SAND2014-17547PE

Exceptional service in the national interest

Sandia National Laboratories

energy.sandia.gov

DOE Office of Electricity (OE)Energy Storage Safety: Executive Summary and Path Forward

September 10, 2014

Summer R. Ferreira, Ph.D.
Advanced Power Sources R&D
Sandia National Laboratories

SAND2014-xxxx

U.S. DEPARTMENT OF ENERGY

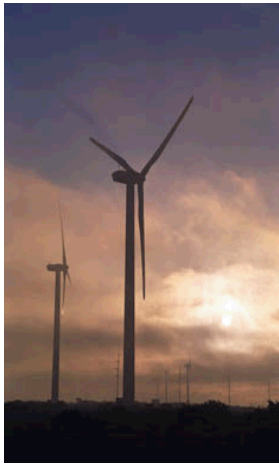
NNSA National Nuclear Security Administration

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

Storage Program Motivation

Energy storage is an enabling technology:

1. Allows for increased *renewables penetration*
2. Improves grid *efficiency*
3. Improves grid *reliability and resilience*



Energy Storage in the Grid

Traditional Grid

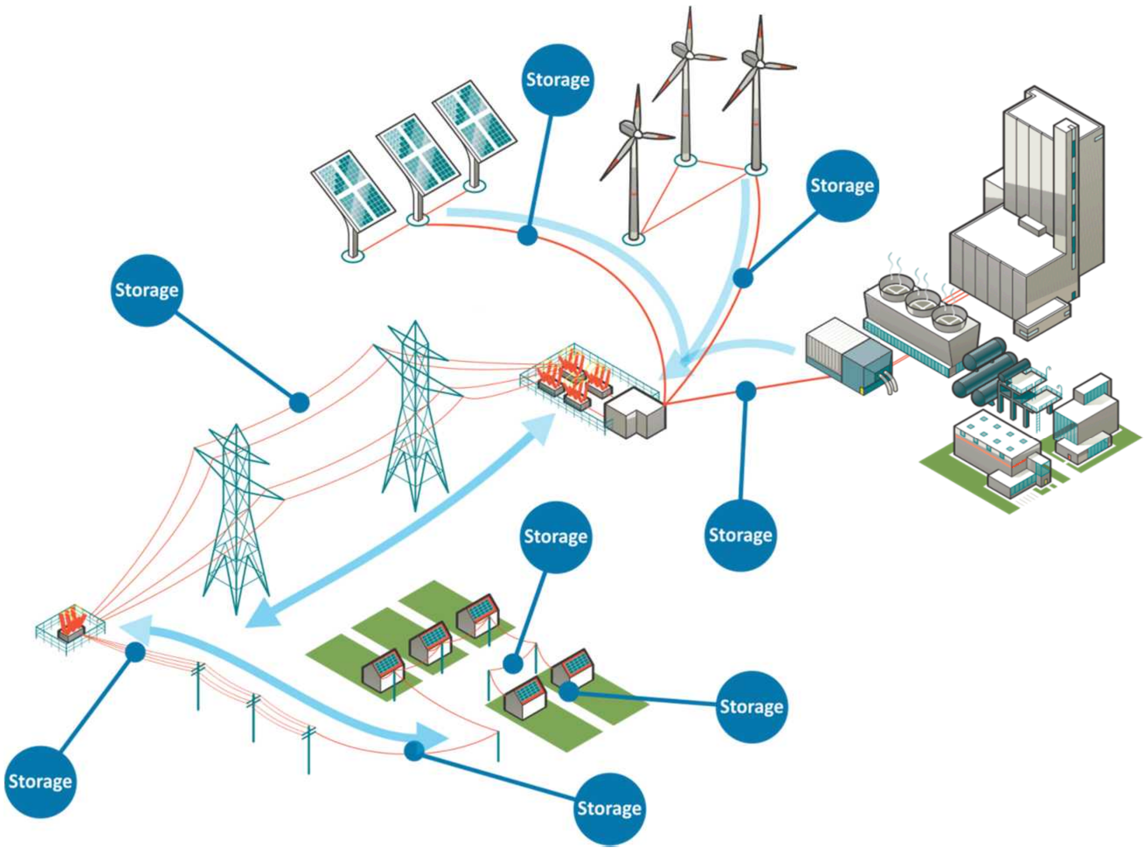
- One way flow
- Little/no renewable energy

Today's Grid

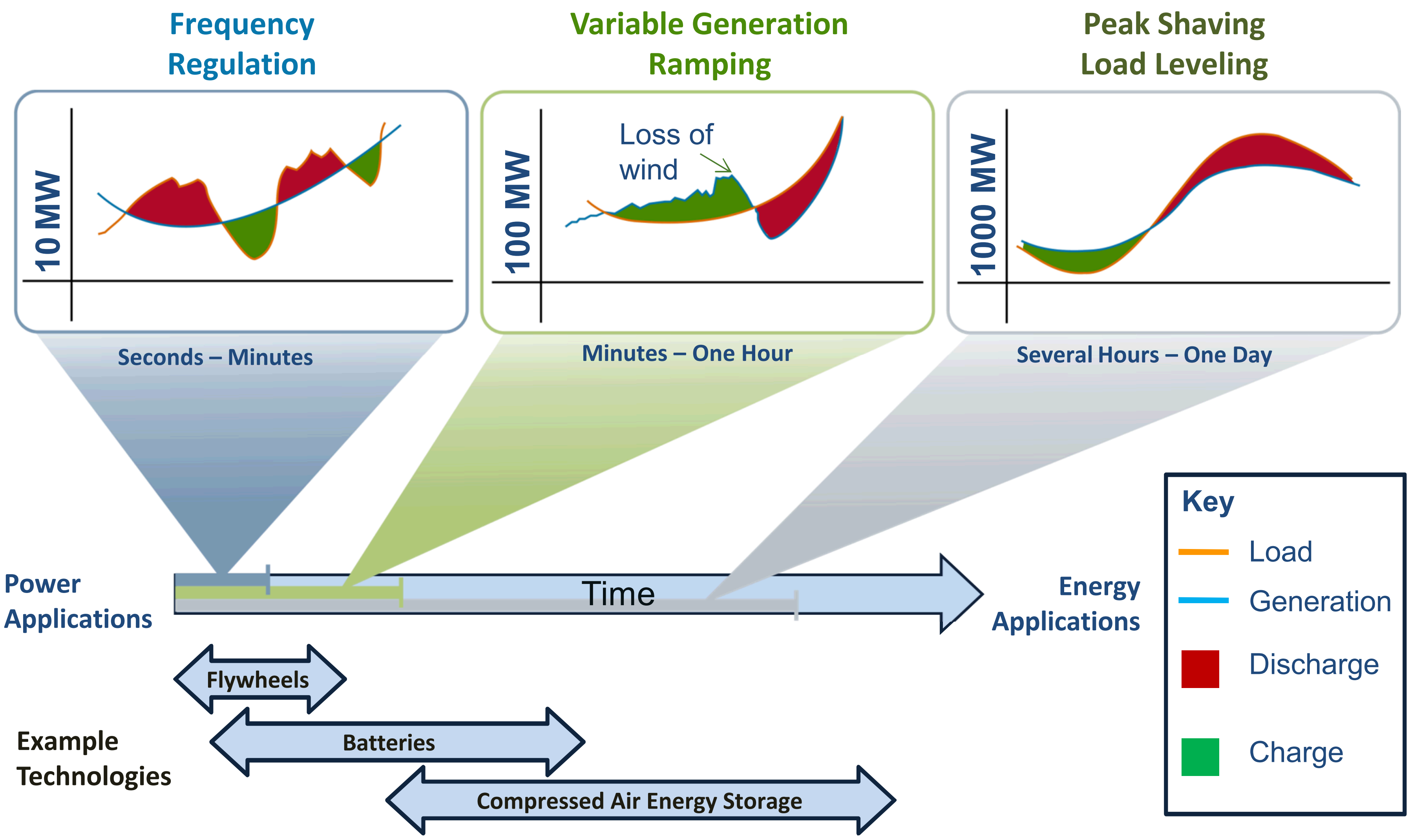
- Integration of grid-scale and distributed renewable generation beginning, but with limited penetration

Future Grid

- Storage provides buffering capability to enable high penetration of renewable energy and asset deferral for T&D systems
- Two-way flow



The Energy Storage Solution



Energy Storage Challenges

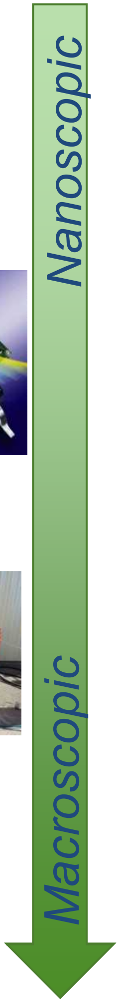
During the commissioning hearings of Dr. Moniz to head US DOE, Senator Wyden requested a strategic plan for grid energy storage.

DOE Published the report in December 2013

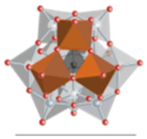
Four Critical Challenges were identified in the report

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

Five Sandia thrusts to meet the Challenge



- **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

The Need for Validated Safety

Challenges

- Continuing evolution of technologies for energy storage
- Rapid increase in deployment of energy storage systems
- Changing application environment
  - Larger to smaller/complex systems unitary ‘plug and play’
  - Scale of deployment range 3 orders of magnitude (tens of kW to tens of MW)
  - Public, private individual and corporate ownership models (and maintenance responsibilities!)
  - Many entities involved in safety regulation

Increased Need for and Challenges to Addressing Safety

- A few safety incidents can adversely affect the entire industry

DOE OE Safety Workshop, February 2014

- Brought together key stakeholders in the energy storage community.
- Shared knowledge on safety validation, commissioning, and operations from the diverse community.
- Identified the current gaps in understanding, validating, standardizing and regulating safety in energy storage systems.

Key Findings from DOE OE Energy Storage Safety Workshop

Sandia National Laboratories

Deployment of Energy Storage is ahead of codes, standards and regulations - Each deployment is addressed uniquely.

- Increases installations costs
- Delays commercial projects
- Becomes a reason to seek other technology solutions

Three root causes:

1. Lack of standardized methods and the scientific basis necessary to validate system safety,
2. Need to update codes, standards and regulations (CSR), and
3. Incident preparedness is not fully developed or standardized for the new technologies.

A strategic plan for energy storage system safety is needed.

Path Forward for Energy Storage Safety

1. Develop and issue the *DOE OE Strategic Plan for Energy Storage Safety.*

2. Collect, organize and disseminate information on codes, standards, regulations and best practices for energy storage safety.

3. Develop and implement process to continually engage the community.
   - Workshops
   - On-line resources (Forums, databases, etc.)

Gap Details

Scientifically-based Validation Techniques

- Science-based methods to validate system safety need to be developed.
- Validation techniques must span micro to macro and enable prediction of safe performance.

Incident preparedness

- Develop best practices for siting and first responders to ensure safety and minimize impact if an incident does occur.
- Training for facility managers/operators and first responders is needed to ensure that an incident can be effectively addressed.

Documenting Safety - Codes, Standards and Regulations (CSRs)

- The lack of accepted methods for validation make it a challenge to document or assess compliance with CSR.
- The CSRs currently available do not specifically address the entire range of technologies.
- These CSR need continual updating due to rapid advances in storage technologies and new citing locations.

Preliminary Outline:
DOE OE Strategic Plan for Energy Storage Safety

Sandia National Laboratories

- Executive Summary
- Motivation for Energy Storage Safety
- State of Safety Validation in the U.S.
- Key Aspects for Addressing Energy Storage Safety
  - Validation Techniques
  - Incident Preparedness
  - Safety Documentation
- Implementation of Goals to Reach Desired End State

Validation Techniques

Current State

- R&D focused on electric vehicle (EV) battery technologies
  - Li-ion, lead-acid, and nickel metal hydride chemistries
- Grid scale storage more complex and diverse every year
  - Comprehensive strategy necessary to address growing safety concerns

Gap Areas

- Failure modes and energy requirements of batteries and flywheels not well characterized
  - Uncertainty regarding risks and consequences
- Significant gap in our ability to understand and quantify potential failures under real-world conditions

Desired End State

- Better understand reproducibility among parts, and influence of defects on failure
- Enhance understanding of degradation and end of life failures under normal operating and abuse conditions
- Structure models that will reliably predict failure with the increasing size of batteries
- Further analyze interactions between fire suppressants and system chemistries

Incident Preparedness

Current State

- Fire departments do not categorize ESS as stand-alone infrastructure capable of causing safety incidents independent of the systems which they support
- Energy storage industry expanding faster than correlating safety documentation (Codes, standards and regulations)

Gap Areas

- Fire control systems and ventilation
- Commodity classification
- First responder education
- Verification and control of stored energy
- Post-incident response and recovery

Desired End State

- Because of low frequency of energy storage incidents, wide variety of systems sizes and technologies, and deployment options there is a need to develop comprehensive emergency preparedness plans
- Education and training currently provided to first responders needs to be enhanced

Safety Documentation

Current State

- Storage technologies are subject to federal, state and local legal requirements designed to protect workers, the public, and the environment
- Safety documentation ineffective in validating the safety of energy storage technologies
- Drafting effective safety documentation difficult
  - Various different stakeholders involved
  - Complex documentation required for each component, module, system, and deployment environment

Gap Areas

- Components of a system have individual CSR while similar documentation often does not exist for the systems as operational entities
- Safety regulations may differ across different municipalities
- Growing body of experience and results of other ESS Safety initiative activities must be transitioned into future CSR

Desired End State

- Safety documentation must be standardized and specific to each chemistry, component, module, and deployment environment of each type of system
- Energy storage industry participants must be aware of multiple sets of regulatory requirements as they relate to the various U.S. and international standards

Energy Storage Safety & Reliability – SNL's Approach

Sandia National Laboratories

Use S&T foundational capabilities to attack the **key science questions** in Energy Storage Safety and Reliability.

For example:

- How do additives in Li-ion batteries modify the SEI layer to increase the life of batteries?
- Commercial batteries must degrade slower than 0.02% per cycle. How does one measure and then predict this is large systems?
- How does strain induced by packaging, and cycling of cells, impact particle cohesion in the anode and cathode and ultimate lifetimes?
- What are critical flaws and the probability that those flaws will cause catastrophic failure?
- How are exothermal processes, i.e. fires, extinguished so that they will not reignite and will also not result in potentially hazardous conditions for the first responder?

Safety and Reliability Key Industry Challenges

How is *reliability* tested?

- No commonly accepted accelerated aging tests – can't wait 10 years for test results
- The cost to testing statistically significant number of systems is often too high?

How can the reliability of a new system be predicted and then optimized during development?

How can systems be demonstrated or certified to be *safe*?

- How can large systems (>1MWh) be tested, as they can't be destructively tested? **[this is the NW problem in a world without nuclear testing]**
- What are the relevant safety tests *and their underlying physical processes*?

How can systems be designed safe?

Safety and Reliability: Built upon a science foundation

Sandia National Laboratories

What can go wrong?
How can we prevent it?
What if it fails anyway?

What are the mechanisms that cause de

- How do we measure them?
- How do we model them?

How can we predict reliability and design against degradation or failure?

What is the reliability in an abnormal envir

What can go wrong?
How can we prevent it?
What if it fails anyway?

What are the failure modes that lead to un
(safety issues)?

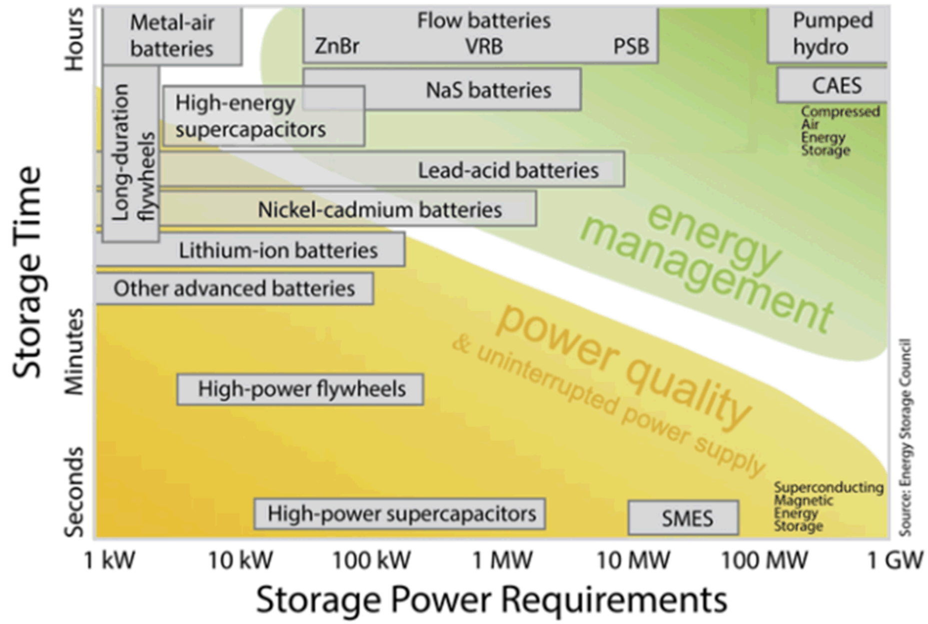
How can we predict and eliminate or minimize safety concerns?

What is the safety in an abnormal environment (fire, impact, crush)?

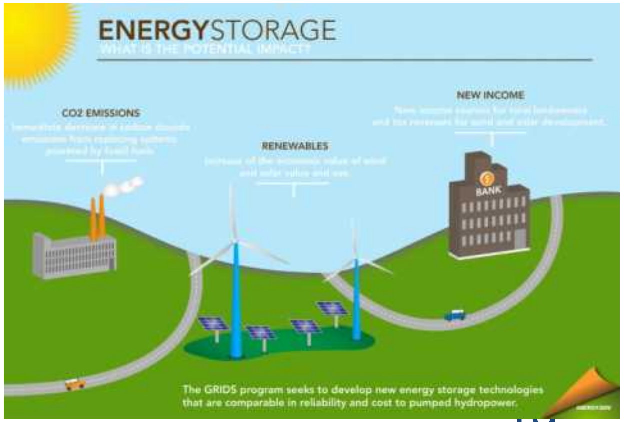
Stationary Energy Storage Technologies

Sandia National Laboratories

- Wide ranging applications
  - Energy applications
  - Power applications
- Widely varying demands
- Wide range of technology options
  - Batteries
  - Capacitors
  - Flywheels
  - Compressed Air (CAES)
  - Pumped Hydro
  - Superconducting Magnetic ES (SMES)
  - We include several beyond conventional thinking:
    - *Thermal*
    - *Fuel Cells, chemical storage (e.g. H_2)*



Source: Energy Storage Council



Back Up Slides

Path Forward from Workshop

1. Develop and issue the *DOE OE Strategic Plan for Energy Storage Safety.*

2. Collect, organize and disseminate information on codes, standards, regulations and best practices for energy storage safety.

3. Develop and implement process to continually engage the community.
   - Workshops
   - On-line resources (Forums, databases, etc.)

Validation Techniques

Gap Areas

- Battery Technologies are more diverse than EV
  - Testing must be more dynamic for growing diversity of technology
- Little information available on performance of additives in large capacity li-ion cells under actual use conditions

Validation Techniques

Plans moving forward

-
- R&D investigation into identifying equivalencies of battery to fuel or other studied materials

6.0 Incident Preparedness

Plans Moving Forward

- Technology-independent standard for ESS integration into a utility or a stand-alone grid must be developed
- New technologies such as grid-scale energy storage should be fully written into CSR
- Development of specialized equipment that fire services can incorporate for electrical incidents

7.0 Safety Documentation

Gaps Identified

- Many standards and protocols have not been codified
- Standards that are not mandatory may have legal implications
  - Cases of negligence when standards may be entered into evidence

7.0 Safety Documentation

Plans Moving Forward

- Market participants in energy storage sector must be prepared to address potential legal liabilities arising during a catastrophic accident
- National Fire Protection Association (NFPA) will continue to develop the National Electrical Code, a standard for the safe installation of electrical wiring and equipment