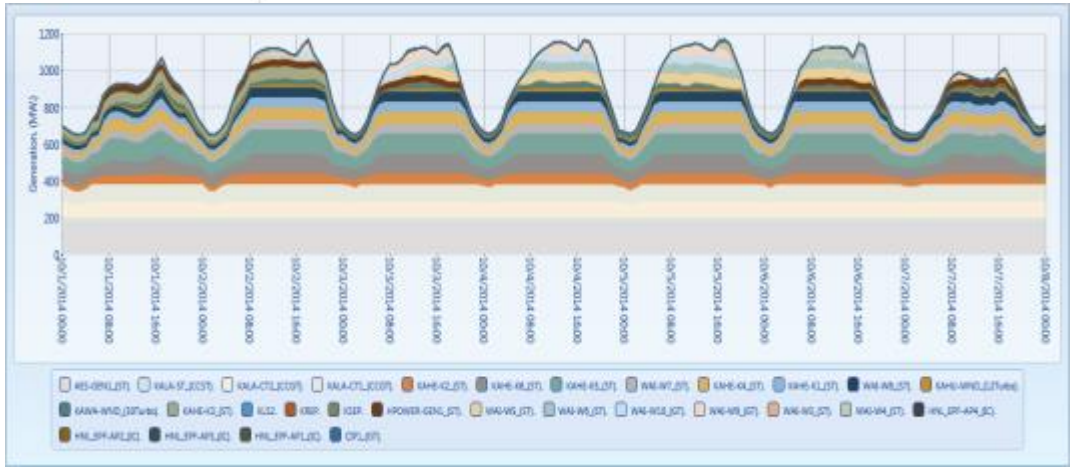
- Scalable from 5 KW to 1 MW, 480 VAC, 3 phase, Both power and energy use tests.
- 1 MW/1 MVAR load bank for either parallel microgrid, or series UPS operations
- Subcycle metering in feeder breakers for system identification and transient analysis
- Safety Analysis
- FY14 – 1MW / 1MWh system evaluated on ESTP

Energy Storage Analytics Thrust

- Estimating the value of energy storage
  - Production cost modeling (vertically integrated utility)
  - LP Optimization (market area)
  - Stochastic unit commitment/planning studies (vertically integrated utility)
- Control strategies for energy storage
  - Wide area damping control
  - Maximizing revenue
- Public policy: identifying and mitigating barriers
- Standards development
- Project evaluation
  - Technical performance
  - Financial performance
- Model development (e.g. for dynamic simulation)



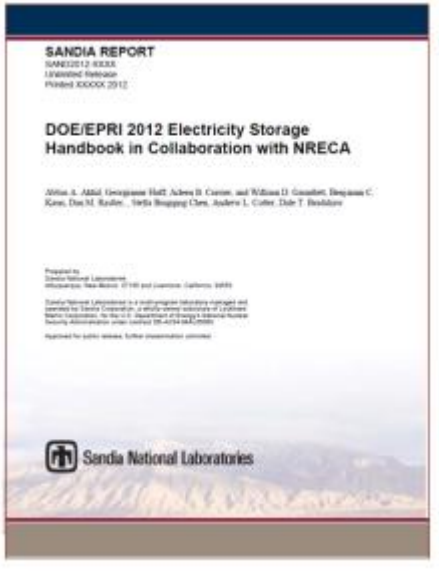




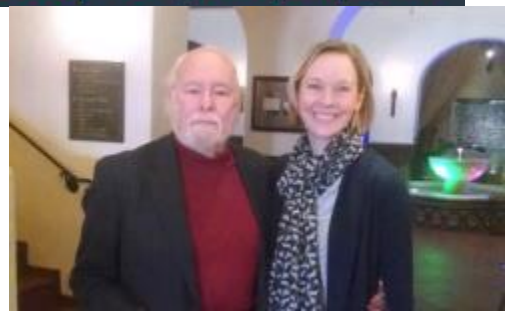
Outreach Thrust

Accomplishments

- **2013 Electrical Energy Storage Applications and Technology Conference (EESAT)**
  - The international conference disseminates the latest advances in storage technology, analytic and economic methods and **demonstrations.**
- **FY14 Peer review**
- **DOE OE ES Safety Workshop**
- **DOE Online Energy Storage Database**
  - >1000 energy storage projects from 58 countries
  - 50 energy storage technologies are represented
- **Handbook Updated**
  - Now interactive
  - Expanded tools for industry



DOE OE Energy Storage Safety Workshop



- Share knowledge on safety validation, commissioning, and operations from the perspectives of a diverse cross section of the energy storage community
- Identify the current gaps in understanding, managing, standardizing and regulating safety in energy storage systems. This input will be the basis of the DOE OE Strategy for Energy Storage Safety.

SNL Industry Collaborations

- Beacon Power, Helix
- SunEdison
- Arkansas Power Electronics Int., GeneSic Semiconductor, United SiC, Princeton Power
- DRS Research, HRL, Sigma Technologies International
- ESA
- Hawaiian Electric Company / Maui Electric Company (HECO/MECO)
- Sprint, RedFlow
- Aquion Energy, Pennsylvania Department of Energy
- Kodiak Electric Association (KEA)
- Milspray Military Technologies, Princeton Power Systems, Raytheon/Ktech, GS Battery, Earl Energy
- Duke Energy, Fiamm
- PNM, NEDO, MDS, East Penn
- CPUC, SunPower/DNV-GL/UCSD, ICE

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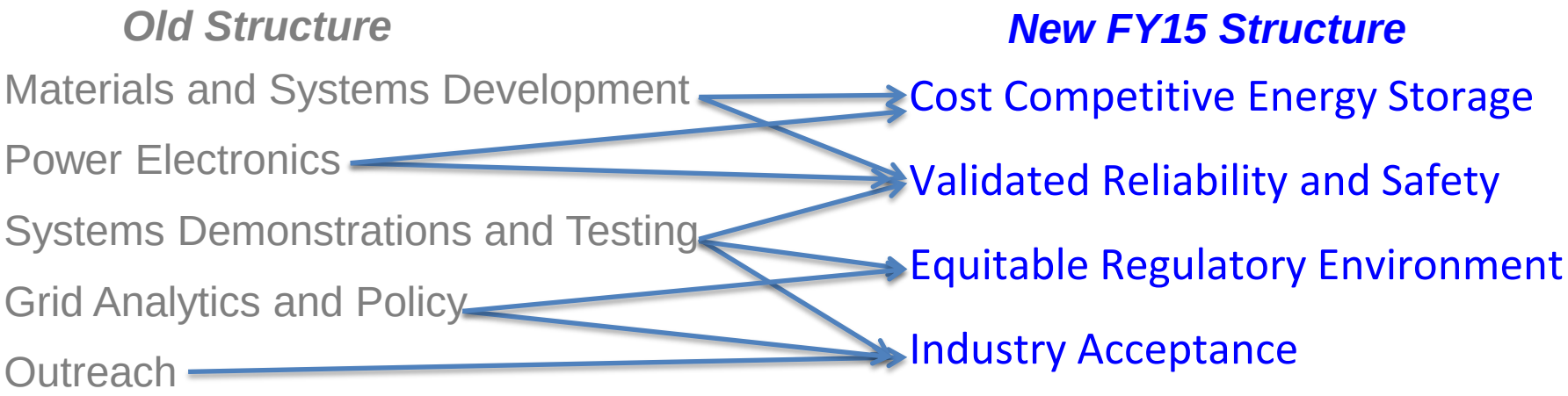
SNL University Collaborations

- Colorado School of Mines, University of Maryland
- Oregon State University
- Iowa State University
- University of California: San Diego, LA, Davis
- Case Western Reserve University
- The State University of New York, University of New Mexico
- Arizona State University, Iowa State University
- Drexel University
- North Carolina State University

Where is SNL headed in FY15?

Sandia National Laboratories

Program Restructure:



FY15 Directions

Sandia National Laboratories

New Industry Acceptance Activities

- Field Evaluation of Grid Scale Storage
- Expanding utility and state interactions
- Commissioning manual

New Safety Efforts

- Science based battery safety
- Modeling and validation of battery safety
- Developing safety validation protocols