SAND2017-4428C

Energy Storage Systems - Overview of the Technology and Safety Related Issues

U.S. DEPARTMENT OF ENERGY

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Purpose and Expected Outcome

Purpose – To introduce new and emerging energy storage technologies, safety related issues and how those issues are being addressed

Expected Outcomes

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

Source - Southern California Edison

Energy Storage Fundamentals

FUNDAMENTALS

The purpose of this section of the presentation is to provide an overview of the **market drivers for energy storage** and **basic functions of the different types of energy storage systems**

Market Forces

DRIVERS

- Energy supply does not exactly track with or match demand
- Energy produced from renewable, waste heat and other energy sources may not be acceptable for its intended use
- Energy cost may change between peak and off peak periods making it advantageous to 'buy low and use high'
- More traditional sources of energy may have periods when they are not readily available
- A desire for consumers to move 'off the grid'
- A need for utilities to more effectively operate and improve the grid

Policy Incentives and Mandates

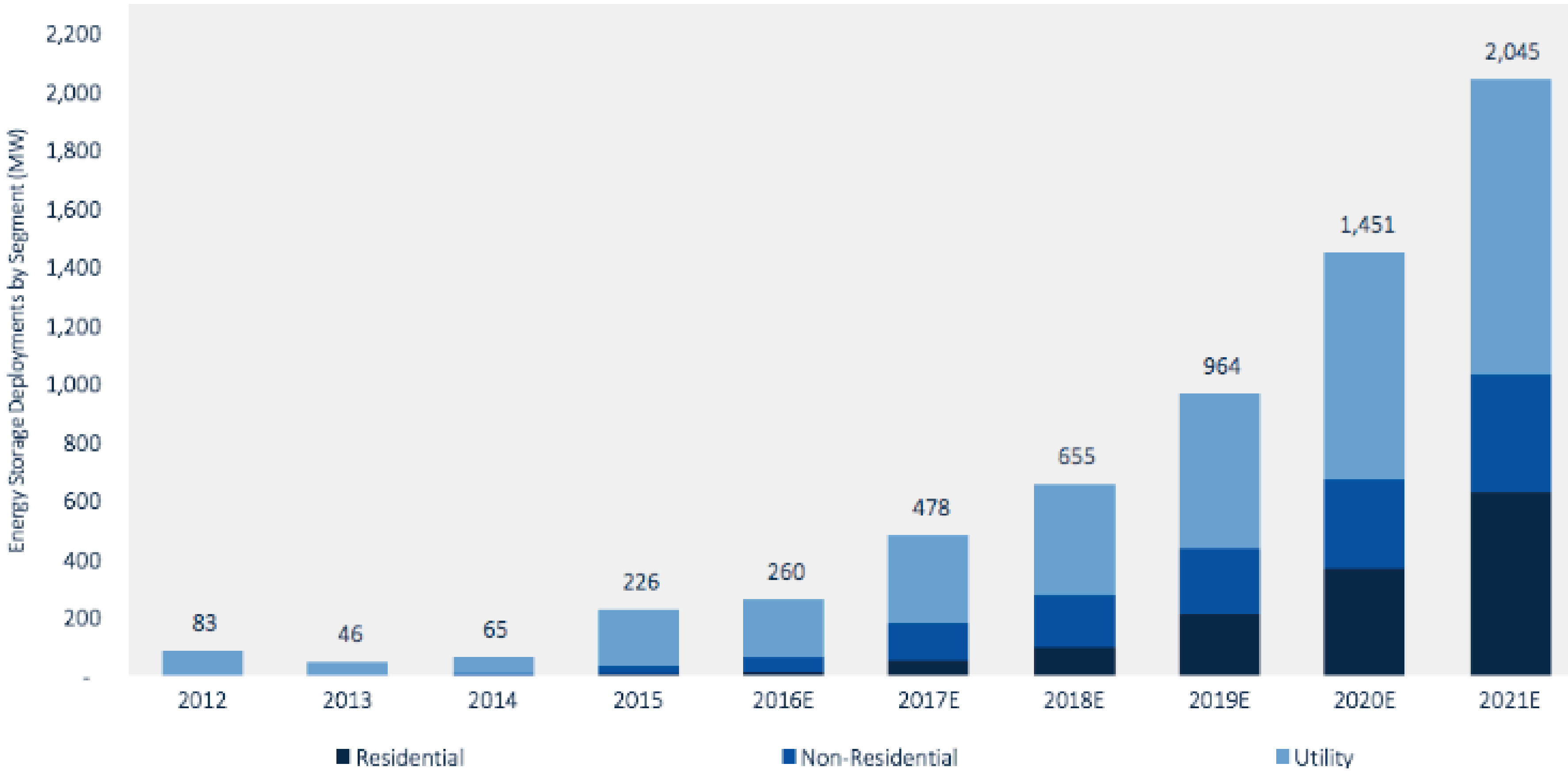
DRIVERS

The demand for energy storage can be accelerated through policy initiatives and incentives that provide needed support until the market matures

- Install 1.4 gigawatts of storage capacity in New York City
- CA PUC initiative
- MA storage requirement
- OR storage requirement

Energy Storage – Projected Deployment

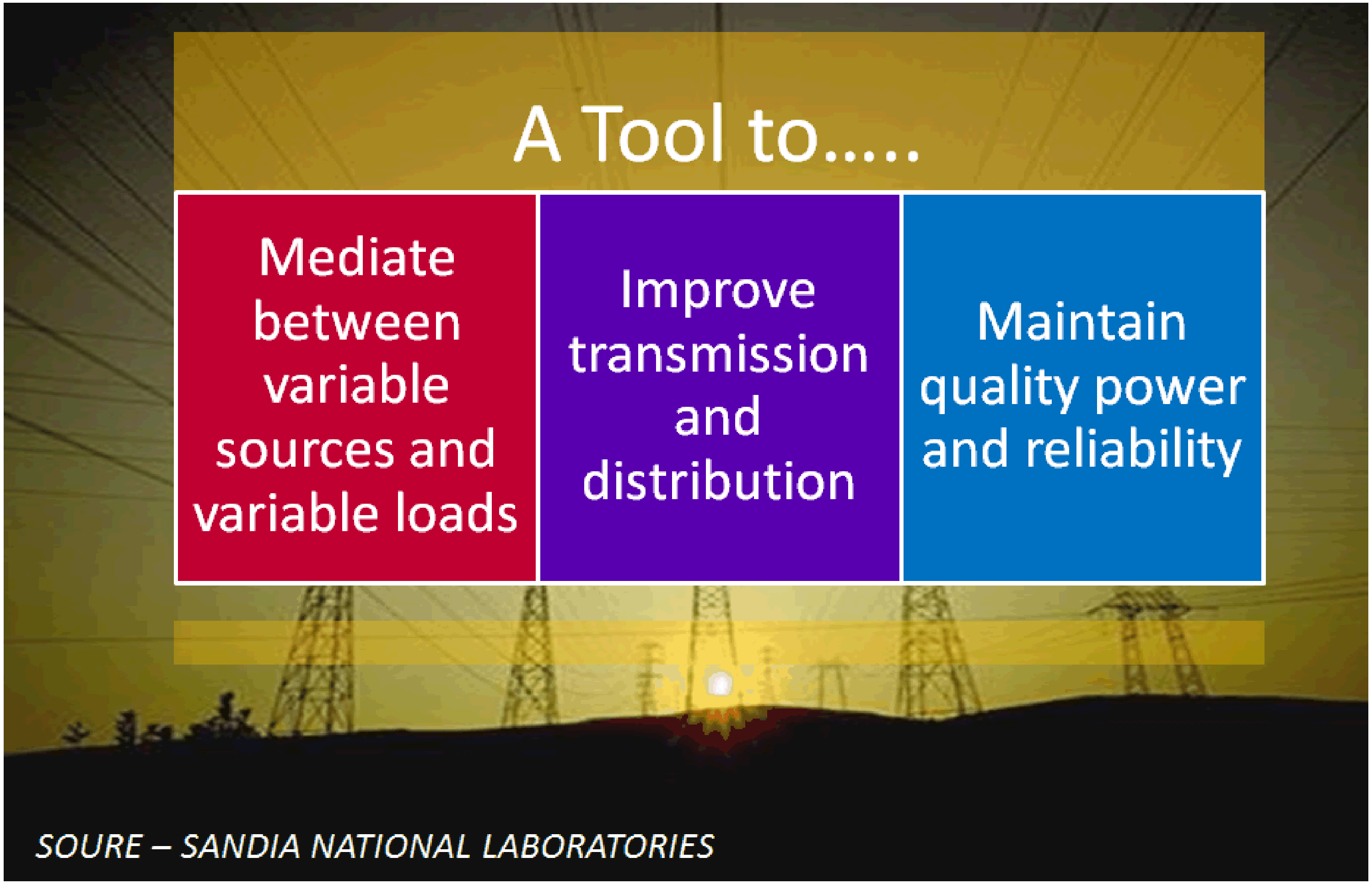
DRIVERS



Source – Green Tech Media Inc.

What is Energy Storage?

BASICS

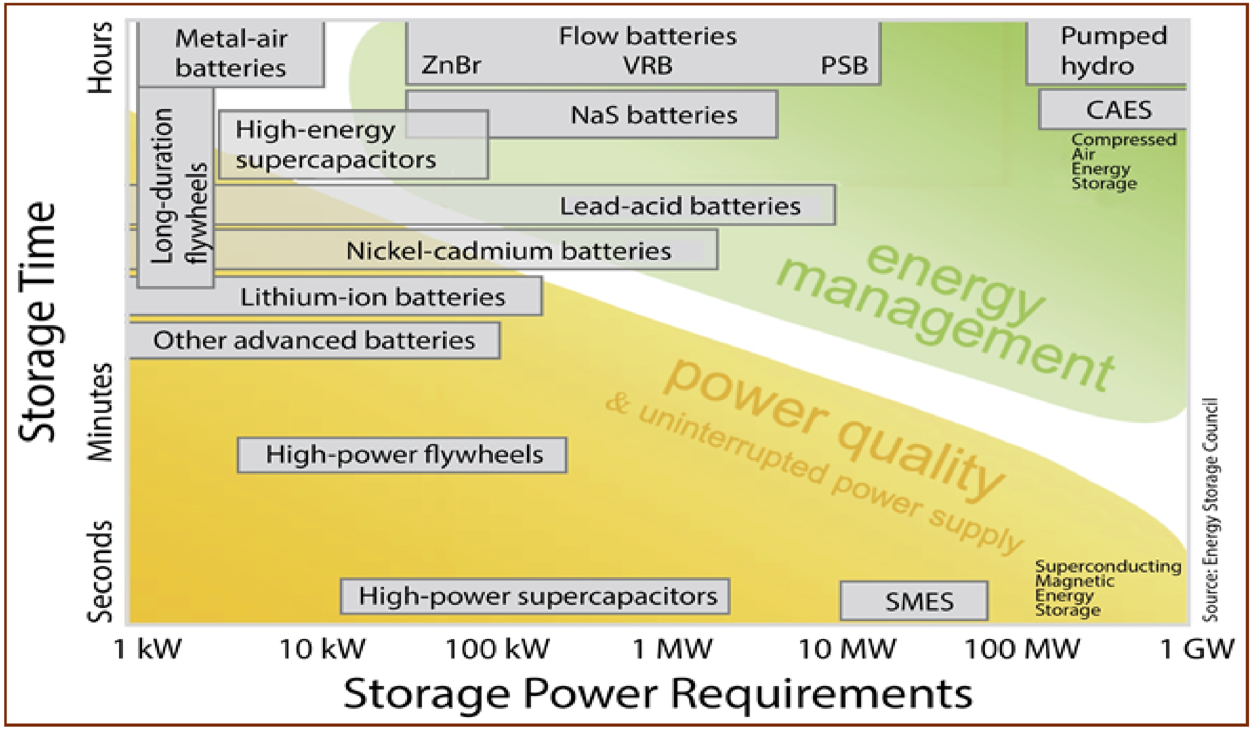


Energy Storage Technologies

BASICS

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

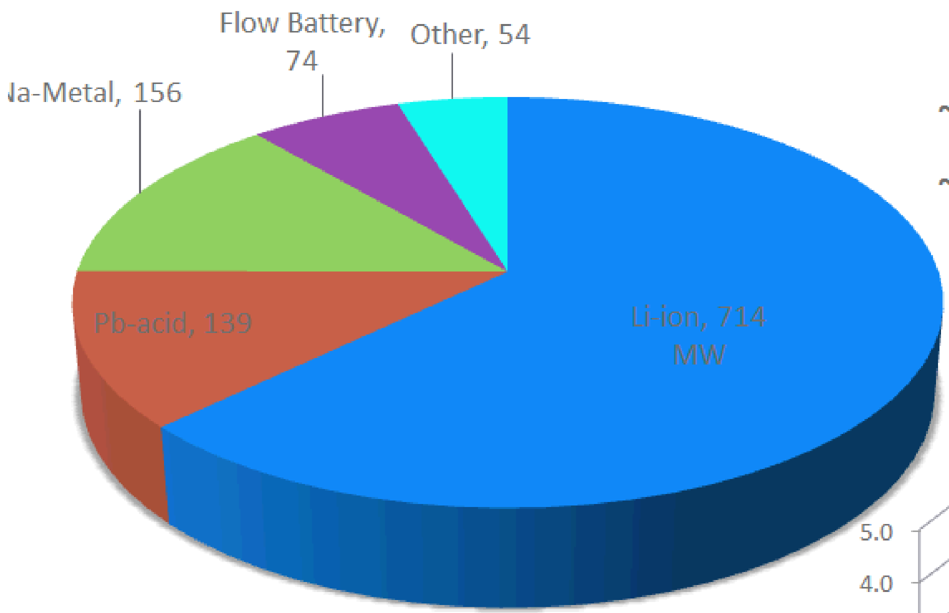
- Pumped Hydro
- Compressed Air Energy Storage (CAES)
- Electrical Storage (Batteries)
  - Sodium Sulfur (NaS)
  - Flow Batteries
  - Lead Acid
  - Advanced Lead Carbon
  - Lithium Ion
- Flywheels
- Electrochemical Capacitors



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

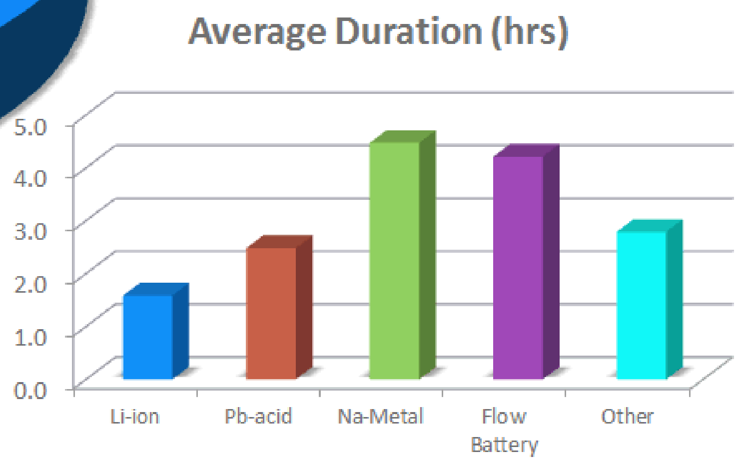
Global Energy Storage Deployments (Battery Only)

BASICS



~ 1.1 GW of Battery Energy Storage

~110 GW of Pumped Hydro

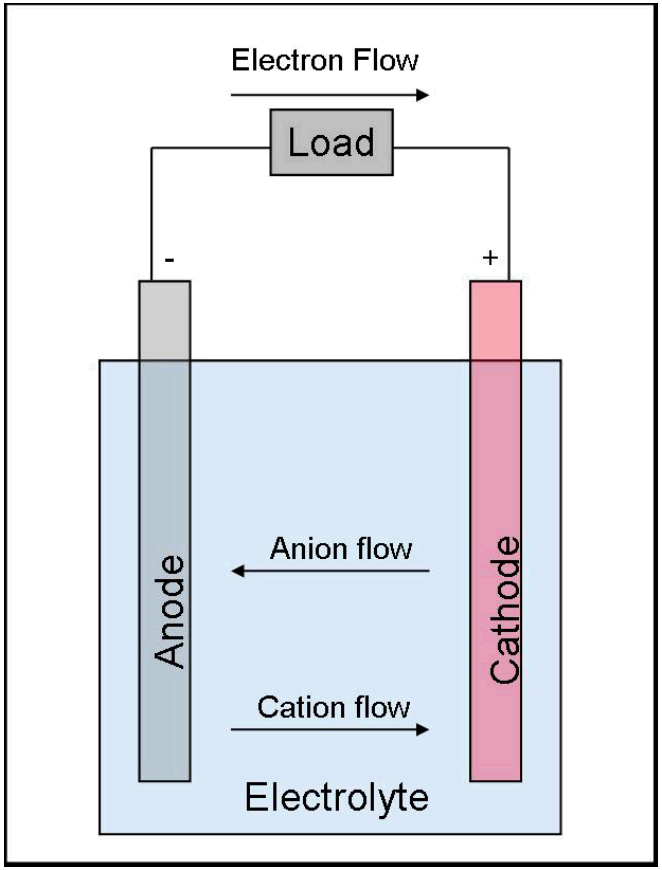


Source: *DOE Global Energy Storage Database http://www.energystorageexchange.org/ July 2015*

Battery Basics

BASICS

- Batteries store energy chemically and through electrochemical reactions produce electricity
- The presence of an anode and 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

Battery Terminology

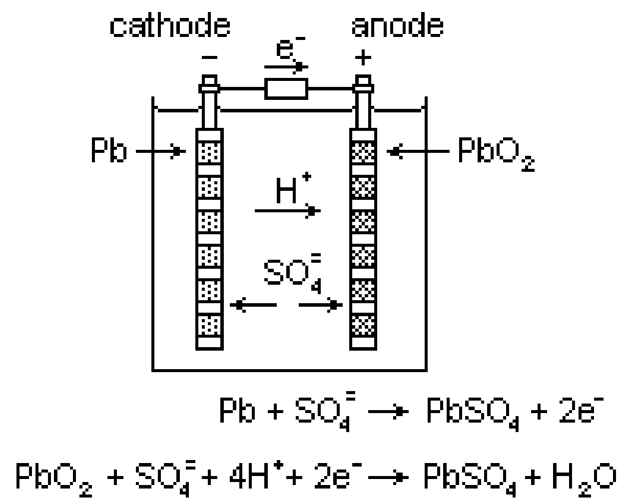
BASICS

- Electrochemical Cell: Cathode(+), Anode (-), and Electrolyte (ion conducting intermediate)
- D.C Efficiencies
  - Columbic – Measure of difference in charge/discharge
  - Voltage – Function of internal resistance
  - Energy – CE x VE
- Energy (kWh) = Voltage (V) difference between anode and cathode multiplied by amount of ion the electrodes are able to store - given as Ah of capacity
- Energy Density (Wh/kg or Wh/L): used to measure the energy density of a battery
  - Note: number often given for cell, pack, and system
  - Generally: pack = ½ cell energy density, and system is fraction of the pack

Lead-Acid Batteries

BASICS

Two electrodes (one lead and one lead-dioxide) immersed in sulfuric acid



Lead-Acid Storage Cell

- **Pros**
  - Low cost/Ubiquitous
  - Mature technology
  - Familiar
- **Cons**
  - Limited life time and degradation w/ deep discharge
  - Poor cycle life/need for replacement
  - Often needs maintenance
  - Low specific energy (30-50 Wh/kg)
  - Overcharging leads to H2 evolution
  - Sulfation from prolonged storage
- **Includes**
  - SLI
  - Flooded SLA
  - Valve-regulating LA

Nickel-Cadmium Batteries

BASICS

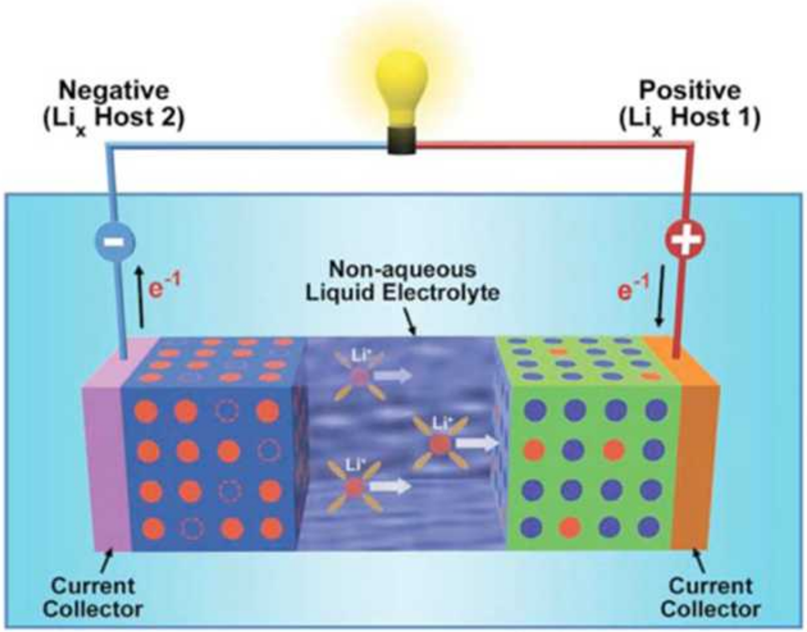
Two electrodes (one nickel and one cadmium) immersed in an aqueous potassium-hydroxide electrolyte

- **Pros**
  - Mature technology
  - Relatively rugged
  - Greater energy density than LA batteries
  - Better life cycle than LA batteries
- **Cons**
  - More expensive than LA batteries
- **Safety**
  - Thermal runaway
  - Contains cadmium

Li-ion Batteries

BASICS

- **Pros**
  - Decreasing costs – Stationary on coattails of increasing EV.
  - Ubiquitous – Multiple vendors
  - Fast response.
  - Higher efficiency
- **Cons**
  - High Temperature
  - Typical operating window 0-50°C
  - Operation above this temperature can lead to organic electrolyte decomposition and flammable gas.
  - Different chemistries have different heat generation
  - Parasitic loads like HVAC often not included

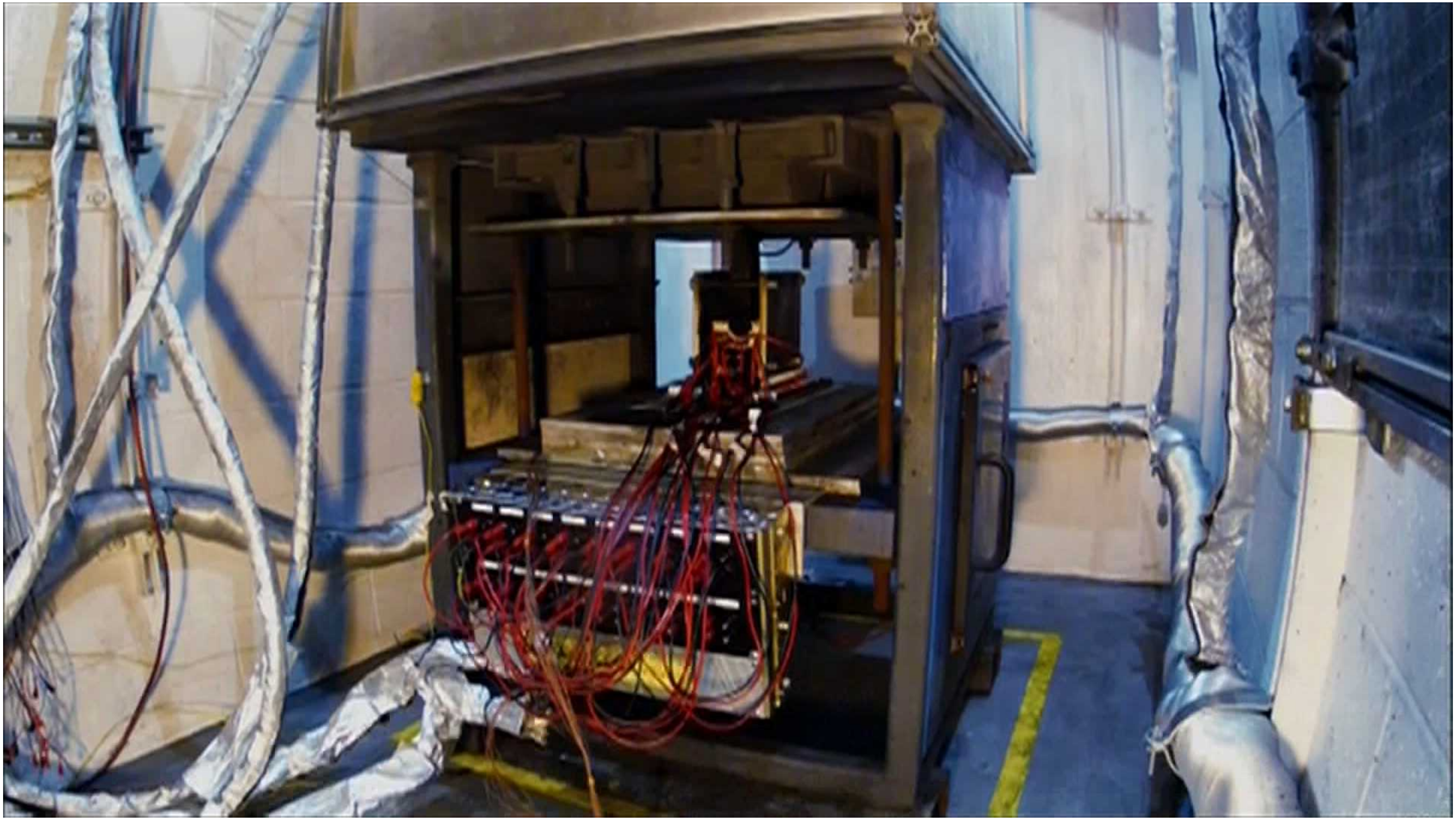


- Overcharging
  - Max voltage depends on materials, overcharging can lead to Li metal plating on anode, potential for short

Li Ion Fire Testing

BASICS

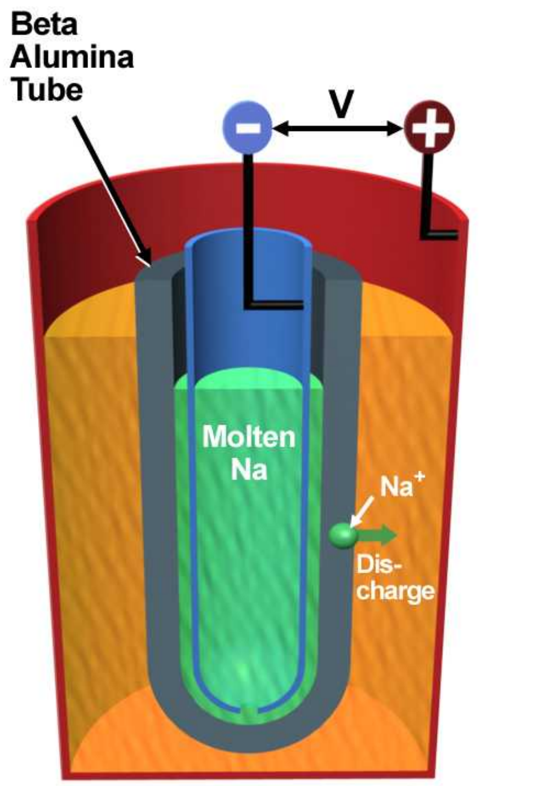
- Li Io batteries have a well known fire hazard
- Sandia National Laboratories fire test video



Na-Metal Batteries Basic Chemistry

BASICS

- Batteries consisting of *molten sodium anode* and *β"-Al_2O_3 solid electrolyte* (BASE).
  - Use of low-cost, abundant sodium → low cost
  - High specific energy density (120~240 Wh/kg)
  - Good specific power (150-230 W/kg)
  - Good candidate for energy applications (4-6 hrs discharge)
  - Operated at relatively high temperature (300~350°C)



- **Sodium-sulfur (Na-S) battery**
  - **$2Na + xS \rightarrow Na_2S_x$** (x = 3~5)
    - E = 2.08~1.78 V at 350°C
- **Sodium-nickel chloride (Zebra) battery**
  - **$2Na + NiCl_2 \rightarrow 2NaCl + Ni$**
    - E = 2.58V at 300°C
    - Use of catholyte ($NaAlCl_4$)

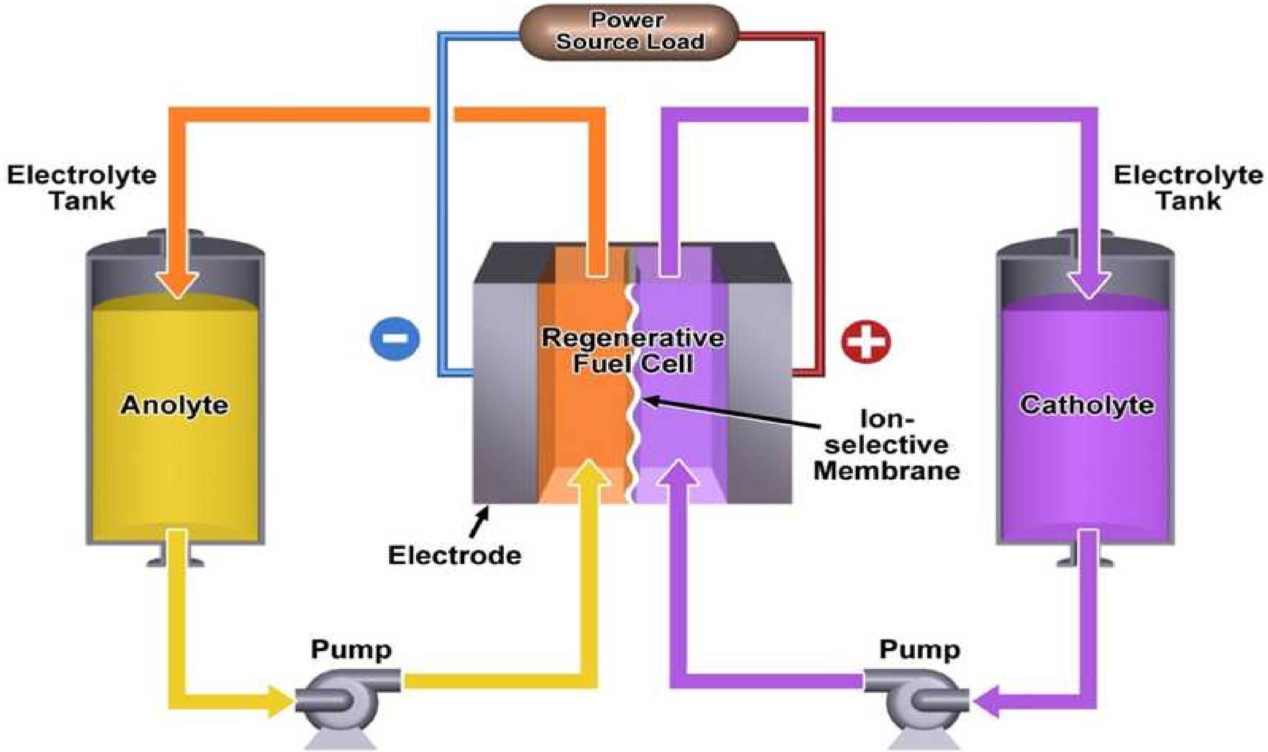
Na-Metal Batteries

BASICS

- **Temperature**
  - Less overtemperature concerns, typical operating window 200-350°C. additional heaters needed when not in use.
  - At < 98°C, Na metal freezes out, degree of distortion to cell dictated by SOC of battery (amount of Na in anode)
- **Charging/Discharging Limitations**
- **Safety Concerns**
  - Solid ceramic electrolyte keeps reactive elements from contact. Failure in electrolyte can lead to exothermic reaction (Na-S)

Redox Flow Battery: Basic Chemistry

BASICS



Key Aspects

- Power and Energy are separate enabling greater flexibility and safety.
- Suitable for wide range of applications 10's MW to ~ 5 kw
- Wide range of chemistries available.
- Low energy density ~ 30 Whr/kg
- Lower energy efficiency

Redox Flow Batteries

BASICS

- **Temperature**
  - High/Low Temperatures can lead to precipitation of species
  - Typical range -10-60°C
- **Charging**
  - Overcharging can lead to evolution of hydrogen (H_2O electrolysis)
- **Toxicity of Elements**
  - Solutions are in pumped system, susceptible to leaks
- **Minimal Fire Hazard**
  - Electroactive element in aqueous solution
- **High Degree of Flexibility**

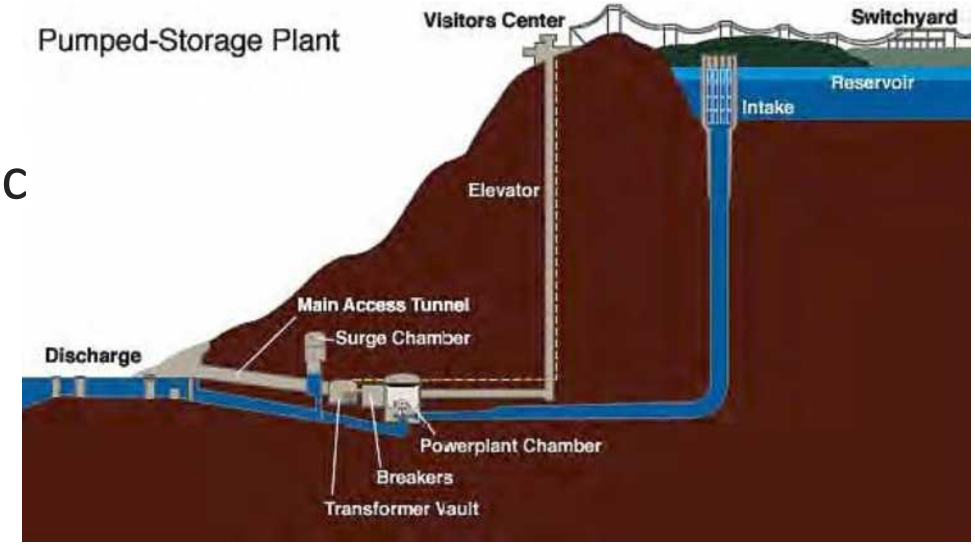
Thermal and Mechanical Systems

BASICS

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. During low energy demand the water is pumped back up to the higher reservoir.

- **Pros**
  - Large scale and mature technology (20+ GW in USA, 129+ GW worldwide)
  - Long term storage
- **Cons**
  - Requires water and specific geography availability
- **Safety Issues**
  - Overfilling
  - Containment failure



DOE/EPRI 2013 Electricity Storage Handbook in Collaboration with NRECA

Thermal and Mechanical Systems

BASICS

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 the motor increasing its rotational speed.

- **Pros**
  - Fast charge/discharge (<5 ms)
  - No hazardous materials
- **Cons**
  - Not attractive for large scale or long term storage

Flywheels

BASICS

- **Safety Issues**
  - Rotor Failure: energetic projectiles
    - Mitigation – 2X design margin
    - Containment not cost effective – 10X mass required to contain
  - Loose Rotor: unintended energy release
    - Failure of bearing, shaft, or hub
    - Mitigation – prevent contact between roto and housing, manage energy release

FLY-WHEEL EXPLOSION UNION BREWING CO., ST. LOUIS, MO., 40,000-POUND WHEEL ON ICE MACHINE RUNNING NORMALLY AT ONLY 50 R.P.M. MACHINE RACED AND BURST WHEEL BY CENTRIFUGAL FORCE, HURLING 8,000-POUND CHUNKS GREAT DISTANCES. RIM SECTION WAS 13″x16″, TO BREAK WHICH REQUIRED 4,000,000 POUNDS. LOSS $13,423. WHEEL INSURED.

Key Takeaways

FUNDAMENTALS

- 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
- There are a wide range of battery types, chemistries, sizes, designs, control mechanisms, operating temperatures and potential locations that 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

What are the Safety Issues?

The purpose of this section of the presentation is to identify the **safety issues that are relevant to energy storage systems**

- Siting (location, loads, protection, egress/access, maximum quantities of chemicals, separation, etc.)
- New versus existing systems and new versus existing building/facility applications
- 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 and markings
- Identification of the applicable authorities having jurisdiction (utility, federal, state or local government, etc.)

Key Takeaways

SAFETY ISSUES

- 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 impacted 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 and finally to decommissioning or recommissioning

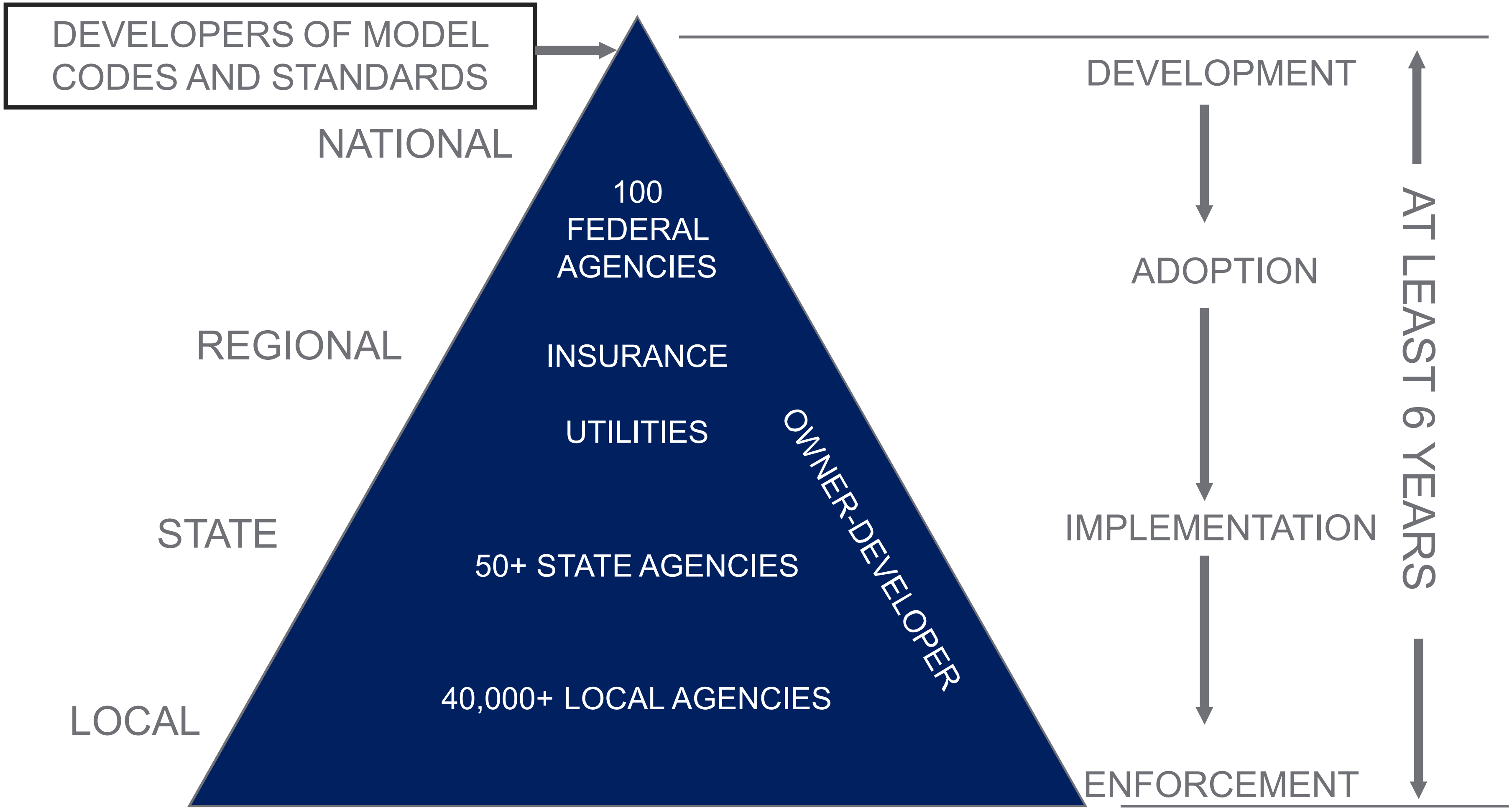
Model Codes and Standards

The purpose of this section of the presentation is to identify the **codes and standards that address the safety issues**

- 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 where those model codes and standards are adopted.
- When adopted those model codes and standards must be satisfied subject to any penalties associated with non-compliance.

Development and Deployment

CODES AND STANDARDS



U.S. Model Codes and Standards

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

Model codes and standards have varying scopes in relation to energy storage systems

- Overarching – cover the built environment at large and that includes energy storage systems
- Installation – address the installation of the energy storage system in relation to other systems and parts of the built environment
- Complete – the entire energy storage system in the aggregate
- Components – components associated with the energy storage system

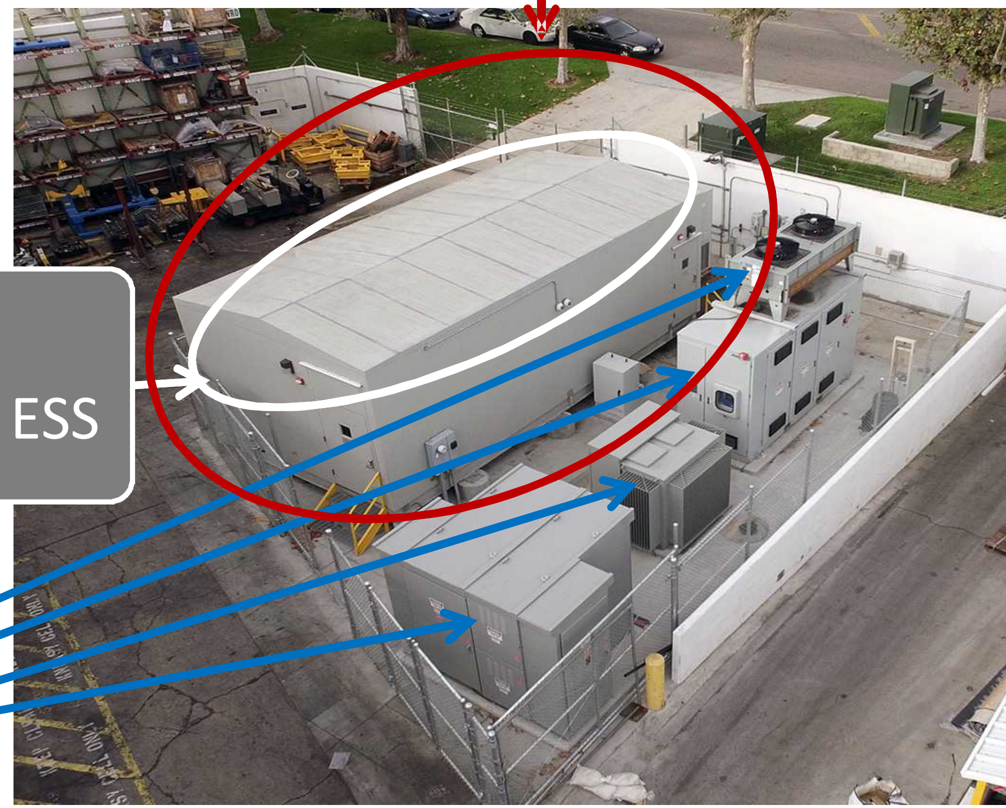
U.S. Model Codes and Standards

CODES AND STANDARDS

Overarching CS

CS for ESS Installation

CS for Complete ESS



CS for ESS Components

U.S. Model Codes and Standards

Specific Overarching CS

- NFPA
  - 1-17 – Fire Code (next activity is to develop 2020 edition)
  - 70-17 – National Electrical Code (next activity is to develop 2020 edition)
  - 5000 - X – Building Code
- ICC
  - 2018 International Fire Code (next activity is to develop 2021 edition)
  - 2018 International Residential Code (next activity is to develop 2021 edition)
  - 2018 International Mechanical Code (next activity is to develop 2021 edition)
  - 2018 International Building Code (next activity is to develop 2021 editions)
- IEEE
  - C2 – X - – 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 (first draft being developed)**
- **NECA**
  - **416-X – Recommended Practice for Installing Stored Energy Systems (draft being finalized for canvass vote)**
- **IEEE**
  - **1653-2012 – Guide for Ventilation and Thermal Management of Batteries for Stationary Applications (next action is comment on proposed revisions)**

U.S. Model Codes and Standards

CS for Complete ESS

- **ASME**
  - TES-1- X – Safety Standard for Thermal Energy Storage Systems (first draft being developed)
- **UL**
  - 9540 – Safety of ES Systems and Equipment (under continuous maintenance)

U.S. Model Codes and Standards

CS for ESS Components

- **UL**
  - 810A - Electrochemical Capacitors
  - 1973 – Batteries for Use in LER and Stationary Applications (under continuous maintenance)
  - 1974 – Evaluation of Batteries for Repurposing (just getting started to draft a standard)
- **CSA**
  - 283 – Battery Reuse (just getting started to draft a standard)

IEC International Standards

- 62813 Lithium-ion capacitors for use in electric and electronic equipment - Test methods for electrical characteristics
- 62932-1 (under development): Secondary Cells and Batteries of the Flow Type: Flow Batteries - Guidance on the Specification, Installation and Operation
- 62933-1 (under development): Electrical energy storage (EES) systems - Part 1: Terminology
- 62933-2-1 (under development): Electrical Energy Storage (EES) systems - Part 2-1: Unit parameters and testing methods - General specification
- 62933-3-1 (under development): Electrical Energy Storage (EES) systems - Part 3-1: Planning and installation - General specification
- 62933-4-1 (under development): Electrical Energy Storage (EES) systems - Part 4-1: Guidance on environmental issues

IEC International Standards

- 62933-5-1 (under development): Electrical Energy Storage (EES) systems - Part 5-1: Safety considerations related to grid integrated electrical energy storage (EES) systems
- 62933-5-2 (under development): Electrical Energy Storage (EES) systems - Part 5-2: Safety considerations related to grid integrated electrical energy storage (EES) systems - Batteries
- 62932-1 (under development): Secondary Cells and Batteries of the Flow Type: Flow Batteries - Guidance on the Specification, Installation and Operation
- 62932-2-1 (under development): Flow batteries - General requirement and test method of vanadium flow batteries
- 62932-2-2 (under development): Flow Battery Technologies – Safety

U.S. Safety-Related Criteria

- **EPRI**
  - ESIC Energy Storage Implementation Guide 2016 (Updates 2015 Integration Guidelines)
  - ESIC Energy Technical Specification Template 2016
  - ESIC Energy Storage Commissioning Guide 2016
  - Energy Storage Safety 2016
- **DNV GL**
  - GRIDSTOR
- **MESA**
  - Modular Energy Storage Architecture

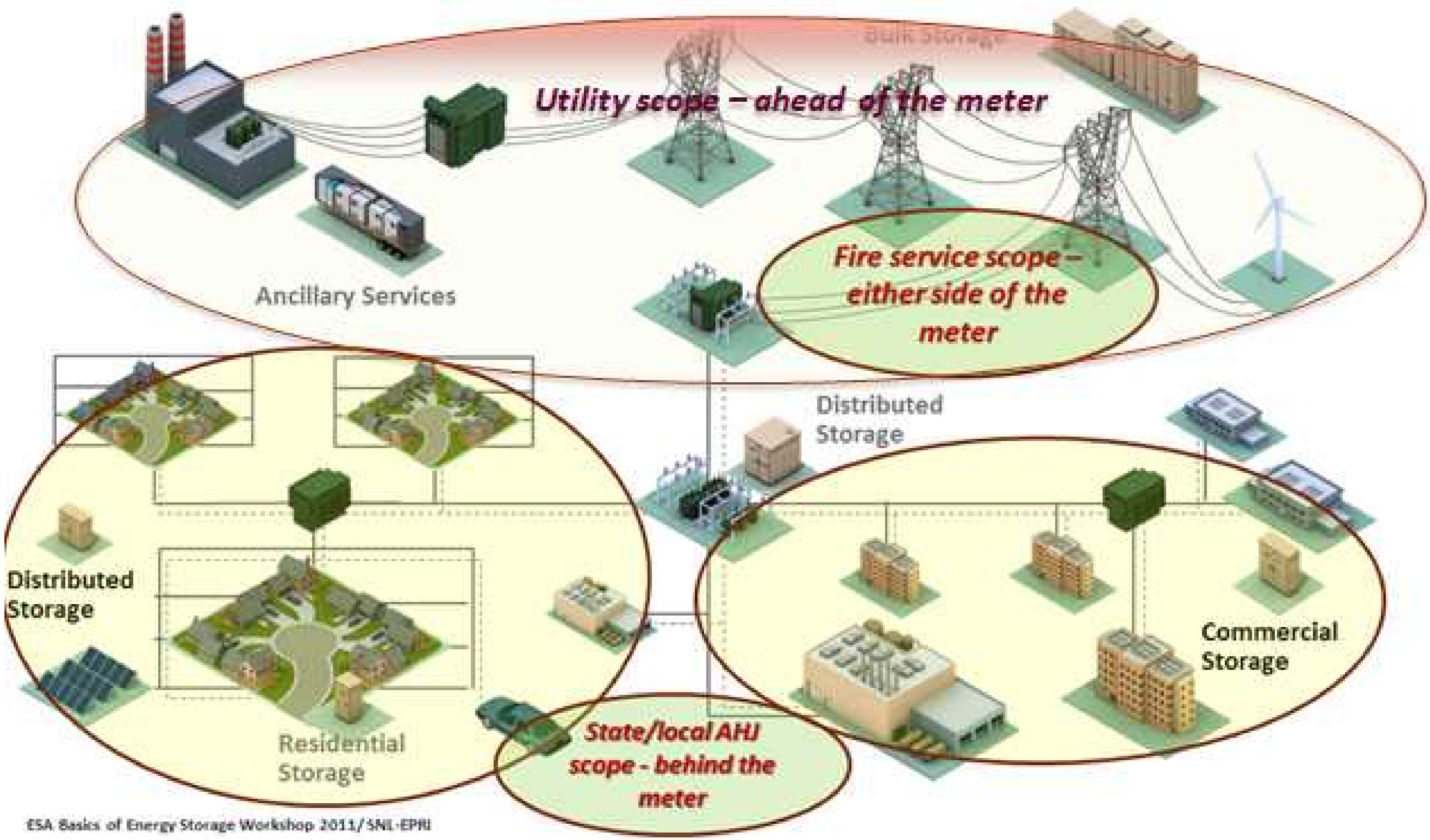
Key Takeaways

- 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
- Development and maintenance of International standards is an ongoing process open to all with participation on a country by country basis with one vote per country
- 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 who 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

Applications of Energy Storage Systems

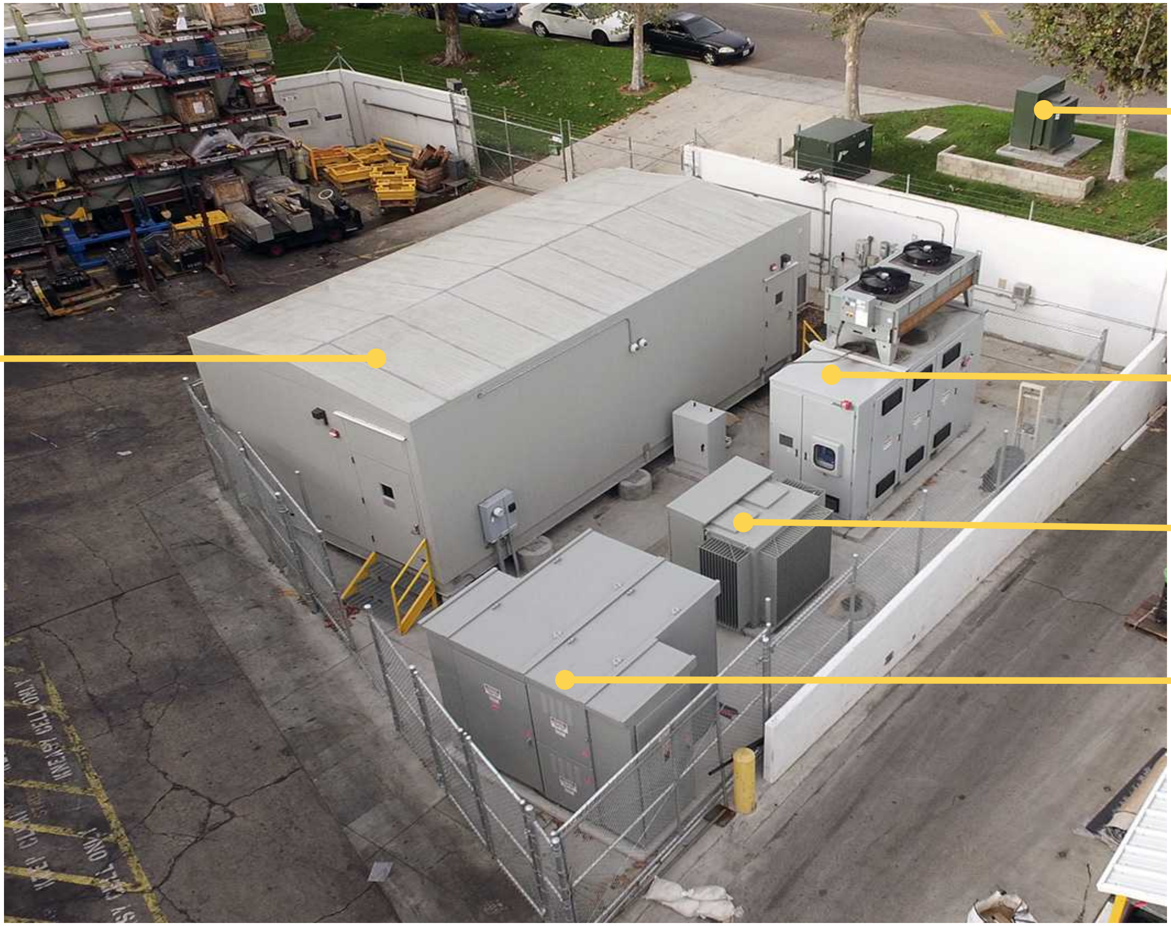
APPLICATIONS

The purpose of this section of the presentation is to provide an overview of **where and how energy storage systems are being applied**



SCE DESI Site

APPLICATIONS



Source - Southern California Edison

SCE DESI ESS

APPLICATIONS

Key Components

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

Source - Southern California Edison

SCE DESI

APPLICATIONS

Source - Southern California Edison

Castle & Cooke Installation

APPLICATIONS

- 1.125 MVA Dynamic Power Resource
- 1.5 MW DC/1.2 MW AC solar farm
- Purpose is to double the output of the solar system and control the ramp rate
- Advanced lead-acid battery technology
- 15 minutes duration at rated power
- Commissioned 9-1-2011
- Located in Lanai, HI
- Technology provider (Xtreme Power filed Chapter 11 in 2015)

Ownership Model	Customer-Owned
Equity Owner 1	Castle & Cooke
Equity Owner 1 Percentage	100%
Energy Storage Technology Provider	Xtreme Power
Integrator Company	Younicos

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

Hawaiian Properties

APPLICATIONS

- 60 kW zinc bromine flow battery
- Part of an elevator system in an R-2 building that uses grid power and power from a 20kW PV array
- Purpose is to double the output of the solar system and control the ramp rate
- 2.5 hours duration at rated power
- Commissioned 7-1-2012
- Honolulu, HI

Ownership Model	Customer-Owned
Equity Owner 1	Hawaiian Properties Ltd.
Energy Storage Technology Provider	ZBB Energy Corporation
Power Electronics Provider	ZBB Energy Corporation
Integrator Company	NIDON

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

Confidential

APPLICATIONS

- 48 kW nickel iron battery
- Powered by a pole mounted solar array
- Purpose is to double the output of the solar system and control the ramp rate
- 10 hours duration at rated power
- Las Cruces, NM

Ownership Model	Customer-Owned
Equity Owner 1	Confidential
Equity Owner 1 Percentage	100%
Energy Storage Technology Provider	Iron Edison Battery Company
Power Electronics Provider	Apollo Solar
Integrator Company	Iron Edison Battery Company

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

Long Island Railroad

APPLICATIONS

- Manufacturer – Maxwell Technologies
- Type – Electro-chemical Capacitor
- Location – Long Island RR (NY)
- Application – voltage support to assist traction power system (capture and store energy produced by trains to help with acceleration
- Rating/Duration – 1,000 kW/ I min.

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

Scripps Ranch Community Center

APPLICATIONS

- ESS Manufacturer – SAFT
- Power Electronics Provider - Princeton Power
- Type – Lithium-ion
- Location – Scripps Ranch Community Center (CA)
- Application – PV (30kW) storage
- Rating/Duration – 100 kW/1 hr.

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

Montezuma Canyon UT

APPLICATIONS

- Manufacturer – Iron Edison
- Type – Nickel Iron Battery (700 Ah 24V)
- Location – adjacent parking structure
- Application – PV storage (2.8kW of panels with 3.2kW pure sine wave inverter and dual 80 amp MPPT charge controllers)
- Rating/Duration – 17 kW for 10 hours

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

SE PA Transportation Authority

APPLICATIONS

- Manufacturer – SAFT
- Type – Lithium-ion battery
- Location – SEPTA
- Application – Capture energy from rail cars through regenerative braking and re-use it to accelerate trains
- Rating/Duration – 800 kW for 30 minutes

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

Santa Clara Data Center

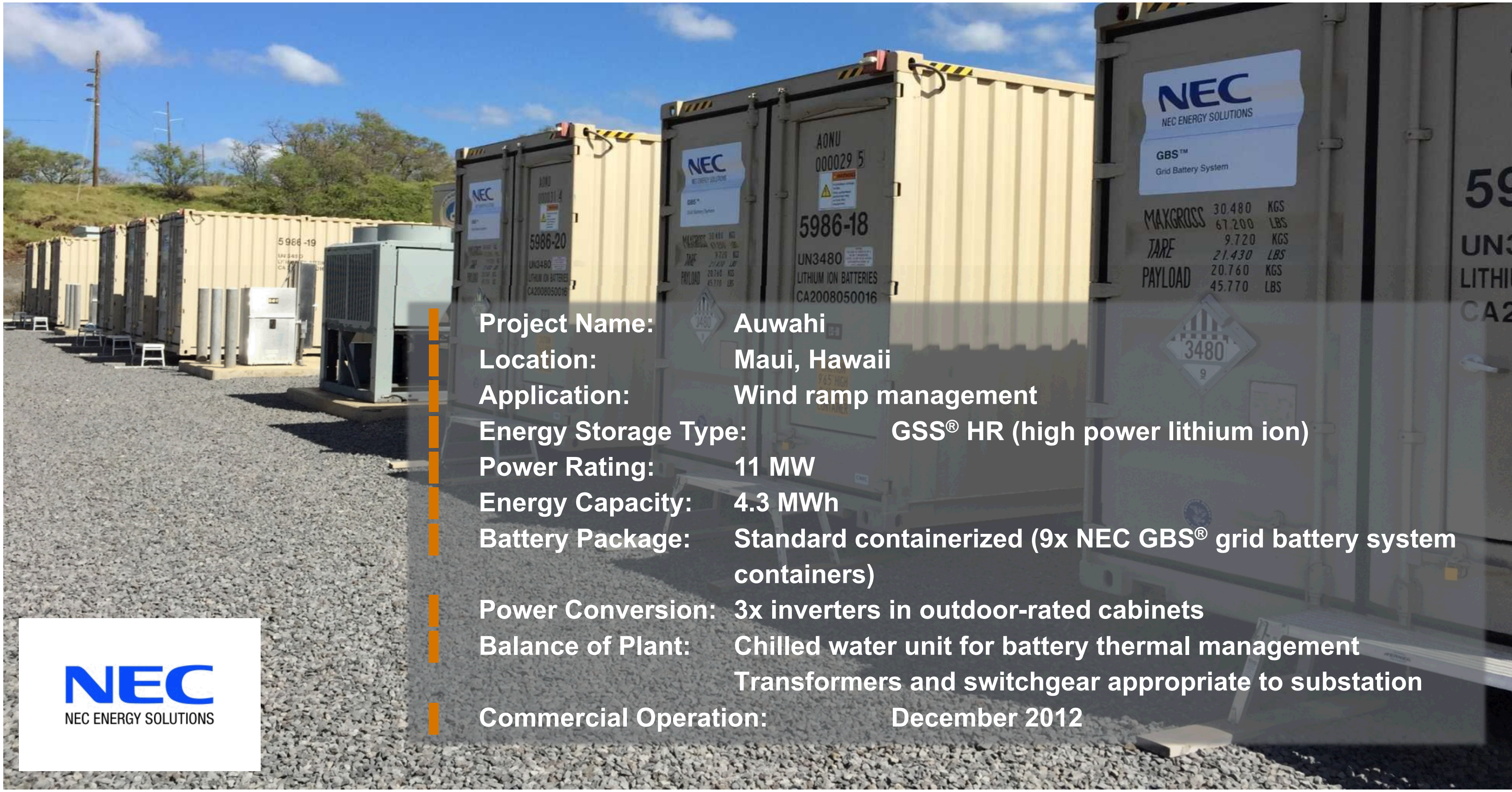
APPLICATIONS

- Manufacturer – Mitsubishi
- Type – Electro-chemical
- Location – CoreSite Realty Corp. (CA)
- Application – UPS for 101K sf. Data Center
- Rating – 1,500 kW

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

Auwahi Wind Farm HI

APPLICATIONS

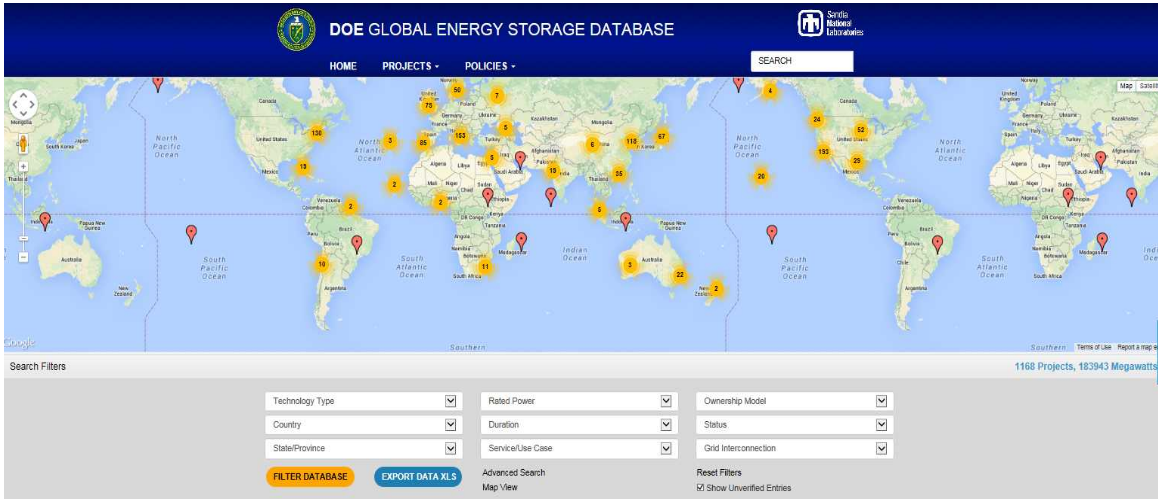


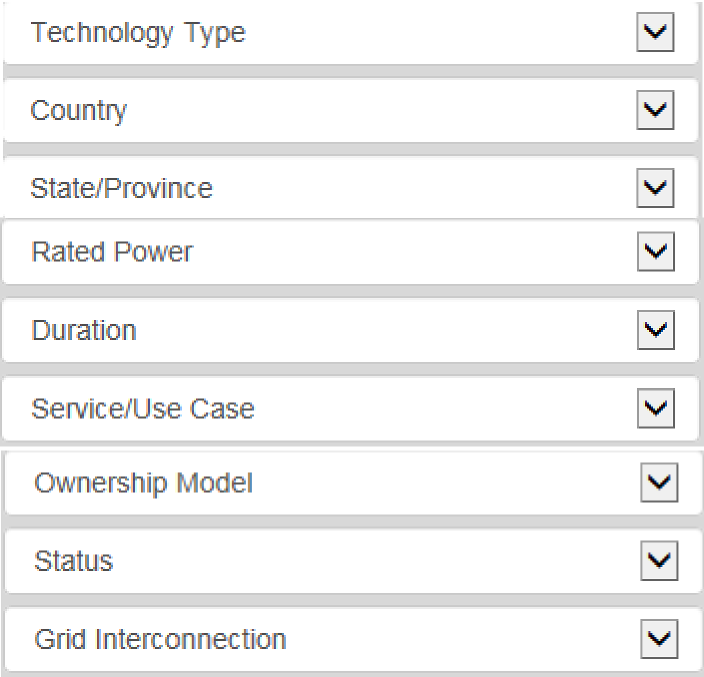
- **Project Name:** Auwahi
- **Location:** Maui, Hawaii
- **Application:** Wind ramp management
- **Energy Storage Type:** GSS® HR (high power lithium ion)
- **Power Rating:** 11 MW
- **Energy Capacity:** 4.3 MWh
- **Battery Package:** Standard containerized (9x NEC GBS® grid battery system containers)
- **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
NEC ENERGY SOLUTIONS

Database of Applications

APPLICATIONS





http://www.energystorageexchange.org/

Key Takeaways

APPLICATIONS

- Batteries are much more than just lead acid or Li Ion and are one of many energy storage technologies
- Economic incentives, policy initiatives and increased use of renewables are spurring more demand for energy storage
- Development of new energy storage technologies is evolving at a considerable rate
- Energy storage technology deployment is increasing in scope, location, size of installation and interaction with other systems
- There is a need to ensure that energy storage 'products' and system installations are safe

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 to the electric meter are likely to become more complex
- While safety issues have been and are being identified the research and information necessary to define how to address each one for each technology application many not exist
- Codes and standards are updated on a regular basis and 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

Acknowledgement

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U.S. DEPARTMENT OF ENERGY

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Sandia

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For more information on DOE OE ESS safety activities contact

energystorage@sandia.gov

- Backup slides

Energy Storage Applications – SCE Distributed Integration (DESI) Pilot Program

APPLICATIONS

- Installed to support overloaded 12kV distribution circuit
- Rated at 2.5MVA / 3.9MWh
- Located in dense urban area environment
  - Sited on customer easement
- Extremely compact system
  - Entire system fits within a 1,600 sq. ft. easement (including 12kV transformer, switchgear and protection)

Source - Southern California Edison

Energy Storage Applications

- Peak shaving
- 2nd life battery system
- 100 kW rated power
- 8 used battery packs from former MINI E Evs
- 240 KWh Li-Ion iron phosphate battery housed in a shipping container
- Fully integrated into an advanced building EMS
- ESS is connected to a 100 kW solar array and network of EV charging stations
- 2 hour 20 minute duration at rated power
- Commissioned 2-1-2015
- Located in Mountain View, CA

Ownership Model	Customer-Owned
Equity Owner 1	BMW of North America
Energy Storage Technology Provider	EV Grid
Power Electronics Provider	Princeton Power Systems
Integrator Company	BMW Group
O&M Contractor	Princeton Power Systems
Developer	BMW Group

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

Energy Storage Applications

- Manufacturer – Princeton Power
- Type – Lithium Polymer
- Location – Del Largo Academy (CA)
- Application – PV storage
- Rating/Duration – 100 kW/2 hrs.

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