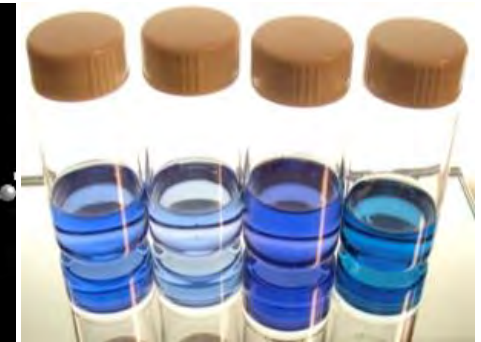
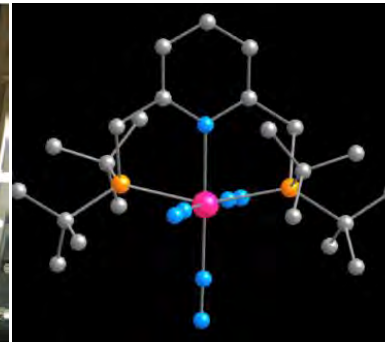


*Exceptional service in the national interest*



# Energy Storage R&D Overview

Babu R. Chalamala

NELHA Energy Storage Workshop, Sept 12, 2016

Sponsored by DOE Office of Electricity  
Dr. Imre Gyuk, Energy Storage Program Manager



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 - Energy Storage R&D

- Energy Storage covering technologies with applications in the grid, transportation, and stationary storage.
  - Basic research through systems engineering
  - Extensive capabilities in cell prototyping, pilot scale manufacturing, safety R&D and reliability
- OE Energy Storage program leverages wide ranging capabilities across the lab in a number of areas including materials sciences, power sources, microsystems, modeling and analytics.
  - In Energy Storage Safety, synergies with capabilities in Electrochemical Power Sources R&D and leverages infrastructure in BATLab
  - In Power Electronics, synergies with Ultra Wide Bandgap Power Electronics and Power On Demand research programs. Levering Fab Capabilities in the MESA Fab

# Grid Energy Storage - Program Goal

## Make Energy Storage Cost Competitive

- Critical challenges for energy storage are high system cost and cycle life
  - Existing storage solutions are too expensive
  - Deep discharge and longer cycle life
  - Safe and reliable chemistry
  - Scalable technology to cover all markets
- To make storage cost competitive, we need advances across all major areas:
  - Batteries, power electronics, PCS
  - BOS and Integration
  - Engineered safety of large systems
  - Codes and Standards
  - Optimal use of storage resources across the entire electricity infrastructure

# Grid Energy Storage Program - Thrust Areas

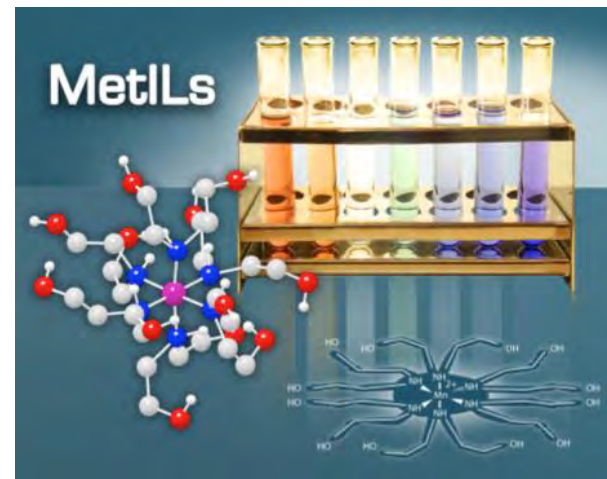


- Materials and Systems Development (Babu Chalamala)
  - Development of next-generation technologies
  - Improving current technology (flow batteries, flywheels, membranes, etc.)
- Power Electronics (Stan Atcitty)
  - Development of power electronics and power conversion systems.
- Energy Storage Systems Safety and Reliability (Summer Ferreira)
  - Fundamental Safety R&D of utility class storage systems
  - Laboratory testing and analysis from individual cells to 1MW systems
- ES Systems Demonstrations and Testing (Dan Borneo)
  - Field deployments; State-Initiated Demonstration Project Development
- Grid Analytics and Policy (Ray Byrne)
  - Providing assessments of the impact of storage placement
- Outreach - publications and meetings to help educate the Grid Energy community (Jaci Hernandez)
  - EESAT and DOE Energy Storage peer review
  - US DOE Global Energy Storage Database

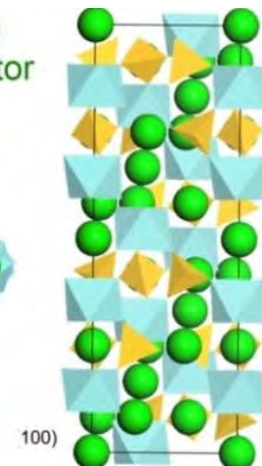
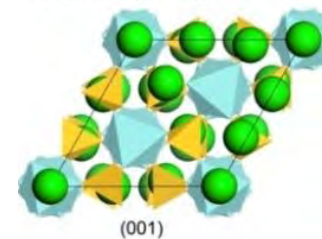
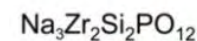
# Energy Storage Materials R&D

## Materials R&D capabilities covers battery chemistry and component technologies

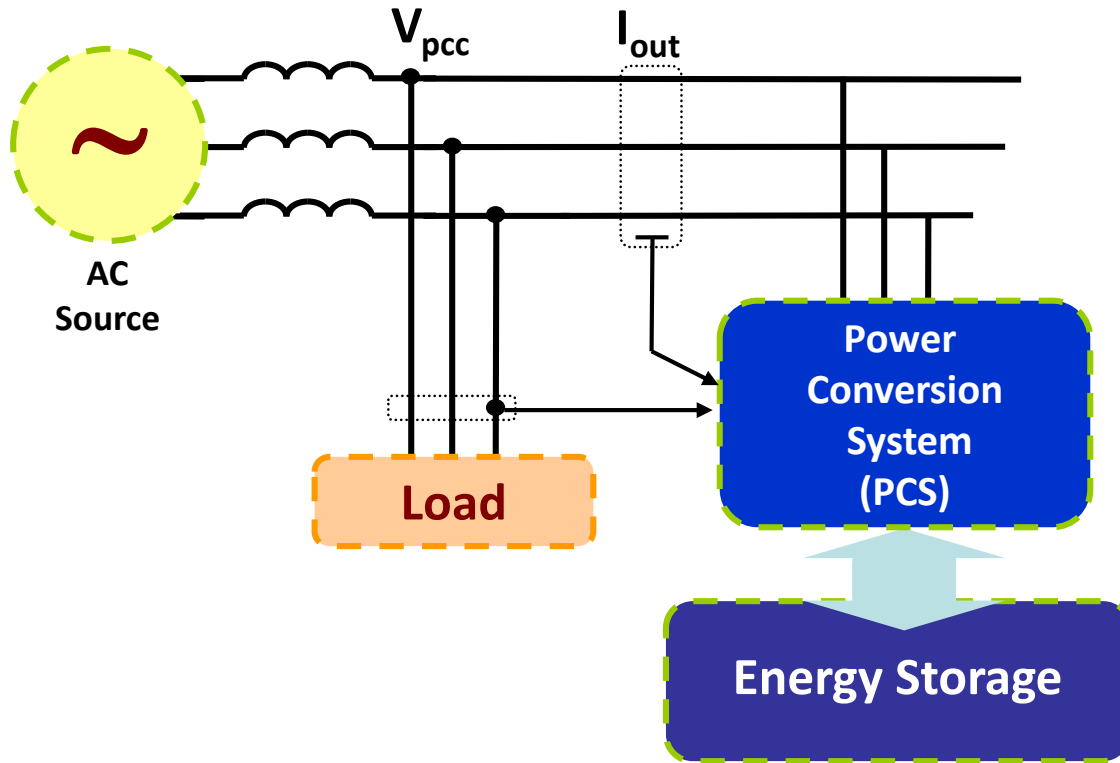
- Lower Temperature Sodium Based Batteries
- High Energy Materials for Flow Batteries
- Low Cost Membranes for Flow Batteries
- Rechargeable Zn-MnO<sub>2</sub> Batteries
  
- High Voltage Capacitors
- Soft Magnetics
- Lightweight Composites for Flywheels
- Wide Bandgap Materials and Devices for Power Electronics



NaSiCON - sodium  
super ionic conductor  
(& separator)



# Power Electronics and PCS R&D

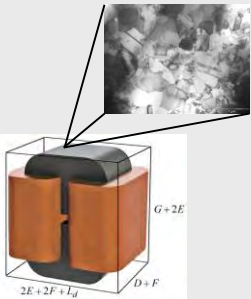
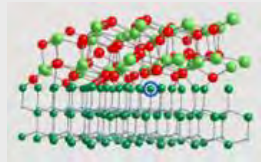


- PCS can be 20-40% of overall energy storage system cost.
- Need for significantly reduced installed cost/kVA and footprint, improved control capability and increased reliability

Low cost Power Electronics and PCS are key the large scale deployment of energy storage and for a future grid with efficient two-way flow

# Power Electronics R&D

## Materials R&D



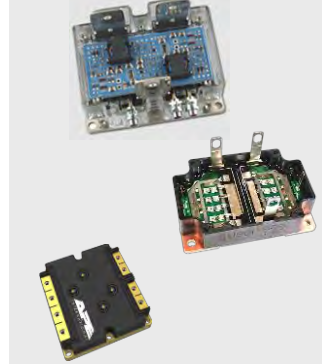
- Gate Oxide R&D
- Advanced Magnetics

## Devices



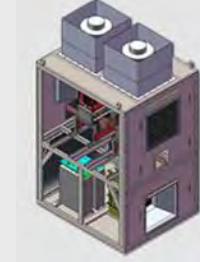
- ETO
- SiC Thyristors
- Monolithically integrated SiC transistors
- WBG Characterization & Reliability
- High energy dielectric capacitors

## Power Modules



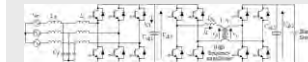
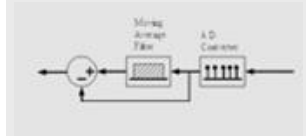
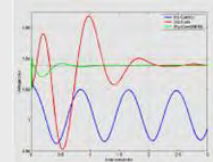
- SiC High Temp/density Power Module
- HV SiC JFET Module
- HV, HT Reworkable SiC half-bridge modules

## Power Conversion System



- Dstatcom plus energy storage for wind energy
- Optically isolated MW Inverter
- High density inverter with integrated thermal management
- High temp power inverter

## Applications



- FACTS and Energy Storage
- Power smoothing and control for renewables
- Dual active bridge for advanced energy storage system designs

# DOE OE Power Electronics Development

**WORLD'S FIRST FIBER OPTIC ELECTRICAL TRANSDUCER TO PASS MILITARY VIBRATION AND SHOCK CERTIFICATION**

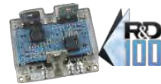
Exceeds 30Mhz  
Capable of Operating up to 34.5kV without additional Insulation, Isolation, or Cooling



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



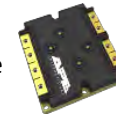
**WORLD'S FIRST HIGH TEMPERATURE SIC POWER MODULE**  
50 kW (1200 V/150 A peak)  
250 °C Junction Temperature  
Integrated HTSOI Gate Driver



**WORLD'S FIRST COMMERCIALY 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



**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 x 48 in Table Size  
6 axis 75 gRMS Vibration



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



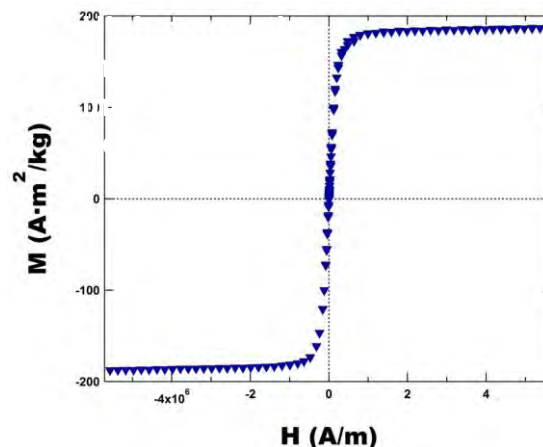
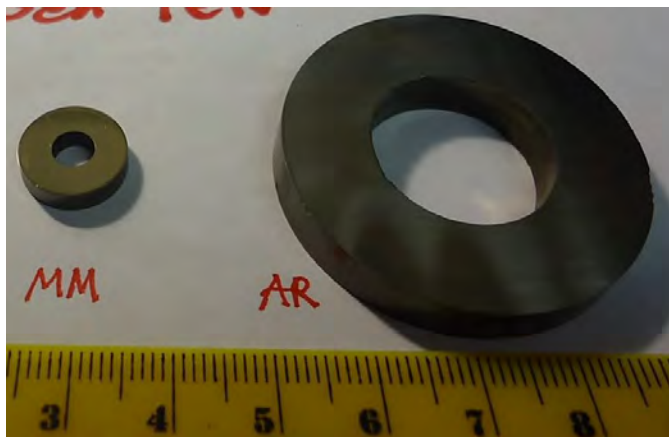
**WORLD'S FIRST HIGH FREQUENCY, HIGH TEMPERATURE, SIC HALF-BRIDGE POWER MODULE**  
15 kV/100 A, 20 kHz, 200C Reworkable  
Low Parasitic Design  
Device Neutral  
HV Isolated Gate Driver





# Soft Magnetics

- Current state of the art: soft ferrites (low power density), nanocrystalline and amorphous materials (very costly, power density can still be improved)
- Current TRL: 3 ( $\gamma'$ -Fe<sub>4</sub>N prototype inductor/transformer cores fabricated)
- Success enables: high frequency (HF) operation, enhanced power density, and sustained performance at elevated temperatures
- Collaborators: University of California, Irvine
- IP: U.S. Patent applications: 15/002,220, 14/531,075

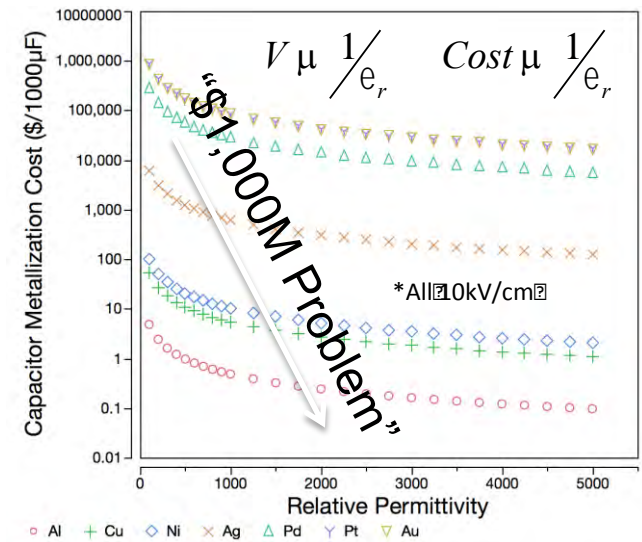
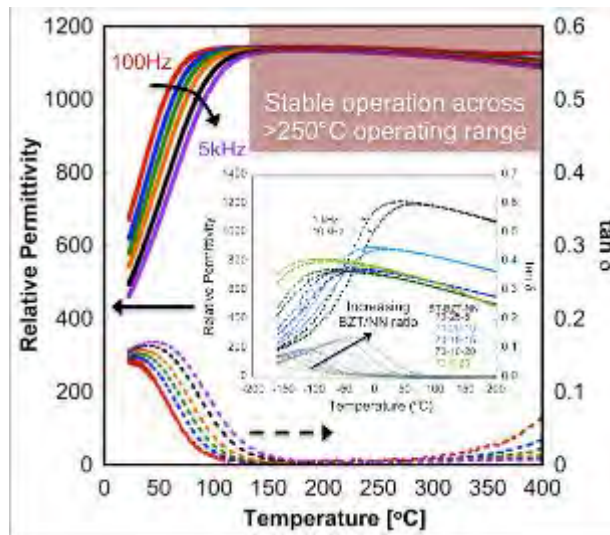


**$\gamma'$ -Fe<sub>4</sub>N prototype toroidal inductor cores fabricated using spark plasma sintering (SPS) & magnetic response**

# High Voltage Capacitors

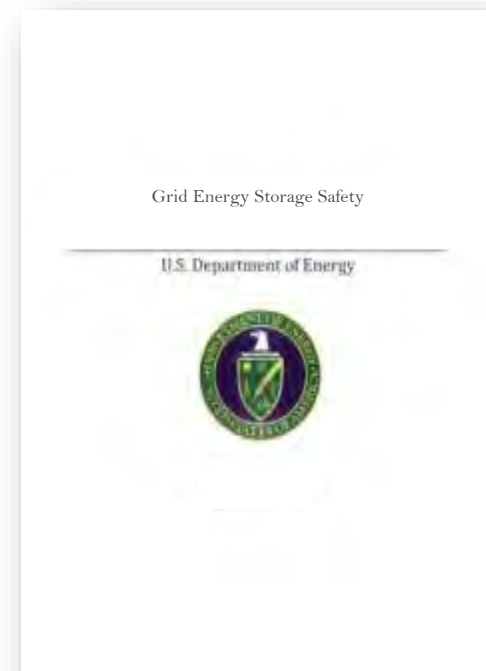
- Current state of the art: High temperature OR high energy density capacitors are available for <1000hr lifetimes at high cost
- Current TRL: 2-3, Relevant compositions were fabricated into multilayer devices that have measurable high temperature stability under relevant DC bias with maintained high permittivity
- Success enables: Move from high capacity electrolytic DC bus (slow frequency, low T) to base metal integrated high temperature capacitors
- Collaborators: TPL Inc. (TCF project and Oregon State University)
- IP: US Patent Application 20160071646

SNL MLCC



# DOE OE Strategic Plan on ESS Safety

- Lack of standardized validation protocol
- Lack of plan around incident preparedness
- Incomplete and dispersed codes, standards and regulations (CSR)



## 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

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 CORE TEAM (ESSCT) WEBINAR SERIES

- 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

# Energy Storage Systems Safety and Reliability

- 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
- Laboratory infrastructure at Energy Storage Test Pad (ESTP) for MW class storage systems evaluation
- Advanced simulation and modeling of energy storage systems



# Unique Capabilities

## Cell and Module Testing Battery Abuse Testing Laboratory (BATLab)



## Battery Pack/System Testing Thermal Test Complex (TTC) and Burnsite



## Battery Calorimetry



*Capabilities include grid tied test and evaluation of energy storage technologies for cell to MW systems*

## Cells and Modules



### 72V 1000A Bitrode (2 Channels)

#### Cell, Battery and Module Analysis

- 14 channels from 36 V, 25 A to 72 V, 1000 A for battery to module performance analysis
- Over 125 channels; 0 V to 10 V, 3 A to 100+ A for cell performance analysis
- Potentiostat/galvanostats for spectral impedance
- Multimeters, shunts and power supply for high precision testing
- Temperature chambers

## Fully Integrated Systems

### Lab Analysis



### Energy Storage Test Pad (ESTP)

- Scalable from 5 KW to 1 MW, 480 VAC, 3 phase
- 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
- Thermal imaging
- System Safety Analysis (new)

### Field Analysis (new)



### Remote Data Acquisition System (RDAS)

- Portable, Modular, Remotely Reconfigurable, and outdoor-ready
- Subcycle metering
- Tractable calibration
- Command Signal Ready for Grid Operator Simulation
- No control over grid conditions

# Grid Analytics and Controls

- Developing program in analytics and control aspects of grid storage systems
- Current projects
  - Wide area damping control and small signal stability of the grid (BPA)
  - Control algorithms and optimization
- New projects in FY17
  - Control strategies and architectures for distributed control of energy storage for different control goals. Impact of communications latency and bandwidth.
  - Software Architectures for control of distributed energy storage and improve the interoperability of energy storage with utility management software

# DOE Global Energy Storage Database

- The DOE Global Energy Storage Database provides free, up-to-date information on grid-connected energy storage projects and relevant state and federal policies.
- All information is vetted through a third-party verification process. All data can be exported to Excel or PDF. Our hope is that this site will contribute to the rapid development and deployment of energy storage technologies.



Metrics Effective June 2016  
1.2 Million Hits/ Site Visits  
1563 Total Operational Projects  
22 Project Created  
261 Projects Updated  
12 Projects Verified



# Acknowledgements

- DOE Office of Electricity – Dr. Imre Gyuk, Energy Storage Program Manager
- Grid Energy Storage Team at Sandia
- Pacific Northwest National Laboratory
- Collaborators across the country (universities, utilities, state and regional entities, and a number of companies)

# 2016 DOE OE Energy Storage Program Peer Review

## Background

The annual peer review serves as a platform to describe and assess before science and engineering colleagues how the funded work from DOE OE met basic and applied research criteria, the appropriateness of methodologies and use do competent personnel with adequate resources.

### Current Agenda

- Program Overview: DOE & National Labs
- 36 Formal Technical Talks: Existing Work
- 30 Poster Presentations: New Work, Early Results
- 3 Panelists: ES & Grid Integration

**SAVE THE DATE:**

***September 25-28, 2016***

***Renaissance Hotel/DuPont Circle***

***Washington, DC***



Images from 2014 DOE OE ES Peer Review

# 2017 Energy Storage Safety Workshop



## Purpose

Meeting the Challenge: 2017 ESS Safety Forum will provide a platform for discussing the current state of ESS and mitigation strategies for improving call to system level safety and reliability. This open forum will provide presenters an opportunity to present their work in ESS, and it will provide attendees the chance to see the work that is creating the future of ESS.

## Hotel

Meeting the Challenge: 2017 ESS Safety Forum will be held at the historic [La Fonda Hotel](#) in Santa Fe, New Mexico from February 22-24, 2017.



## Meeting the Challenge: 2017 ESS Safety Forum

La Fonda Hotel in Santa Fe, New Mexico

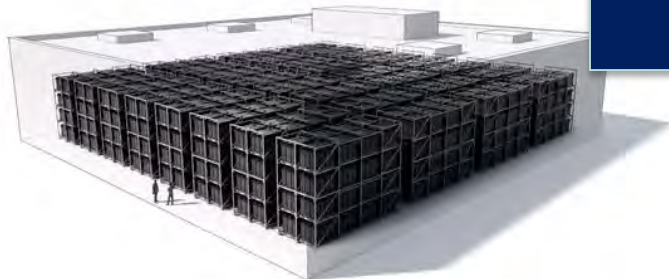
February 22-24, 2017

# Advanced Battery Diagnostics



*Transportation*

Advanced Battery  
Diagnostics



*Grid Storage*

*Development of advanced diagnostics for **battery health and stability***

***Predict** life, performance, and safety issues*

***Inform** system operators, workers, and responders*