Energy Storage Systems Overview – Fundamentals, Applications, Safety Issues and Codes/Standards

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Purpose and Expected Outcome

Purpose – To provide an overview of energy storage (ES) technology tailored for those responsible for ensuring the safety of energy storage system (ESS) installations

Expected Outcomes

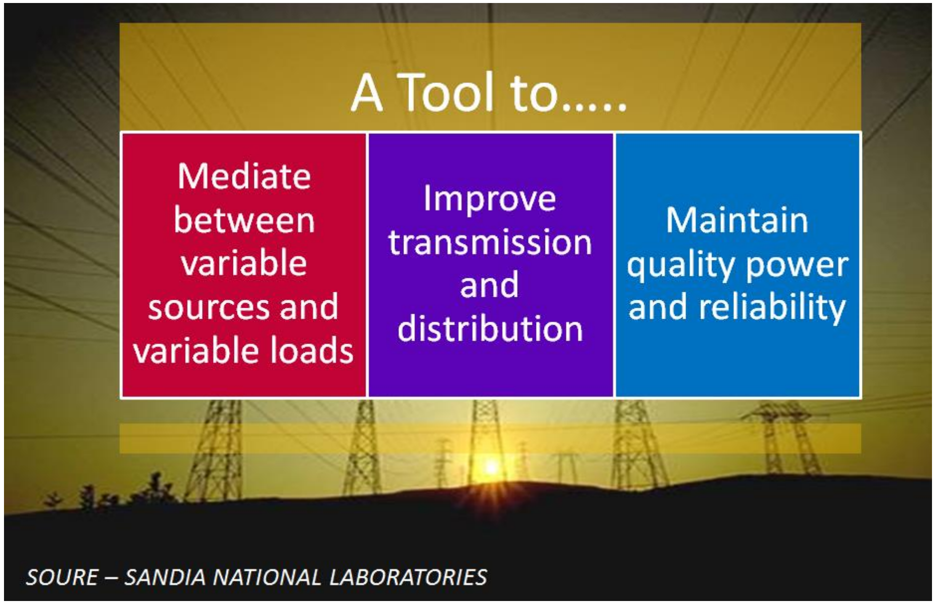
- A basic understanding of energy storage technologies – FUNDAMENTALS
- Knowledge about the various applications for energy storage in the built environment – APPLICATIONS
- Identification of safety-related issues associated with energy storage systems – SAFETY ISSUES
- Identification of the standards and codes applicable to energy storage systems – CODES AND STANDARDS

Source - Southern California Edison

Energy Storage Fundamentals

An overview of the different types of ESS and how they operate

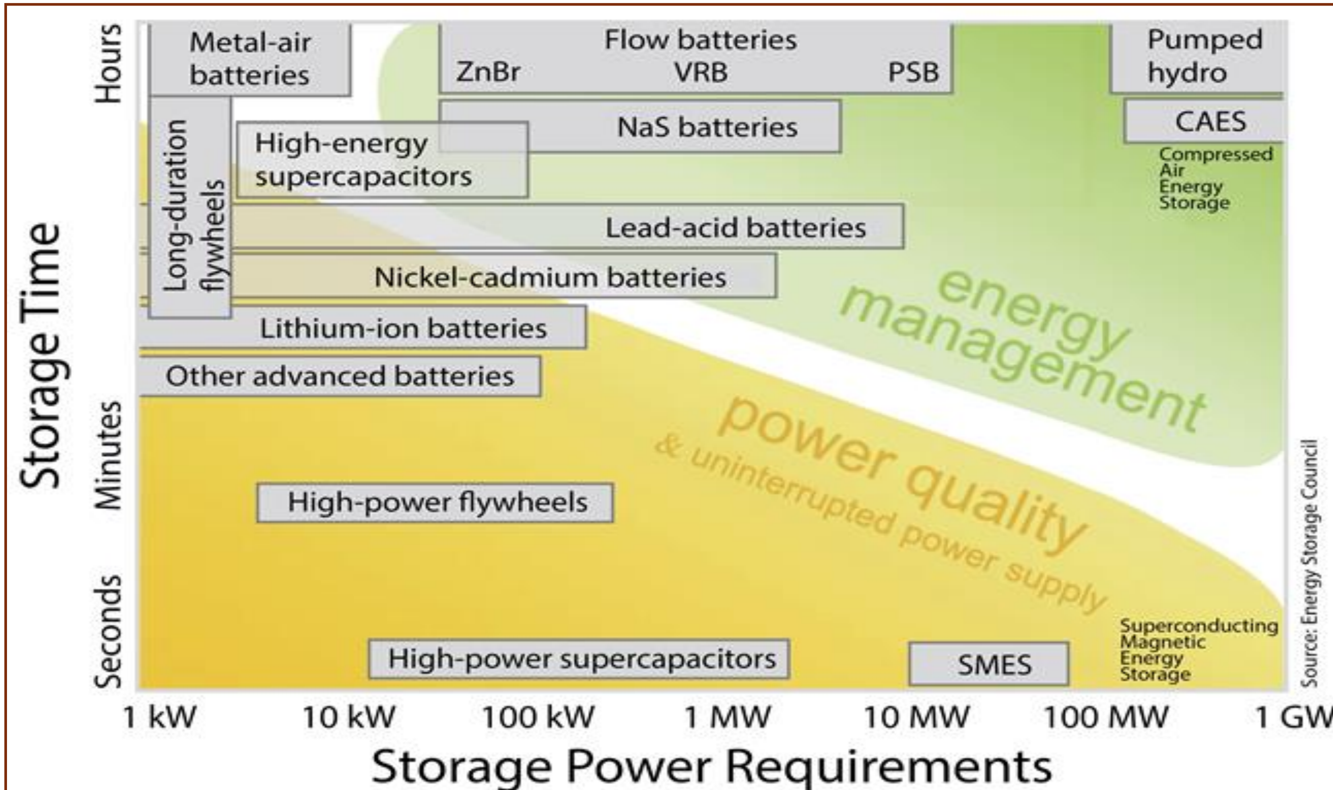
- Electro-chemical
- Thermal
- Mechanical



Energy Storage Technologies

Energy – long discharges (min to hr) ala a "10K"

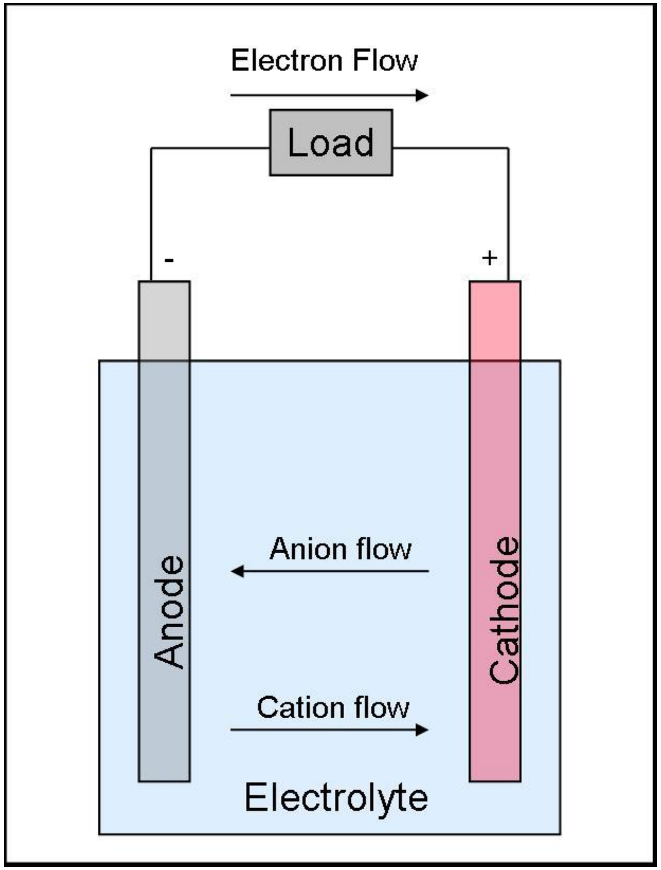
- Pumped Hydro
- Compressed Air Energy Storage (CAES)
- Electrical Storage (Batteries)
- Sodium Sulfur (NaS)
  - Flow Batteries
  - Lead Acid
  - Advanced Lead Carbon
  - Lithium Ion
- Flywheels
- Electrochemical Capacitors



Power – short discharges (sec to min) ala a "100 m sprint"

Battery Basics

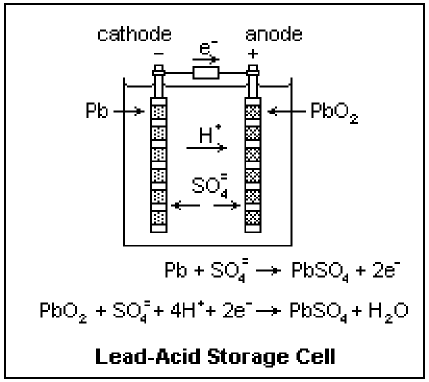
- Batteries store energy chemically and through electrochemical reactions produce electricity.
- The presence of an anode, cathode, and electrolyte provides the basis for storing energy and satisfying energy loads.
- There are a wide range of battery types, sizes, designs, operating temperatures, control mechanisms, and chemistries.
- Beyond storing energy, all batteries are not created equal.

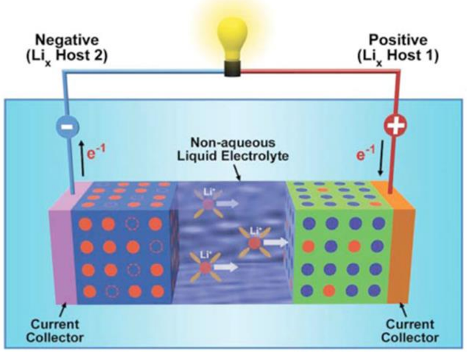


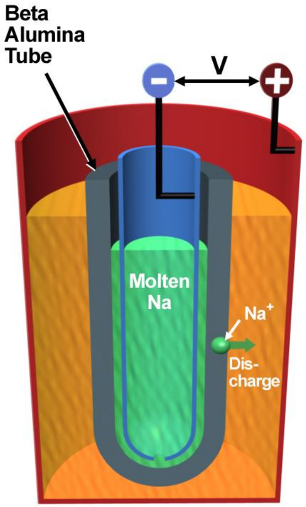
Source – Kamath, EPRI ES Technology Overview

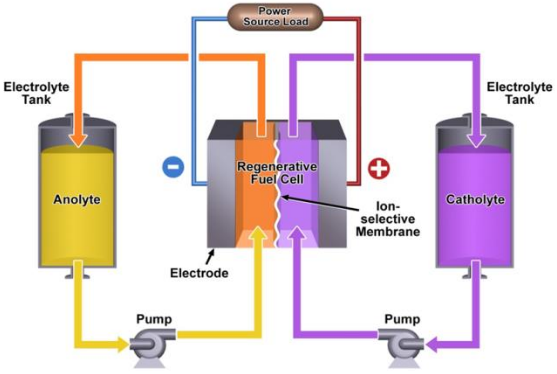
Electro-chemical ESS Types

- Lead-Acid (LA) Batteries – two electrodes (one lead and one lead-dioxide) immersed in sulfuric acid
- Nickel-Cadmium (Ni-Cd) Batteries – two electrodes (one nickel and one cadmium) immersed in an aqueous potassium-hydroxide electrolyte
- Lithium-Ion (Li-ion) Batteries – two electrodes (varying chemistries)
- Na-Metal Batteries – consisting of a molten sodium anode and β"-Al_2O_3 solid electrolyte
- Redox Flow Batteries – two electrolytes are stored in separate tanks and are pumped to a fuel cell when energy is desired



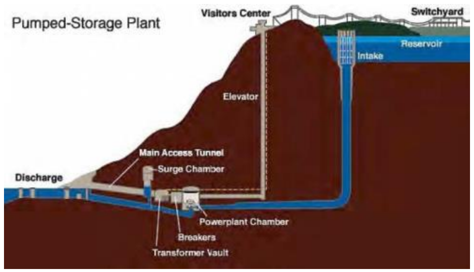






Thermal and Mechanical ESS

- Pumped hydroelectric storage – energy is stored in the form of a water reservoir at a higher altitude that is released through turbines to a lower reservoir and is pumped back up to the higher reservoir during periods of low energy demand.



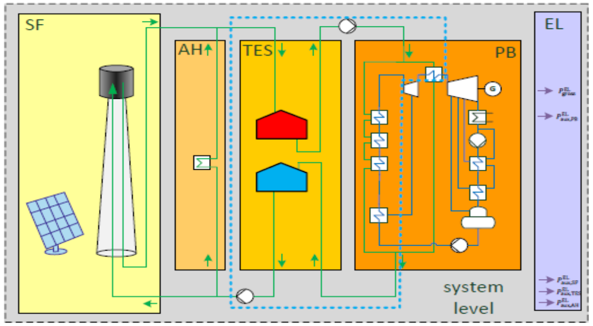
DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA

- Flywheels – a spinning mass in its center that is driven by a motor. When energy is needed, the spinning force drives a turbine, which slows the rate of rotation. The system is recharged by a motor.

SAND2015-10759 “*Recommended Practices for the Safe Design and Operation of Flywheels*” http://www.sandia.gov/ess/publications/SAND2015-10759.pdf

- Molten salt – formulations composed of mixtures of nitrates or nitrites that can store heat and then use that heat to power turbines to generate electric power.

Molten Salt Tower



Molten-Salt Power Tower SubSystems:
SF = Solar Field
AH = Auxiliary Heater
TES = Thermal Energy Storage
PB = Power Block
EL = Electric Switchyard

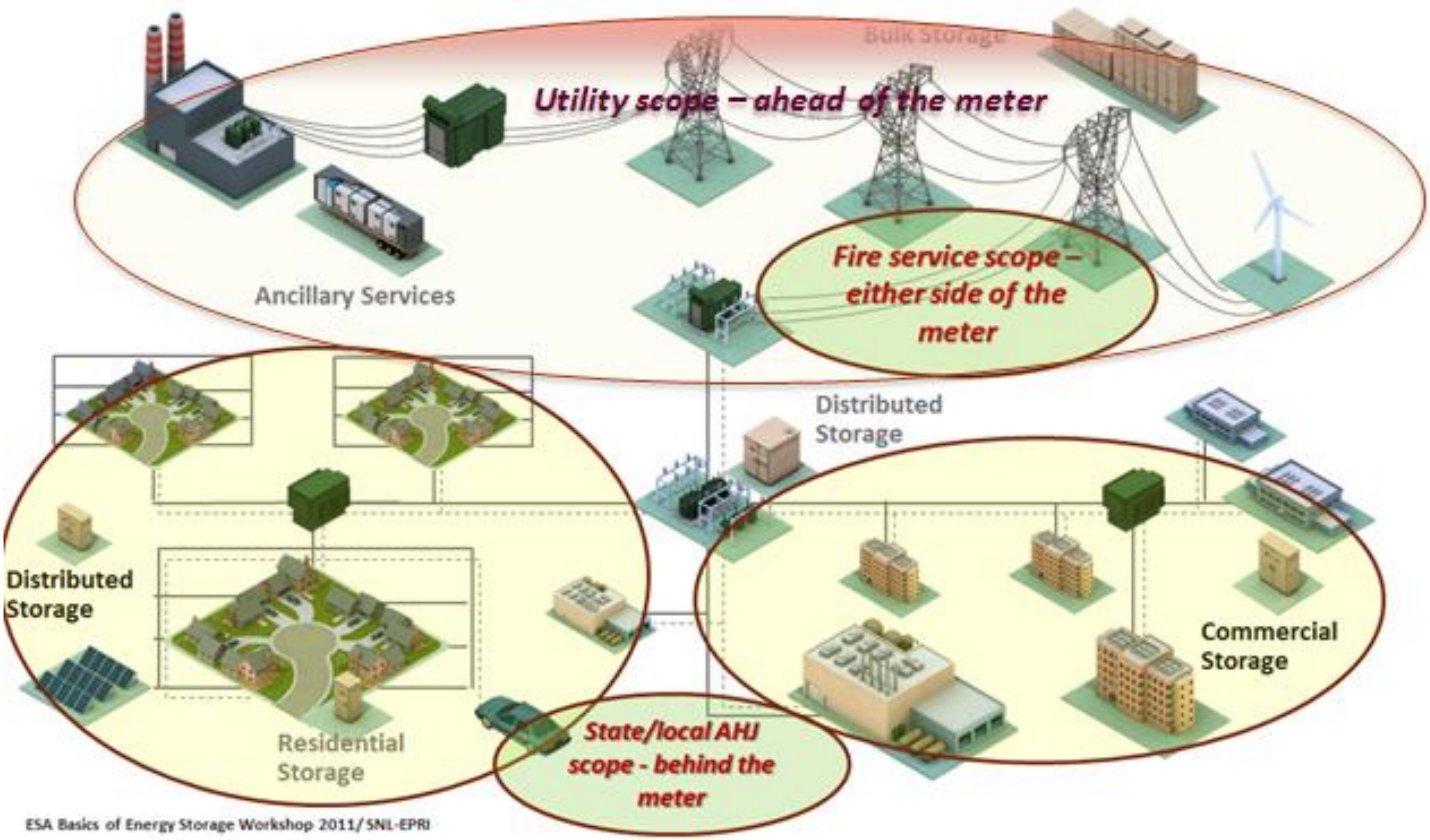
Blue dashed box indicates the systems covered in this guideline.
Graphic courtesy SolarPACES Guideline for Bankable STE Yield Assessment

Key Takeaways

- There are a wide range of energy storage technologies today and there will be more in the future.
- Energy, economic, and environmental issues are creating a demand for energy storage, and policy initiatives are accelerating that demand.
- Energy storage includes batteries but also thermal and mechanical technologies.
- Beyond storing energy, all batteries are not the same.
- The wide range of battery types, chemistries, sizes, designs, control mechanisms, operating temperatures, and potential locations suggest an almost infinite number of possibilities.
- Just when you think you have all the information you need there will be new energy storage technologies to keep you engaged.

Applications of Energy Storage Systems

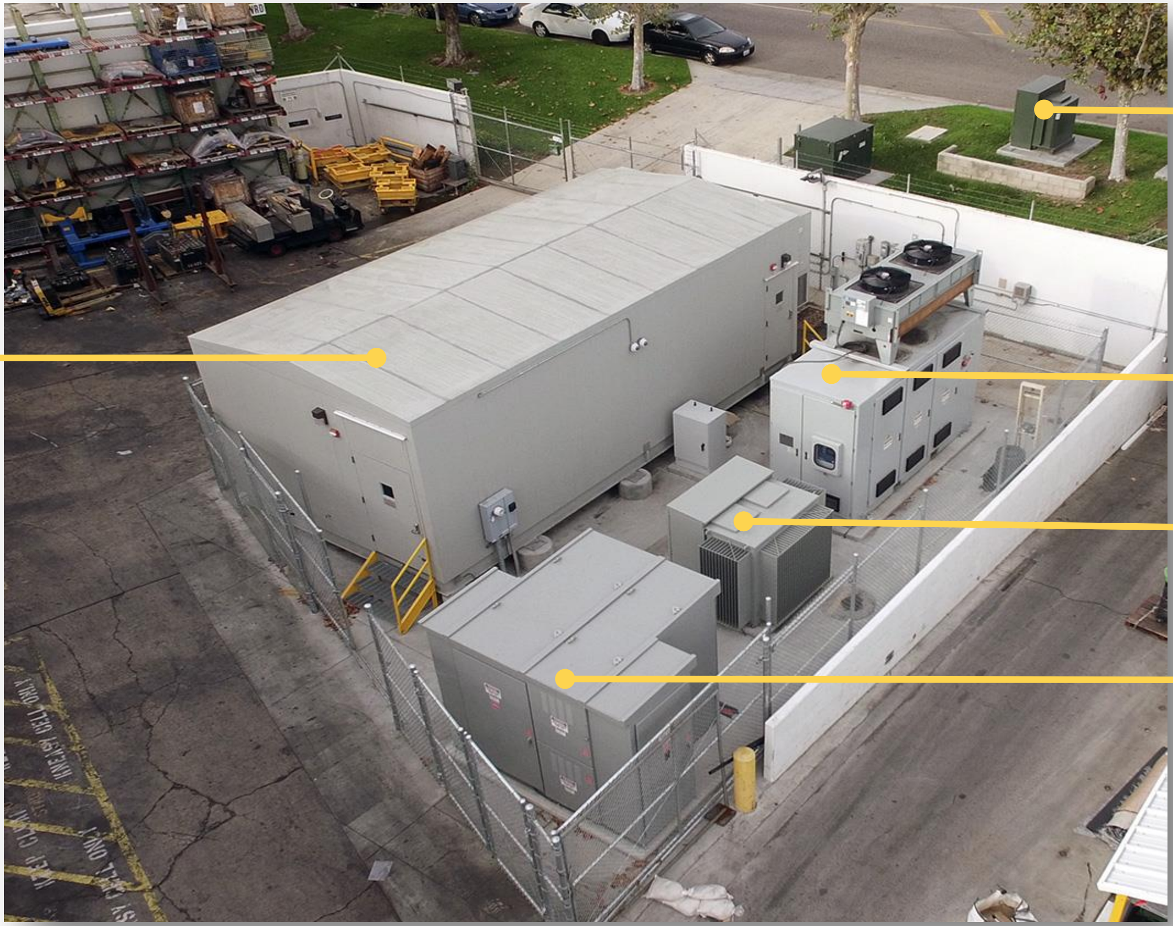
An overview of where and how ESS are being applied



ESA Basics of Energy Storage Workshop 2011/SNL-EPRI

APPLICATIONS

SCE DESI Site



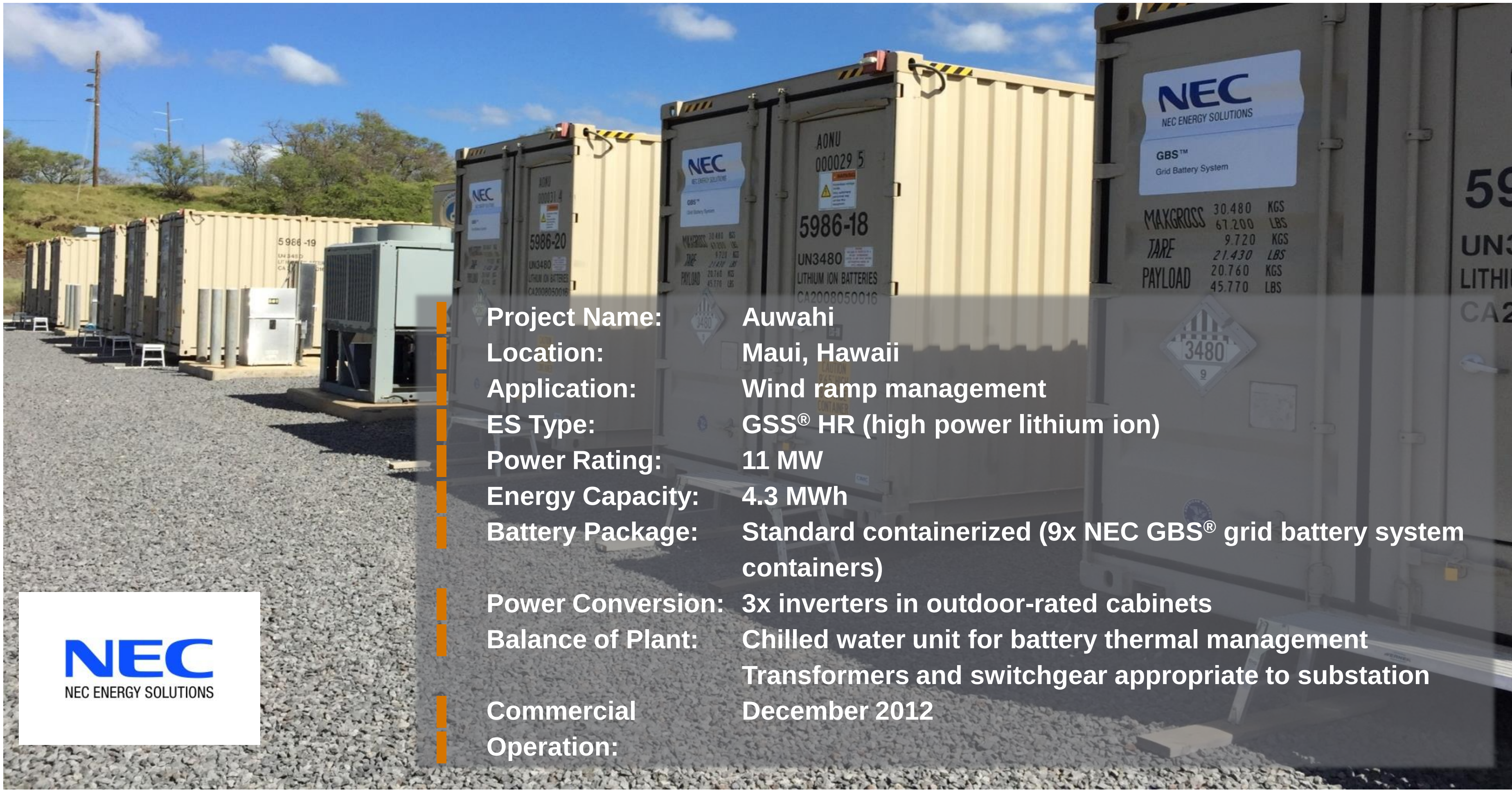
Source - Southern California Edison

SCE DESI ESS

- Key Components
  - Battery System
  - Power Conversion System (PCS)
  - Medium Voltage Transformer
  - Medium Voltage Switchgear and Protection

Source - Southern California Edison

Auwahi Wind Farm, HI



Project Name:	**Auwahi**
Location:	**Maui, Hawaii**
Application:	**Wind ramp management**
ES Type:	**GSS® HR (high power lithium ion)**
Power Rating:	**11 MW**
Energy Capacity:	**4.3 MWh**
Battery Package:	**Standard containerized (9x NEC GBS® grid battery system containers)**
Power Conversion:	**3x inverters in outdoor-rated cabinets**
Balance of Plant:	**Chilled water unit for battery thermal management Transformers and switchgear appropriate to substation**
Commercial Operation:	**December 2012**

NEC
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APPLICATIONS

ESS Application Examples

- Xtreme Power ESS at a Castle & Cooke – 1.5 MW DC/1.2 MW AC advanced lead-acid battery that doubles the output of the solar system and control the ramp rate.

- ZZB Energy Corporation at Hawaiian Properties – 60 kW zinc bromine flow battery that is part of an elevator system in an R-2 building that uses grid power and power from a 20 kW PV array.

- Iron Edison at Confidential – 48 kW nickel iron battery powered by a pole-mounted solar array.

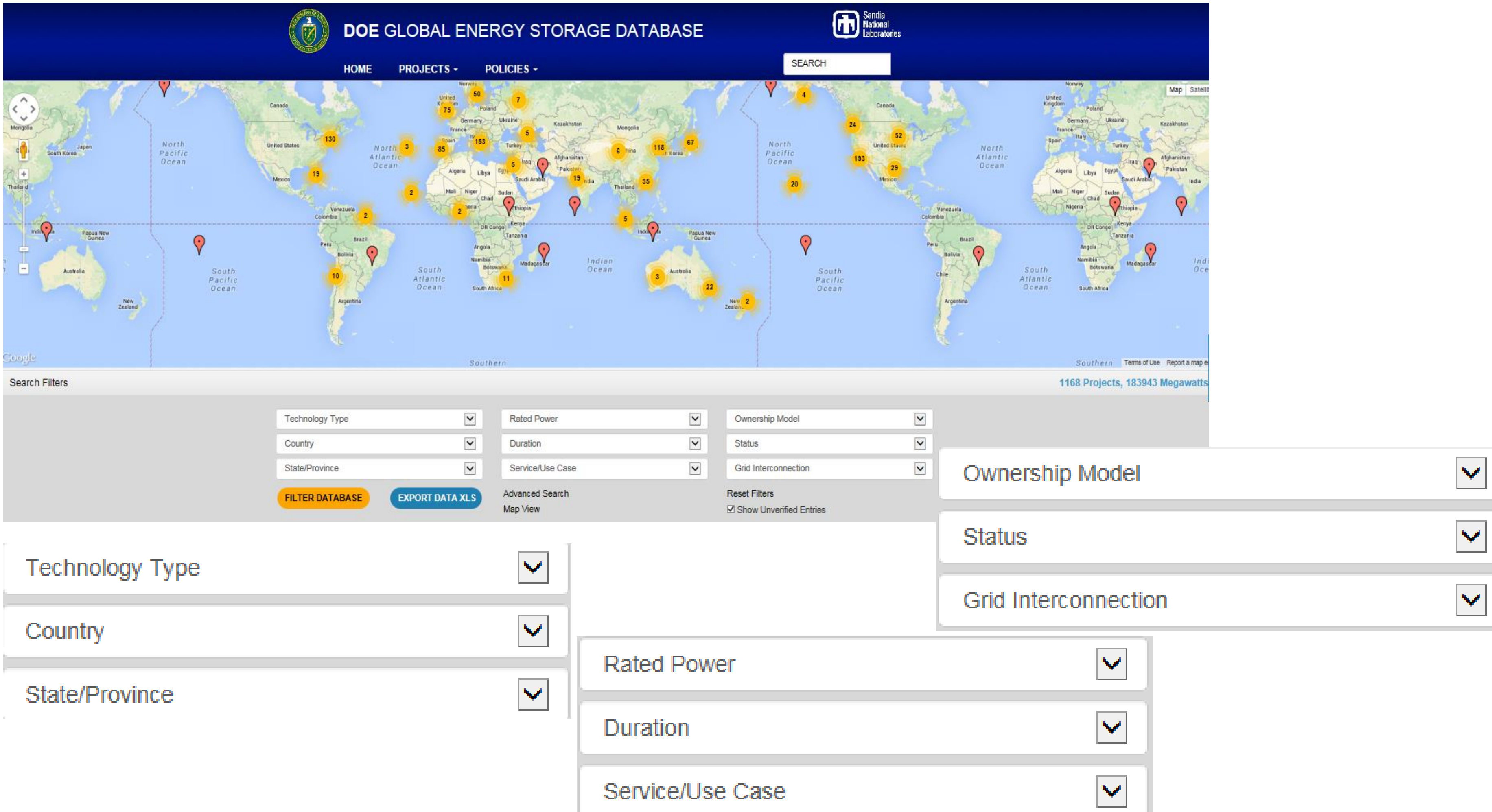
- Maxwell Technologies at Long Island RR – electro-chemical capacitor to provide voltage support to assist traction power system (capture and store energy produced by trains to help with acceleration).

- SAFT at Scripps Ranch Community Center – 30 kW lithium-ion ESS used for PV energy storage.

- Mitsubishi at Santa Clara Data Center – 1.5 kW electro-chemical VLRA applied as a UPS.

DOE ESS Database http://www.energystorageexchange.org/

Database of Applications



http://www.energystorageexchange.org/

Safety Issues

- Siting (location, loads, protection, egress/access, maximum quantities of chemicals, separation, etc.).
- New versus existing systems and new versus existing building/facility applications.
- Stationary, mobile, and portable systems vary in application and use.
- Ventilation, thermal management, exhausts (when necessary, flow rates, how controlled, etc.).
- Interconnection with other systems (energy sources, communications, controls, etc.).
- Fire protection (detection, suppression, containment, smoke removal, etc.).
- Containment of fluids (from the ESS and from incident response).
- Signage, markings, and security.
- Identification of the applicable authorities having jurisdiction (utility, federal, state or local government, etc.).

Safety Takeaways

- Energy storage technologies may or may not be similar to other technologies; the system and its component parts must be validated as being safe.
- The safety of an energy storage technology is also affected by the location in which it is installed and manner in which that installation is implemented.
- While there are a set number of safety issues, the manner in which they are addressed to ensure safety is significant due to the number of variables associated with the technologies and their relationship with the built environment.
- Safety does not stop when a new system is commissioned, and the safety issues remain relevant through operation, repair, or renewal of the system, any needed recommissioning, and finally through decommissioning.

Model Codes and Standards

- Model codes and standards in the aggregate address the design, construction, commissioning, rehabilitation, operation, maintenance, repair, and demolition of components of the built environment, such as buildings, facilities, products, systems, and equipment therein.
- Standards each have a very specific scope and where needed will reference other standards.
- Model codes reference standards.
- Regulations, rules, laws, specifications, tariffs, contracts, and other means are the vehicles by which those model codes and standards are adopted.
- When adopted, the model codes and standards must be satisfied subject to any penalties associated with noncompliance.

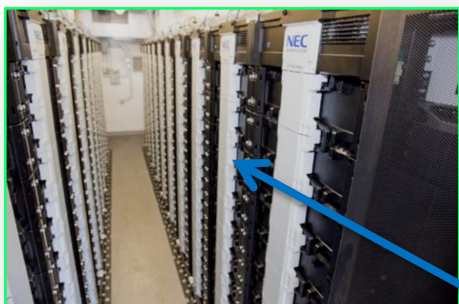
U.S. Model Codes and Standards

Cover the built environment at large and that includes the ESS

Overarching CS

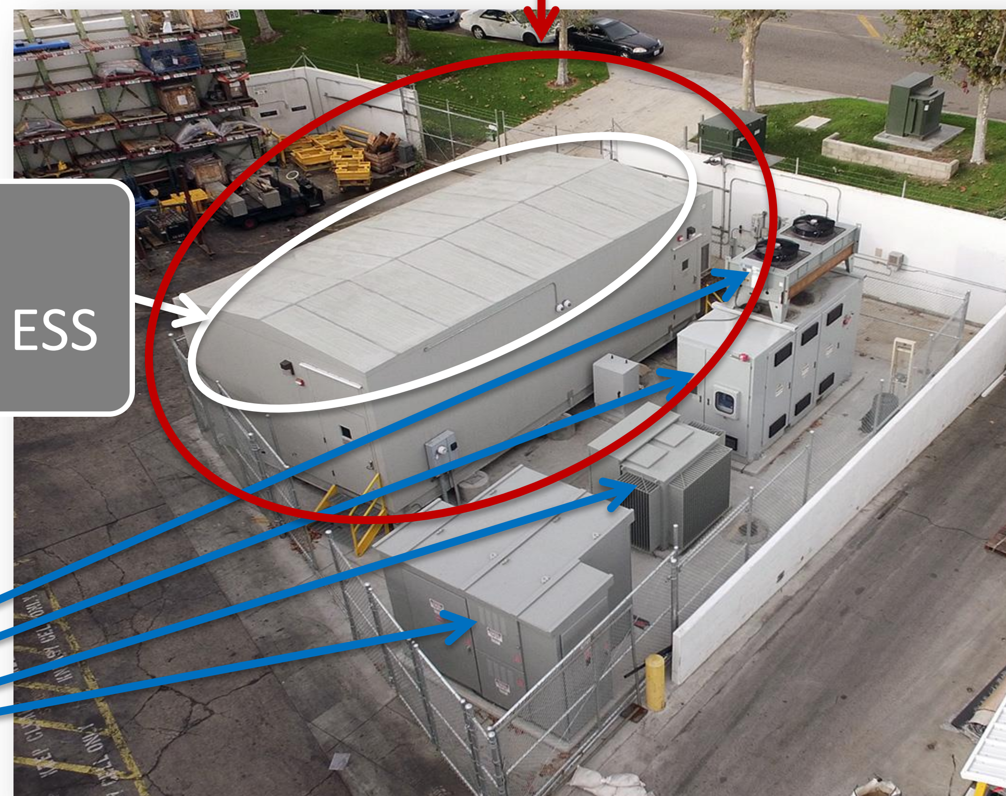
CS for ESS Installation

Address the installation of the ESS in relation to other systems and the built environment



CS for Complete ESS

The entire ESS in the aggregate



CS for ESS Components

Components associated with or part of the ESS

U.S. Model Codes and Standards

Overarching CS

- NFPA
  - 1-15 – Fire Code
  - 70-17 – National Electric Code
  - 5000-15 – Building Code

- ICC
  - 2015 International Fire Code
  - 2015 International Residential Code
  - 2015 International Mechanical Code
  - 2015 International Building Code

- IEEE
  - C2-17 – National Electrical Safety Code

U.S. Model Codes and Standards

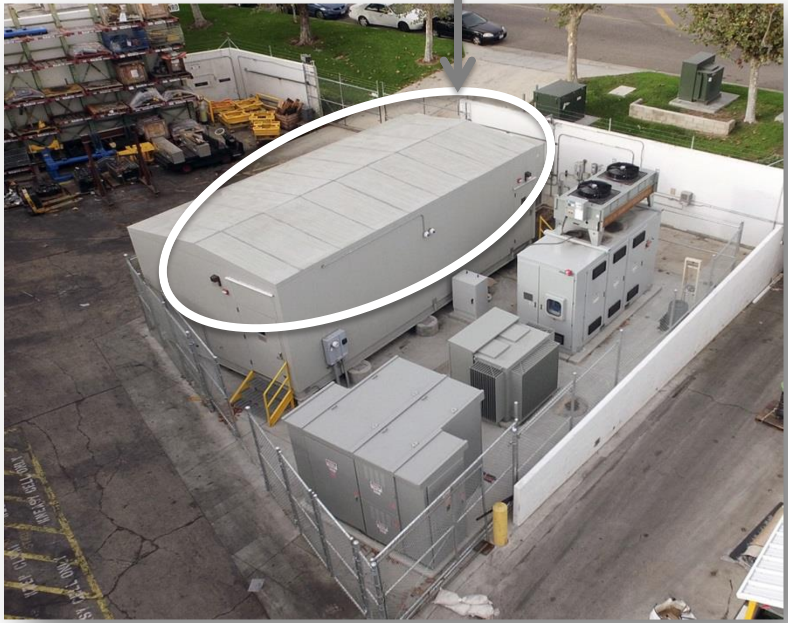
CS for ESS Installation

- **NFPA**
  - **855-X – Standard for the Installation of Stationary Energy Storage Systems**
- **NECA**
  - **416-17 – Recommended Practice for Installing Stored Energy Systems**
- **IEEE**
  - **1653-2012 – Guide for Ventilation and Thermal Management of Batteries for Stationary Applications**
  - **P1578 Recommended Practice for Stationary Battery Electrolyte Spill Containment**

U.S. Model Codes and Standards

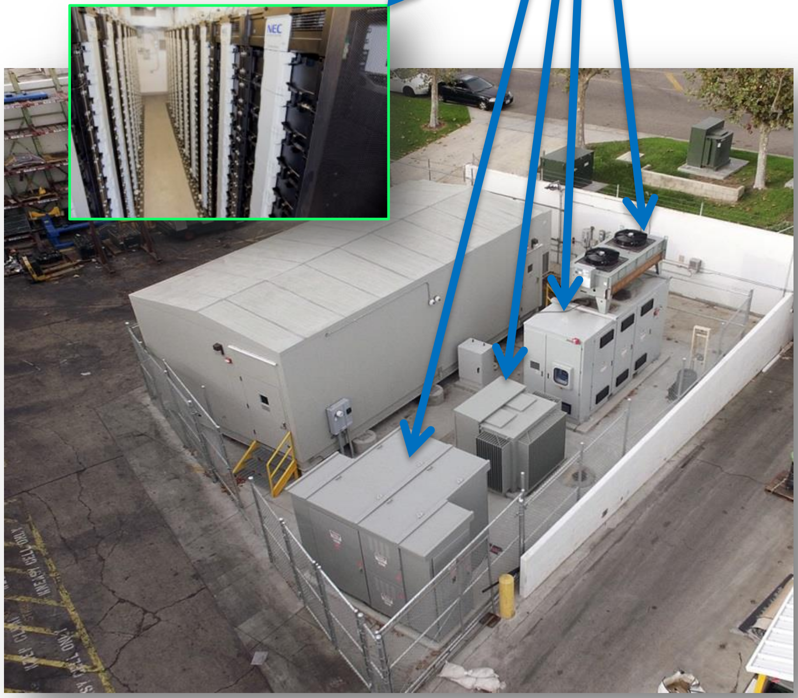
- **ASME**
  - TES-1 – Safety Standard for Thermal Energy Storage Systems
- **NFPA**
  - 791-14 – Recommended Practice and Procedures for Unlabeled Electrical Equipment
- **UL**
  - 9540 – Safety of ES Systems and Equipment

CS for Complete ESS



U.S. Model Codes and Standards

CS for ESS Components



- **UL**
  - **810A – Electrochemical Capacitors**
  - **1642 – Standard for Lithium Batteries**
  - **1741 – Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources**
  - **1973 – Batteries for Use in LER and Stationary Applications**
  - **1974 – Evaluation of Batteries for Repurposing**

- **CSA**
  - **CSA C22.2 No. 107.1-2016 – Power Conversion Equipment**

- **IEEE**
  - **P1697.1 Guide for the Characterization and Evaluation of Lithium-Based Batteries in Stationary Applications**

  - **IEEE P1679.2 Guide for the Characterization and Evaluation of Sodium-Beta Batteries in Stationary Applications**

U.S. Model Codes and Standards

Ongoing information about model codes and standards is provided through….

- ✓ **Regular webinars involving the relevant standards development organizations**
- ✓ **A monthly codes and standards report**

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DOE OE Energy Storage Systems Safety Roadmap Focus on Codes and Standards – August 2017

The goal of the DOE OE ESS Safety Roadmap[1] is to *foster confidence in the safety and reliability of energy storage systems.*

There are three interrelated objectives to support the realization of that goal: research, codes and standards and communication/coordination. The objective focused on codes and standards is…..

> *To apply research and development to support efforts that are focused on ensuring that codes and standards are available to enable the safe implementation of energy storage systems in a comprehensive, non-discriminatory and science-based manner.*

The following activities are intended to support that objective and realization of the goal:

a. Review and assess codes and standards which affect the design, installation, and operation of ESS systems.
b. Identify gaps in knowledge that require research and analysis that can serve as a basis for criteria in those codes and standards.
c. Identify areas in codes and standards that are potentially in need of revision or enhancement and can benefit from activities conducted under research and development.
d. Develop input for new or revisions to existing codes and standards through individual stakeholders, facilitated task forces, or through laboratory staff supporting these efforts.

What's Noteworthy?

The opportunity to provide public input on NFPA 855 will close October 4, 2017 see www.nfpa.org/855next for more information.

IEEE has initiated the development of a "Recommended Practice for Stationary Battery Electrolyte Spill Containment" (IEEE P1578)

Additional requirements for PV Rapid Shutdown Equipment and Systems are being proposed to UL 1741. STP ballots and all comments are due October 2, 2017.

Inclusion of information related to standards being developed by NEMA

The purpose of this document is to support the above activities by providing information on current and upcoming efforts being conducted by U.S. standards developing organizations (SDOs) and other entities that are focused on energy storage system safety (IEC efforts are listed on the last page).

For the purposes of presenting this information the model codes, standards and other documents (guidelines, recommended practices, etc.) covered are classified in relation to their scope relative to energy storage systems from the 'macro to the micro' as indicated below, noting that more 'macro' documents are likely to adopt by reference more 'micro' documents. ***Changes in current activity from the prior edition are shown in bold italics.***

Overarching CS — CS for ESS Installation — CS for Complete ESS — CS for ESS Components

1) Overarching Codes and Standards– the built environment at large that includes but is not limited to energy storage systems.
2) Codes and Standards for ESS Installations– the installation of the energy storage system in relation to other systems and parts of the built environment.
3) Codes and Standards for a Complete ESS– the entire energy storage system in the aggregate.
4) Codes and Standards for ESS Components– components associated with the energy storage system.

[1] DOE OE Energy Storage Systems Safety Roadmap, PNNL-SA-126115 I SAND2017-5140 R

PNNL-SA-128707/SAND2017-9147R

Energy Storage System Safety Roadmap Codes and Standards Update

Web Meeting

September 26, 2017

Sandia National Laboratories | U.S. DEPARTMENT OF ENERGY | Pacific Northwest NATIONAL LABORATORY

Key Takeaways

- Development and maintenance of U.S. model codes and standards is an ongoing process open to all interested parties and is facilitated by a number of standards development organizations.
- Advancements in energy storage technology and lessons learned from existing system installations will necessitate continual updating and enhancement of codes and standards.
- Once codes and standards are published there are a myriad of entities that will adopt and focus on ensuring compliance with those codes and standards.
- Participation by all relevant parties in the development, adoption, and implementation of codes and standards will help ensure energy storage technology can be deployed safety and in a timely less complicated manner.

Summary

- Energy storage technology development and deployment are dynamic and touch on a number of critical safety issues.
- Due to energy, economic, and environmental influences a significant increase in the application of energy storage systems can be expected in the near term and beyond.
- Traditional roles determined based on the location of a technology relative to the electric meter are likely to become more complex.
- While safety issues have been and are being identified, the information necessary to define how to address each one for each technology application many not exist, thereby driving the need for additional research.
- Codes and standards are updated regularly and are available for adoption to help ensure system safety as designed, installed, and during/after safety related incidents.
- Gaps between what we know and can prescribe in codes and standards can be filled through testing, failure modes and effects analysis, hazard mitigation guidance, and collaboration by all interested parties to address safety issues.

Website

ESS Safety WORKING GROUP

Research & Development
- Research & Development Overview
- Safety Research Priorities
- Finding Research Collaborators
- Collaborative Research Publications

Codes & Standards
- Overview of Codes and Standards
- Status of Codes and Standards
- Adoption of Codes and Standards
- Documenting and Verifying Compliance

Task Forces
- Large Scale ESS Fire Performance Testing Protocol

Publications

External Resources

For more information about Energy Storage Safety efforts visit our website

The goal of the energy storage safety effort is to ***"Foster confidence in the safety and reliability of energy storage systems."***

http://www.sandia.gov/energystoragesafety/

Acknowledgment

Dr. Imre Gyuk, DOE-Office of Electricity Delivery and Energy Reliability

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Thanks

For more information about DOE OE ESS safety activities contact

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