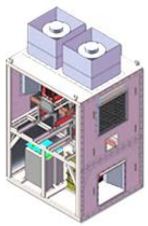
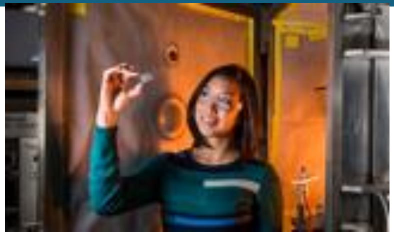
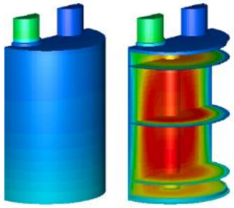
Sandia National Laboratories

Advancing Grid-Scale Electrical Energy Storage







Erik D. Spoerke, Ph.D.

Sandia National Laboratories, Albuquerque, NM

2nd NELHA Conference on Energy Storage Trends and Opportunities
December 5-6, 2018
Kailua-Kona, HI

U.S. Department of Energy   NNSA

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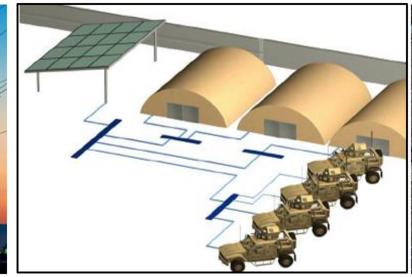
A Need for Grid-Scale Energy Storage Research


Renewable/Remote Energy

Grid Reliability



National Defense

Emergency Aid

We will need much, much more storage on our grid to accommodate increasing renewable penetration and the transition to a clean energy economy.

- “Energy” applications – slower times scale, large amounts of energy
- “Power” applications – faster time scale, real-time control of the electric grid

Current Barriers:

- Expensive, especially in energy markets (need for continued R&D)
- Electricity markets do not have market mechanisms for services ES can provide (need to reduce regulatory and policy hurdles)

Energy Storage Comparison (Nov., 2017)

<u>Globally</u>

- *1.7 GW - Battery Energy Storage (BES)*
- *~170 GW - Pumped Hydro Storage (PHS)*

<u>U.S.</u>

- *0.33 GW BES*
- *22.7 GW PHS*

<u>% of U.S. Generation Capacity</u>

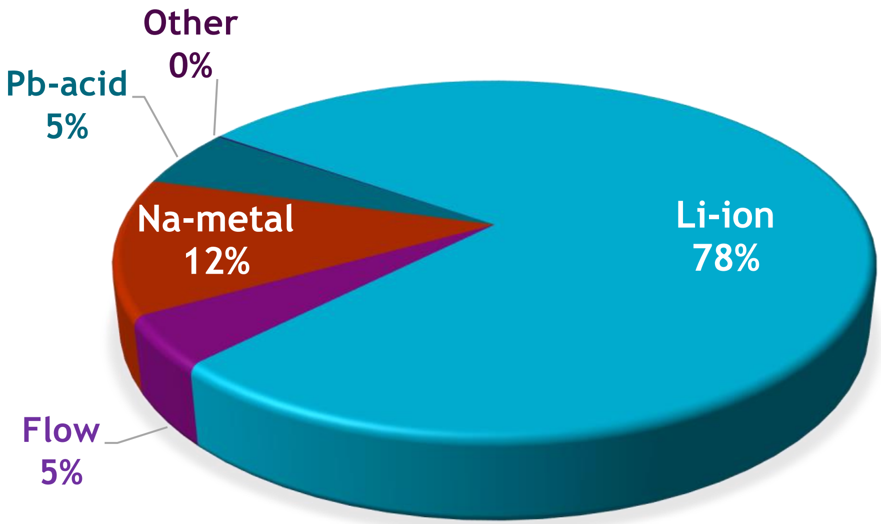
- *0.03% BES*
- *2.2% BES + PHS*

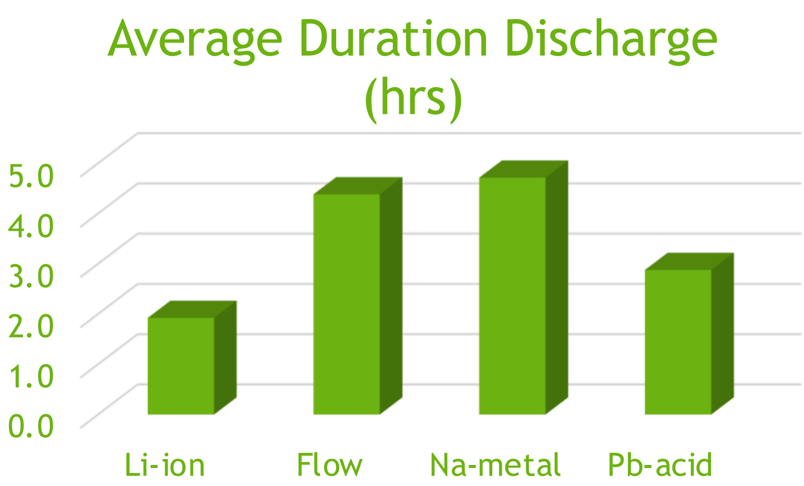
All the installed storage we have today translates to 15 min of backup power!

Source: *DOE Global Energy Storage Database http://www.energystorageexchange.org/ Nov. 2017*

Current Battery Energy Storage Deployments

*(Operational as of Nov. 2017)





Source: *DOE Global Energy Storage Database*
http://www.energystorageexchange.org/ Nov. 2017

Limited battery technology options has led to limited application diversity.

Advances in several areas will make grid-based storage systems safer, more reliable, and cost-effective:

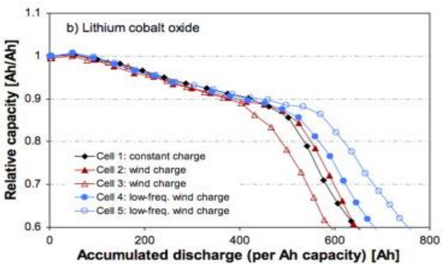
- Technology Advances
  - Lower cost storage systems
  - Deep discharge and longer cycle life
  - Safe and reliable chemistry
  - Scalable technologies to cover all markets/applications
- Manufacturing and scale-up
- Analytics, Controls, and Energy Management Systems
- Codes and standards

Challenges with Existing Batteries

Li-ion (E_{cell} ~ 3.6V)

$LiC_6 + CoO_2 \leftrightarrow C_6 + LiCoO_2$

- Safety (flammable organic electrolytes
- Cycle lifetime limited
- Cost

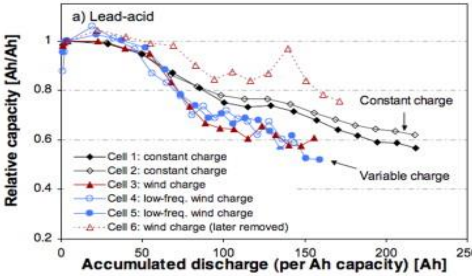


E. Krieger, *et al.* (2013) *Energy* **60.** 492-500.

Pb-Acid (E_{cell} ~ 2.1V)

$Pb + PbO_2 + 2H_2SO_4 \leftrightarrow 2PbSO_4 + 2H_2O$

- Capacity fades quickly (typically 200-300 cycles)
- Temperature-sensitive



E. Krieger, *et al.* (2013) *Energy* **60.** 492-500.

Na-S (E_{cell} ~ 2V)

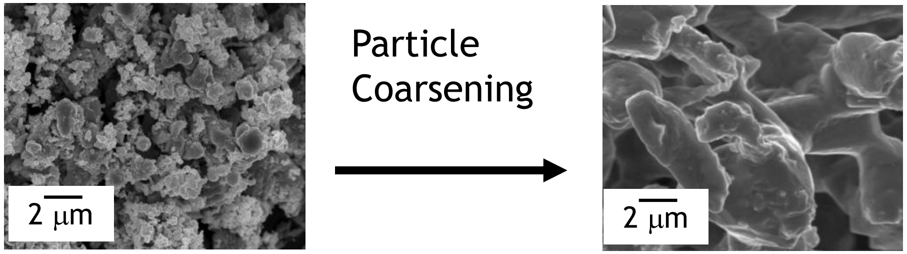
$2Na + 4S \leftrightarrow Na_2S_4$

- Safety: Violent, toxic reactions between molten Na and molten S – cascading runaway!
- Corrosive, toxic chemistries
- High temperature operation (270-350^oC)

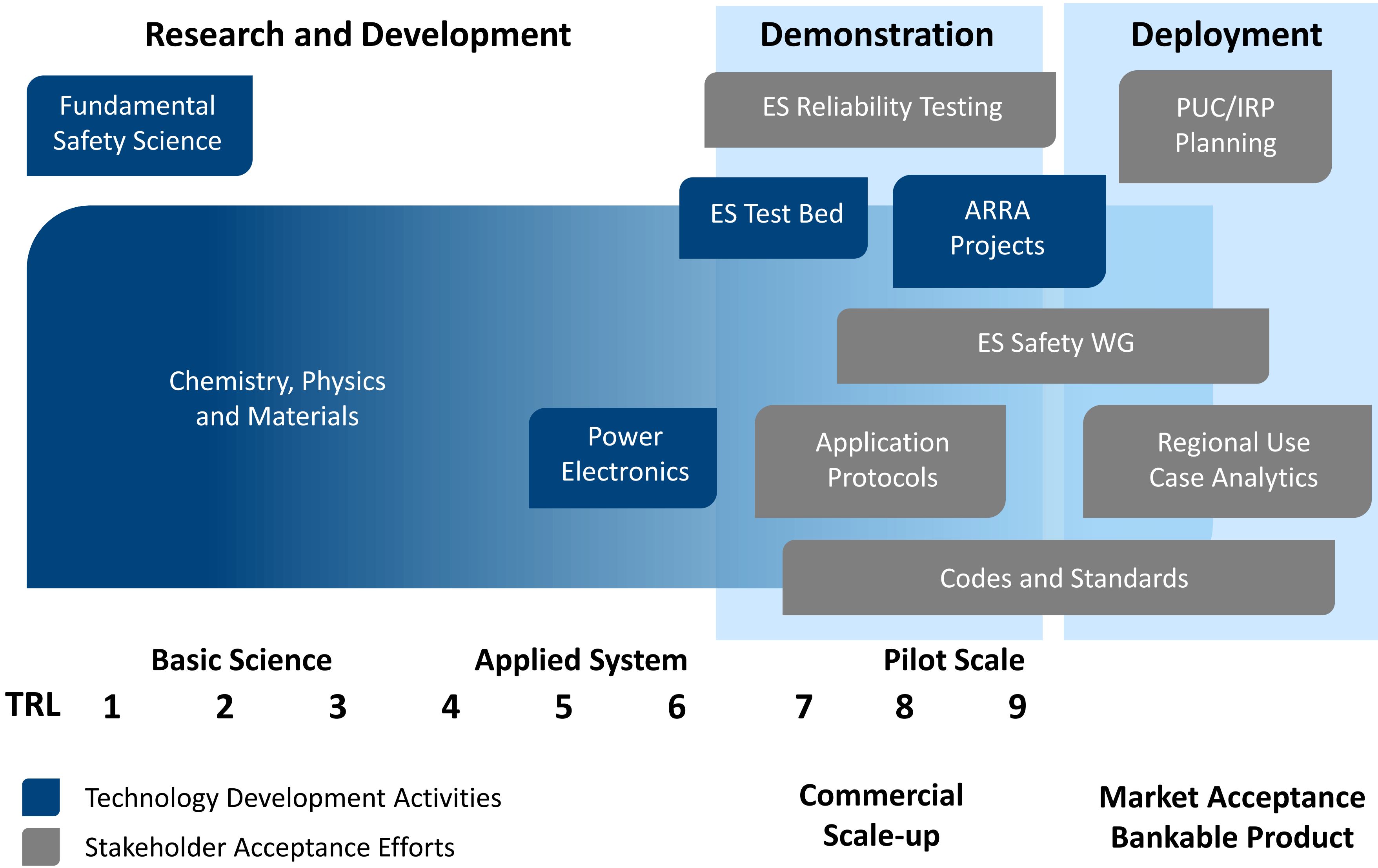
Na-NiCl$_2$ (E_{cell} ~ 2.6V)

$2Na + NiCl_2 \leftrightarrow 2Na^+ + 2Cl^- + Ni(s)$

- Cycle lifetime (solid cathode phase)
- Cost (related to cycle lifetime and material costs)
- High temperature operation (typically > 200^oC)



DOE Energy Storage Development Path

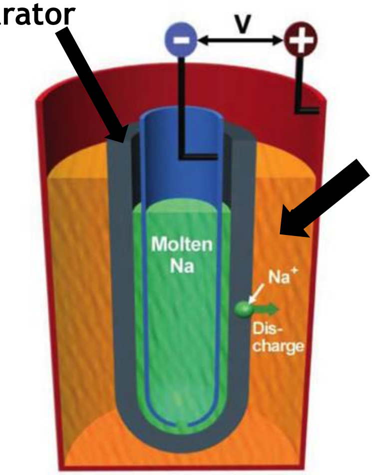


Energy Storage Priority Technologies

Sodium based Batteries

- 6th most abundant element on earth.
- 5X the annual production of aluminum.
- Proven technology base with NGK Sodium – Sulfur (NaS) Technology.
  - Reduce high temperature operation through development on fast-ion transport electrolytes.
  - Improve safety and reliability through development of chemically and mechanically stable electrolytes.
  - Develop lower cost and scalable manufacturing processes.
- New Na-metal and Na-Ion batteries in development.

- Sandia ES R&D Focus
  - Low temperature Na-ion conducting membranes leading to Na- batteries that can operate at 100-120°C.
  - New electrolytes that can operate at lower temperature.



Ceramic Separator Development

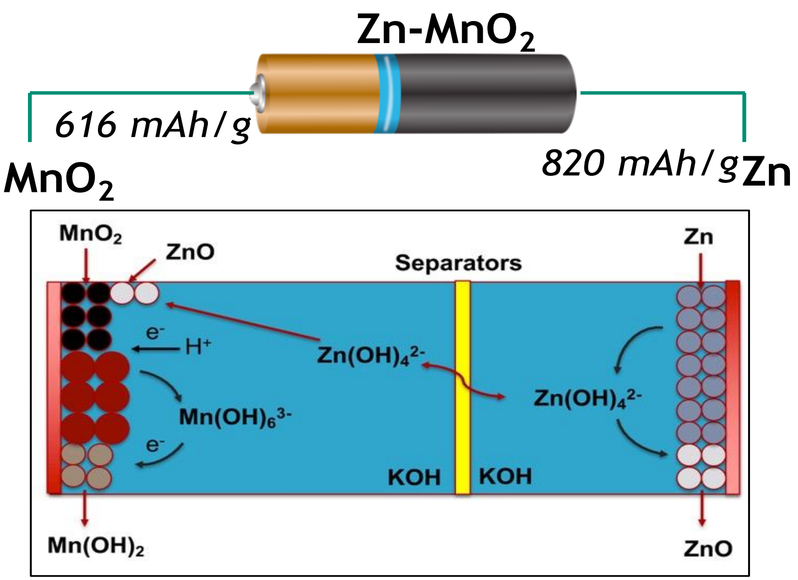
SNL work in collaboration with University of Kentucky, Field Upgrading (former Ceramatec).

Energy Storage Priority Technologies

Zn-based Batteries

- Zinc - $2,500/metric ton compared to $15,000/metric ton for Li carbonate precursor for Li-ion.
- Zn-MnO_2 - mature supply chain with developed infrastructure.
  - Must improve cycle-life through development of advanced materials and engineered interfaces.
  - Additional 2X reduction in cost through improved materials utilization.
  - Requires development of large format batteries and demonstrate low-cost manufacturing process.

- Sandia ES R&D Focus
  - Fundamental and applied research on Zn anodes and MnO_2 cathodes.
  - Zinc blocking separators.
  - Enable US based manufacturing. Development of manufacturing processes to reach $50/kWh with second generation Zn-MnO_2 batteries by 2021.

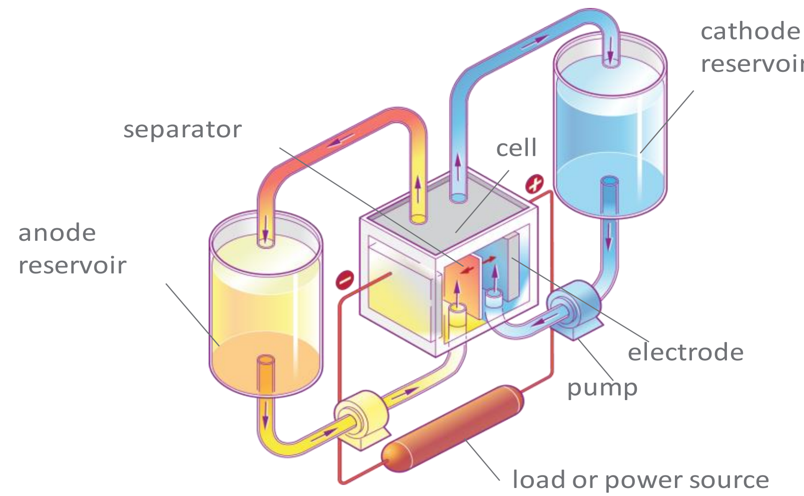


SNL work In collaboration with CUNY, Northeastern University, New Mexico State, Stony Brook University, Urban Electric Power.

Energy Storage Priority Technologies

Redox Flow Batteries

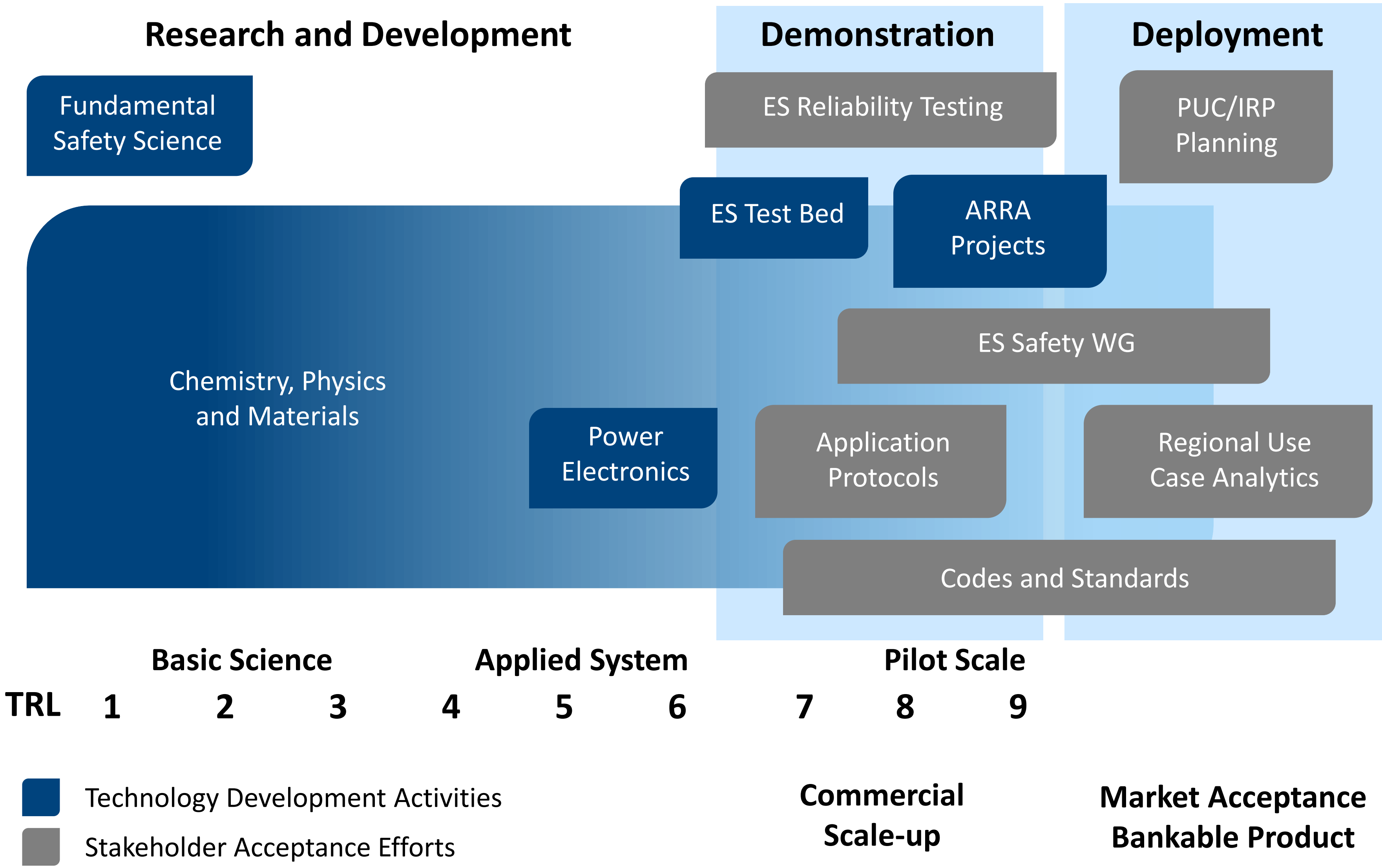
- Use of Aqueous Soluble Organic (ASO) based electrolytes to replace commodity metal (e.g Vanadium).
  - 10X reduction in materials cost if performance comparable to V/V is achieved.
  - 3X reduction in stack cost through adoption of higher performance materials and common flow battery design.
  - 10X reduction in membrane cost by development and commercialization of novel polymeric membrane.



- Sandia ES R&D Focus
  - Membrane technology
  - Next generation electrolytes

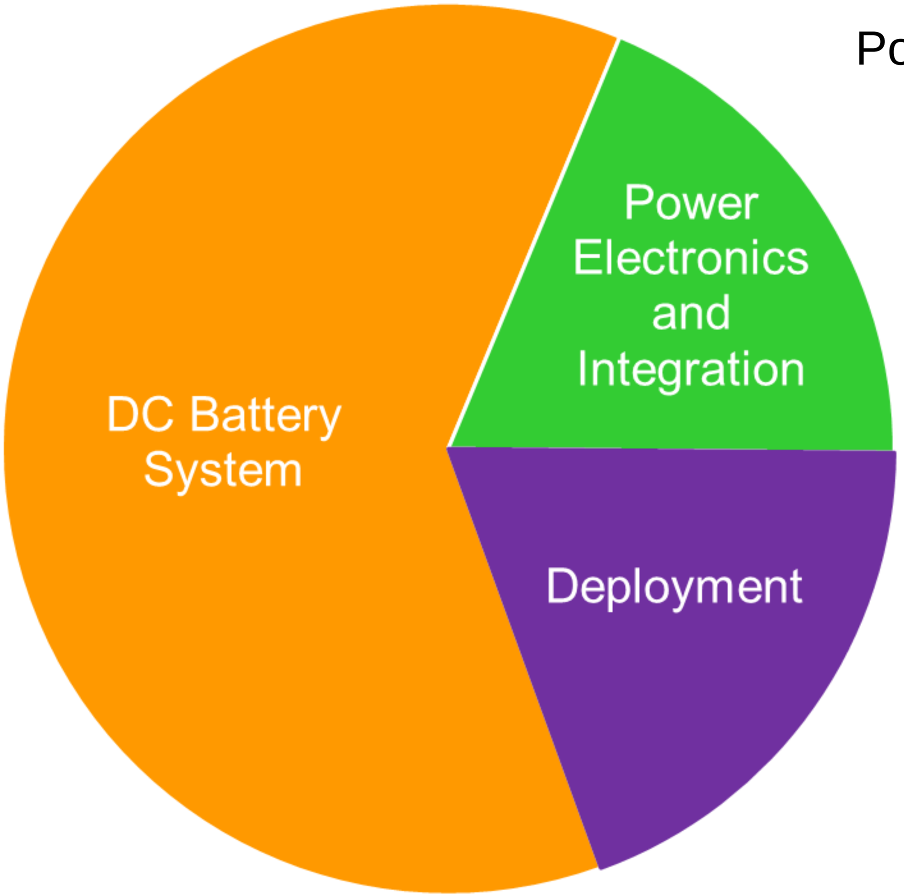
SNL work in collaboration with University of Washington, Davidson College, LANL, WattJoule

DOE Energy Storage Development Path



Costs Beyond the Battery

Reducing ES System Cost requires more than just DC System Development



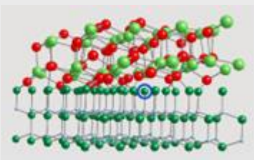
2018
DC System Costs
$450-600/kWh

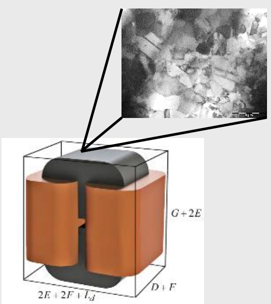
2018
Power Electronics
$150-200/kW

2018
Installation and Commissioning
$150-200/kWh

Power Electronics Research

Materials R&D



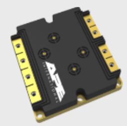


- Gate Oxide R&D
- Advanced Magnetics

Devices

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

Power Modules

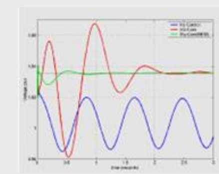


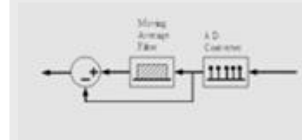
- SiC High Temp/density Power Module
- HV SiC JFET Module
- HV, HT Reworkable SiC half-bridge modules

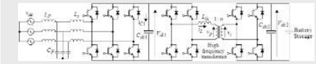
Power Conversion System

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

Applications





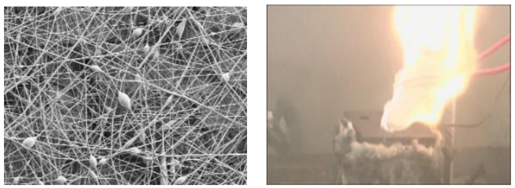


- FACTS and Energy Storage
- Power smoothing and control for renewables
- Dual active bridge for advanced energy storage system designs

Storage Deployment Needs

- Fundamental safety and reliability investigations and validation to de-risk new technologies for stakeholders.
- Distributed controls and operational tools for real-time state of health determinations, cyber-security, and coordinated power flow.
- Storage Valuation and analytics tools for optimal sizing, location, and valuation for grid applications.
- Demonstration and validation of new storage technologies focused on regional and application diversity.

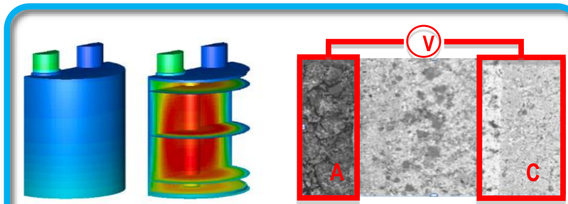
Battery Safety – Stationary Storage



Materials R&D to date:
- Non-flammable electrolytes
- Electrolyte salts
- Coated active materials
- Thermally stable materials

Materials R&D needs:
- Viable flow batteries
- Aqueous electrolyte batteries
- High specific heat suppressants
- Vent gas composition

Testing
- Electrical, thermal, mechanical abuse testing
- Failure propagation testing on batteries/systems
- Suppressants and delivery with systems and environments
- Large scale thermal and fire testing (TTC)



Simulations and Modeling
- Multi-scale models for understanding thermal runaway
- Validating failure propagation models
- Fire Dynamic Simulations (FDS) to predict the size, scope, and consequences of battery fires

Procedures, Policy, and Regulation
- UL 1973-13 Batteries for Use in Stationary Applications
- ANSI/UL 9540-P (ESS Safety)
- UL 1974 (Repurposing)
- IEEE 1635-12 (Ventilation and thermal management)

Active University Collaborations

CUNY Energy Institute

Davidson College

Northeastern University

Stony Brook University

University of Kentucky

University of Washington

UC Irvine

University of Alaska Fairbanks

University Texas at Austin

New Mexico State University

Ohio State University

University Texas Arlington

New Mexico Tech

University New Mexico

Washington University at S. L.

Michigan State University

University of Utah

South Dakota State University

Clemson University

Southern Methodist University

$2.2M in funding to universities

Industry and Utility Collaborators

- GeneSic Semiconductor
- Creare
- InnoCit
- Mainstream Engineering
- Powdermet
- Urban Electric Power
- Helix Power Corporation
- Eugene Water and Electric Board
- Cordova Electric Cooperative
- Strategen
- Mustang Prairie Energy
- ANZA Electric
- PNM Resources

- WattJoule
- UniEnergy Technologies
- Sterling Municipal Light Department
- Public Service of New Mexico
- National Rural Electric Cooperative Association
- Hawaii Electric Light
- Green Mountain Power
- Electric Power Board of Chattanooga
- Electric Power Research Institute
- Ecoult Battery
- Demand Energy
- Burlington Electric Department
- NELHA

Overview of Sandia's Energy Storage Effort

Multidisciplinary R&D program with synergetic collaboration across several departments within Sandia

- Materials Research - Advancing battery chemistries through technology development and commercialization.
- Power Electronics - Optimization at the interface between power electronics and electrochemistry. New power converter topologies, high voltage passives and magnetics.
- Energy Storage Safety – Cell and module level safety test and analysis. Engineered safety of large systems. Predictive models for ES safety. Storage safety standards and protocols.
- Energy Storage Analytics and Controls - Developing competencies in analytics and controls for integration of utility class storage systems. Lower BOS and integration costs. Software tools for optimal use of energy storage across the electricity infrastructure. Standards development.
- Energy Storage Project Development – Support for DOE demonstration projects
- Industry Outreach - Outreach to utilities, regulators, and the industry.

Outward looking program with significant external reach to industry and academic collaborators.

Although this overview summarizes Sandia's efforts, it represents a broader view of how the energy storage community is are tackling important challenges to widespread utilization of electrical energy storage.

Acknowledgements

Thank you!

Work at Sandia National Laboratories is supported by Dr. Imre Gyuk through the Department of Energy Office of Electricity Delivery and Energy Reliability.

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