ESS Safety: Best Practices From the Field

May 12, 2020

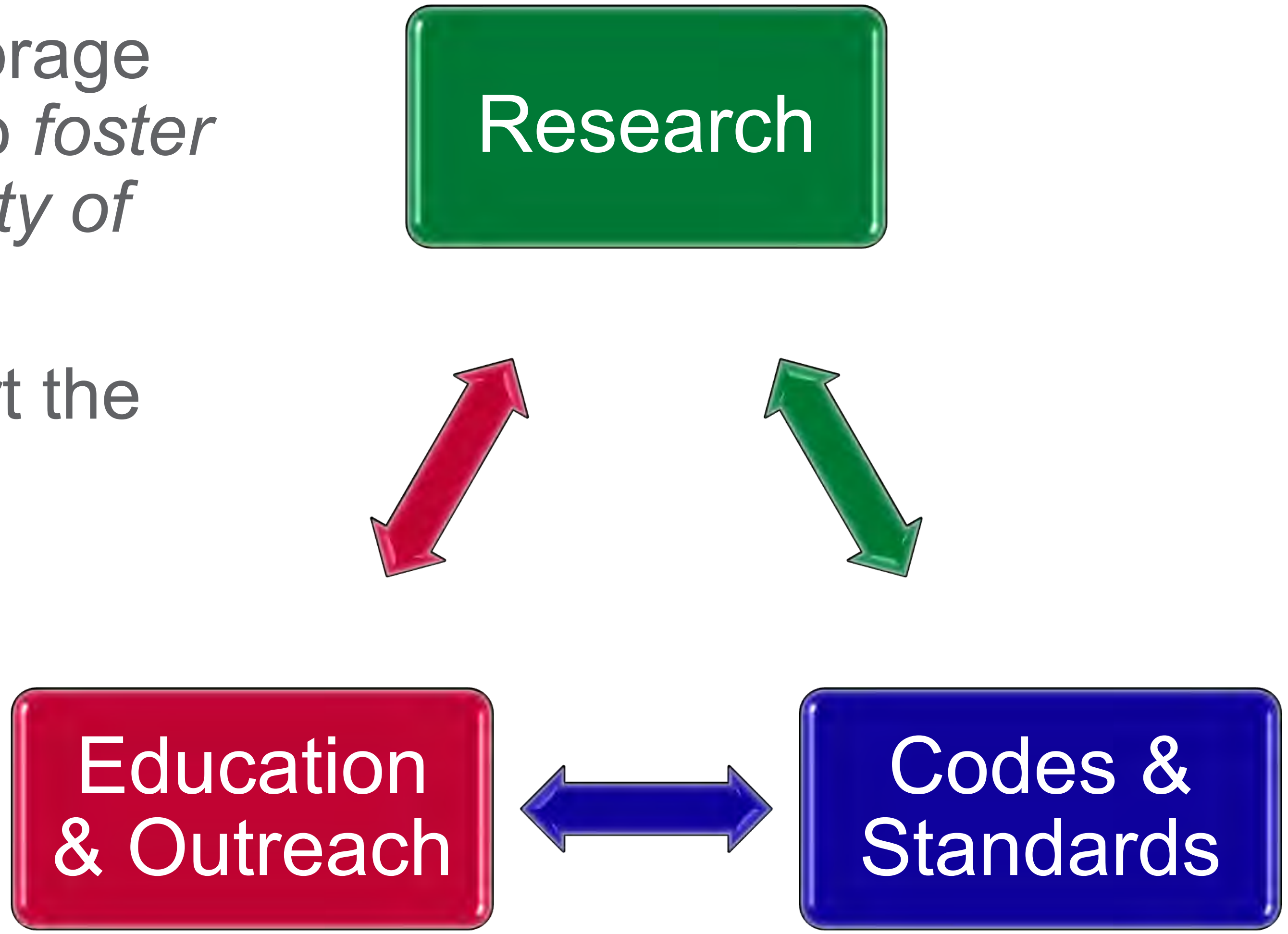
Matthew Paiss
Technical Advisor

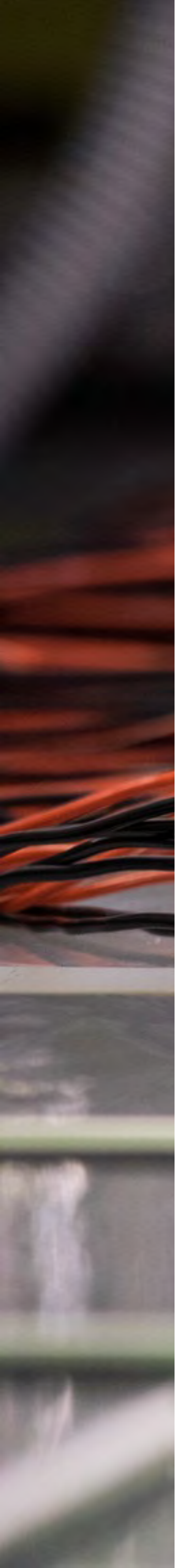
PNNL is operated by Battelle for the U.S. Department of Energy

PNNL-SA-152388

Energy Storage Systems Safety Roadmap

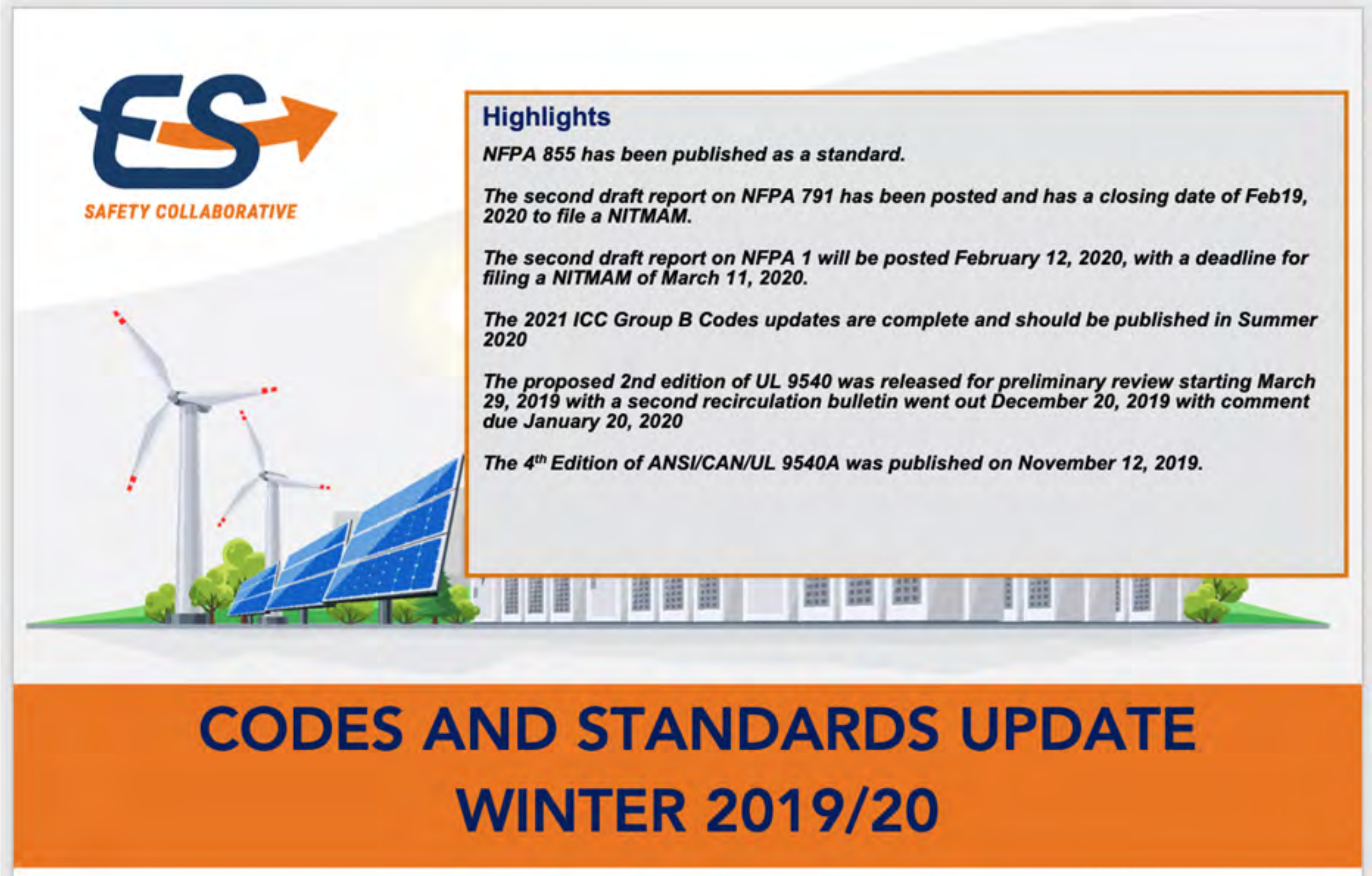
- The goal of the DOE OE Energy Storage System (ESS) Safety Roadmap is to *foster confidence in the safety and reliability of ESS.*
- Three interrelated objectives support the realization of that goal.
  - Research
  - Codes & Standards Development
  - Education & Outreach





Energy Storage Safety Collaborative Reports

Get the free reports to remain alerted to key Codes & Standards updates!



ES SAFETY COLLABORATIVE

Highlights

NFPA 855 has been published as a standard.

The second draft report on NFPA 791 has been posted and has a closing date of Feb19, 2020 to file a NITMAM.

The second draft report on NFPA 1 will be posted February 12, 2020, with a deadline for filing a NITMAM of March 11, 2020.

The 2021 ICC Group B Codes updates are complete and should be published in Summer 2020

The proposed 2nd edition of UL 9540 was released for preliminary review starting March 29, 2019 with a second recirculation bulletin went out December 20, 2019 with comment due January 20, 2020

The 4th Edition of ANSI/CAN/UL 9540A was published on November 12, 2019.

CODES AND STANDARDS UPDATE
WINTER 2019/20

Take photo of code to sign-up to receive quarterly reports

https://public.govdelivery.com/accounts/USDOESNLEC/subscriber/new?topic_id=USDOESNLEC_195

Types of ESS

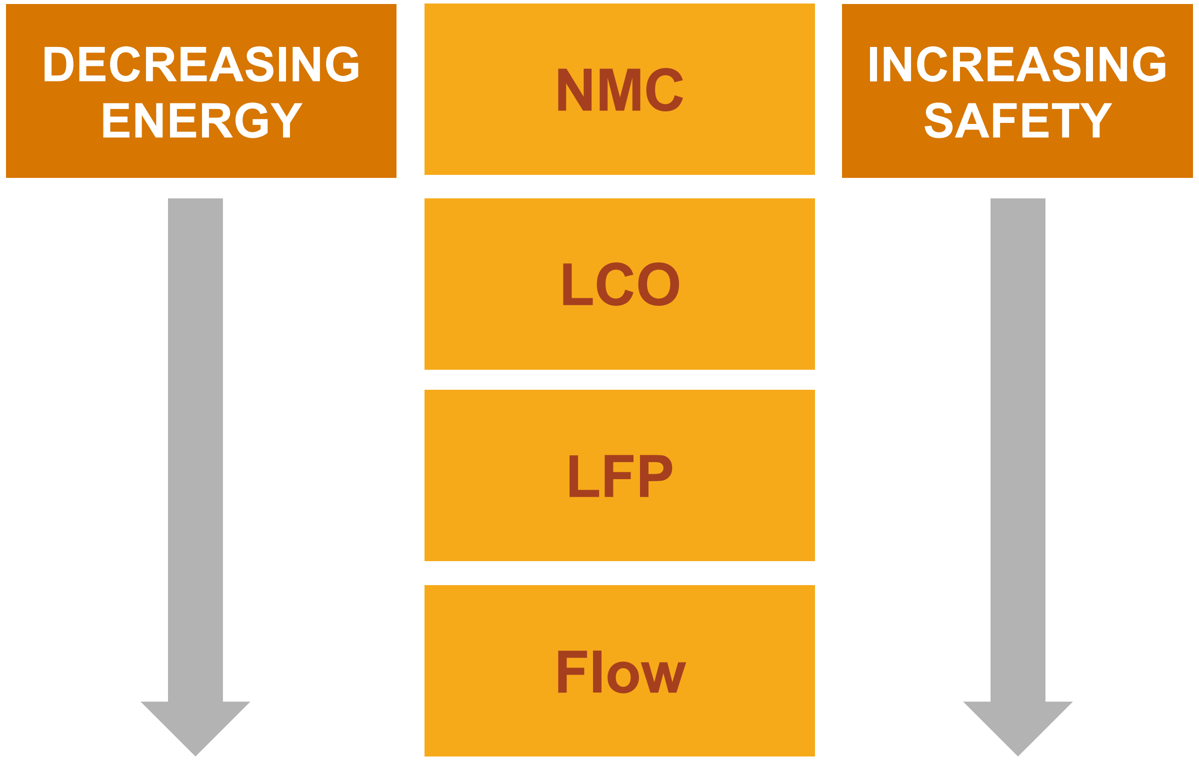
- Hydro
- Mechanical
- Thermal
- Electrochemical

Pacific Northwest
NATIONAL LABORATORY

Chemistries - Lithium-Ion Family

Current Positive Electrodes

- **LiCoO2**
  Lithium Cobalt Oxide (LCO)
- **LiNiCoAlO2**
  Lithium Nickel Cobalt Aluminum (“NCA”)
- **LiNiMnCoO2**
  Lithium Nickel Manganese Cobalt ("NMC")
- **LiMn2O4**
  Lithium Manganese Oxide (LMO)
- **LiFePO4**
  Lithium Iron Phosphate ("LFP")



Safety: Li-ion Primary Abuse Mechanisms

Thermal Abuse

Electrical Abuse

Mechanical Abuse

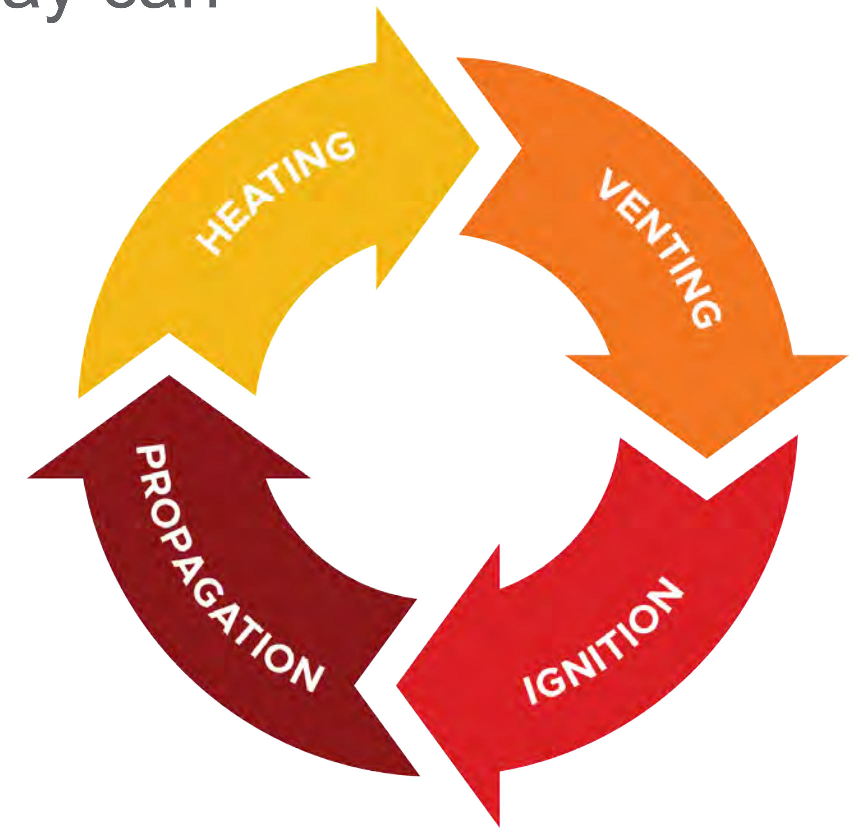
Internal Faults

- Thermal Abuse
  - Exposed to high heat (internal/external), poorly designed HVAC
- Electrical Abuse
  - Overcharging, rapid discharging, unbalancing
- Mechanical Abuse
  - Dropping, vibration, shorting (more common in mfg)
- Internal defects
  - Dendrites, separator QC, other contaminations

Hazards - Thermal Runaway

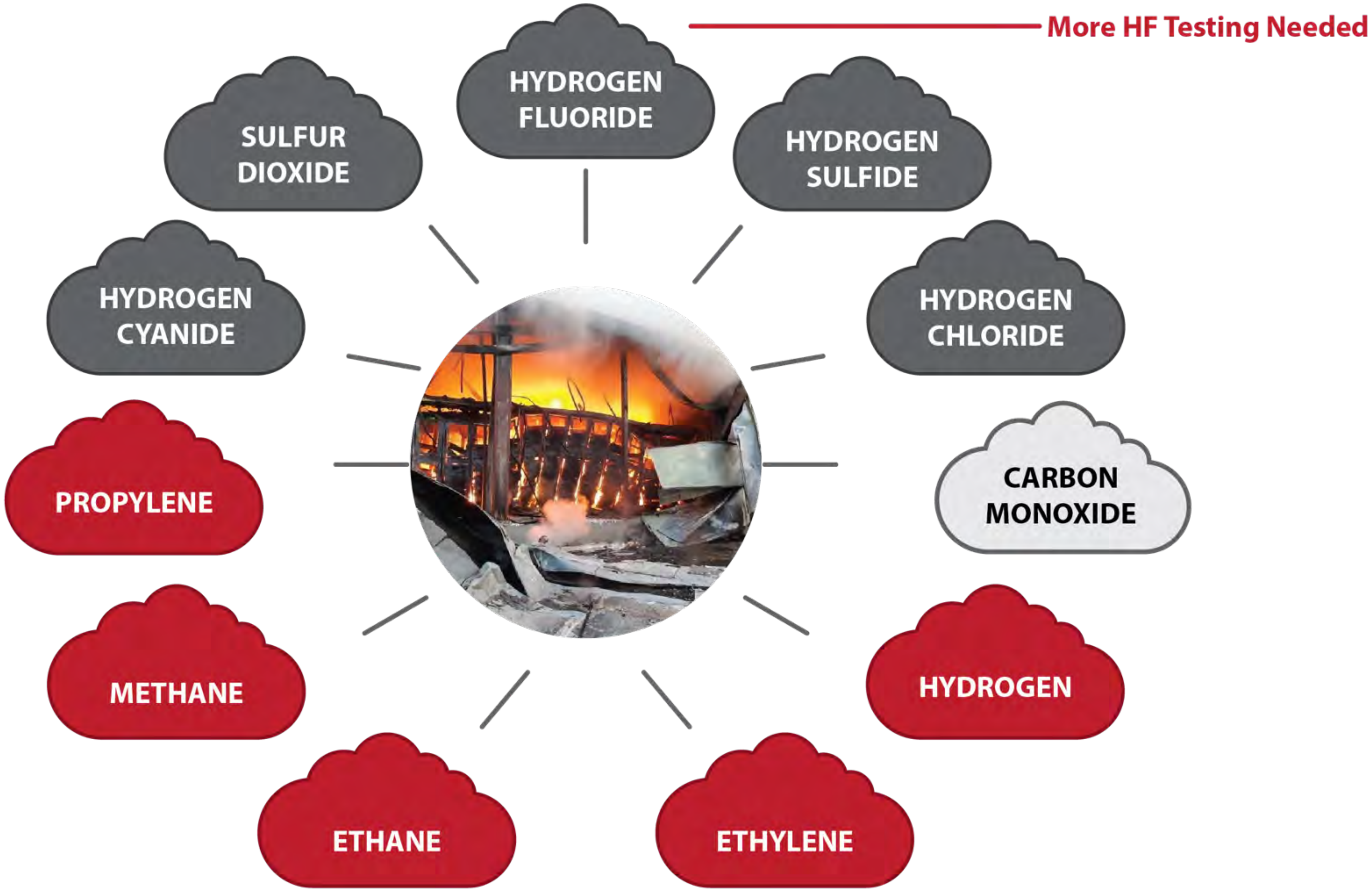
“The process where self heating occurs faster than can be dissipated resulting in vaporized electrolyte, fire, and or explosions”

- Initial exothermic reactions leading to thermal runaway can begin at 80° - 120°C.
- Venting of electrolyte gasses
- Ignition of gasses (fire or explosive)
- Propagation within module
- External flame initiates preheating of additional cells/modules



Hazards – Thermal Runaway

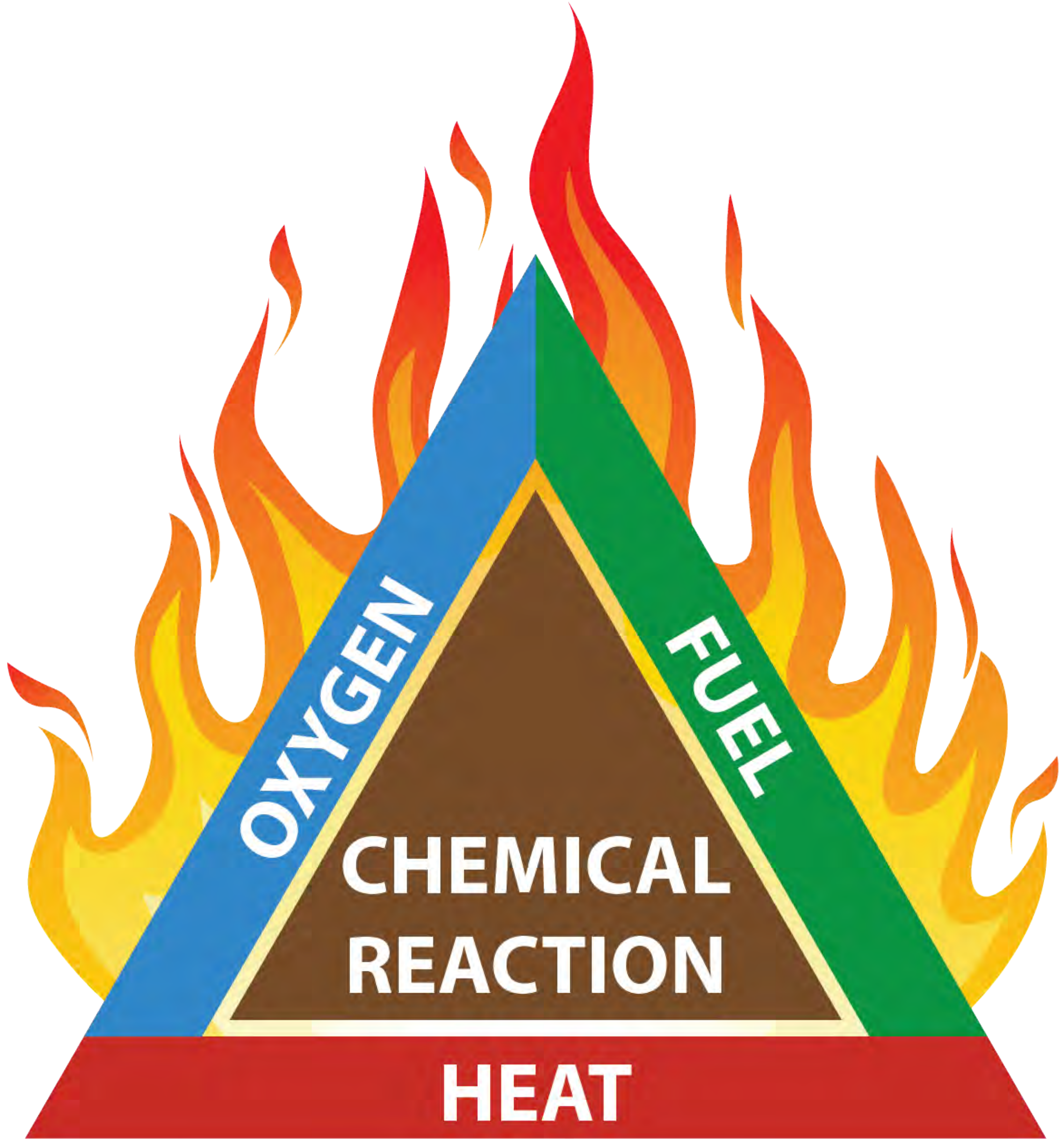
Hazards – Flammable/Toxic Gases



Pacific Northwest NATIONAL LABORATORY

Fire Tetrahedron

- Typically all that is required for fires to occur is O^2, Fuel, and Heat.
- Some chemistries contain metal oxides that release O^2 rapidly under high heat conditions.
- Li-ion fires can occur in low O^2 atmospheres
- Flammable gasses will continue to be produced after clean agent systems discharge.



PREVENTING/REMOVING HEAT IS KEY

Incident Response

Incident Management - APS Explosion April 19, 2019

Key timeline events:

4:35 p.m.	Smoke detector triggers release of clean agent
5:41p.m.	911 called for possible grass fire near substation
5:48 p.m.	First FD Units on scene, updated event to a battery fire
6:28 p.m.	Hazmat Unit on scene, light white smoke low on ground outside, from HVAC units on side of building, and seeping from nearby switchgear.
6:51 p.m.	Hazmat getting readings of HCN outside building. No active smoke/fire present.
8:00 p.m.	Hazmat opens door to obtain temp & gas readings at threshold. Dense white smoke present 2’ up from floor. Temp 104F inside (exact spot not clear)
8:02:06 p.m.	Explosion occurs. 2 Firefighters seriously hurt. One lands 73’ away.

- *Still under investigation for root cause.*
- *Fire Department actions are public and just one side of the event.*

Incident Management - APS Explosion

Ground smoke present on arrival. Not clean agent.

Photos credit: Surprise Fire Department

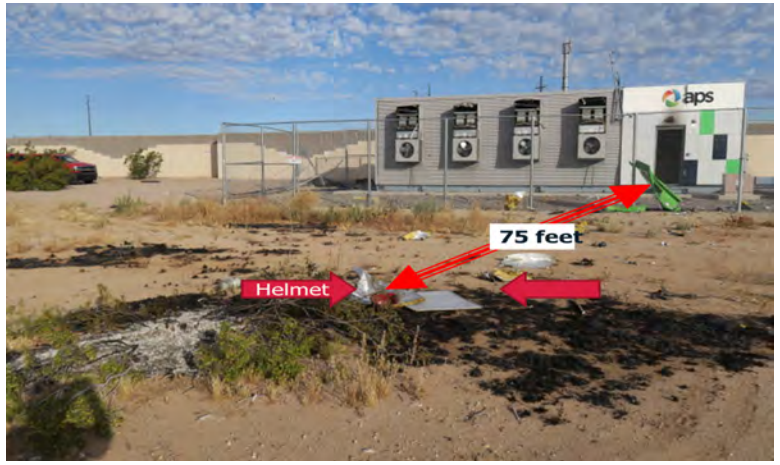
Incident Management - APS Explosion

Hose line and areas of smoke

Overview of container and fence

Detail of force damage to door

Fence section FF thrown under



Overview distance from container

SCBA airline separated from pack

Photos credit: Surprise Fire Department

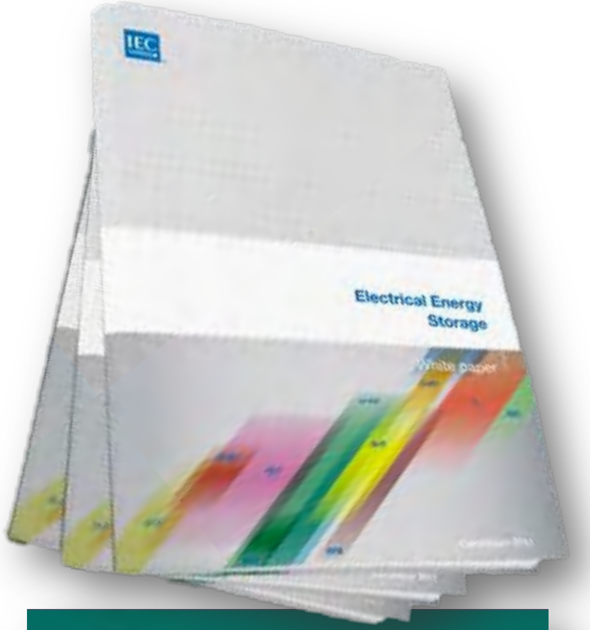
S. Korea ESS Fire Causes

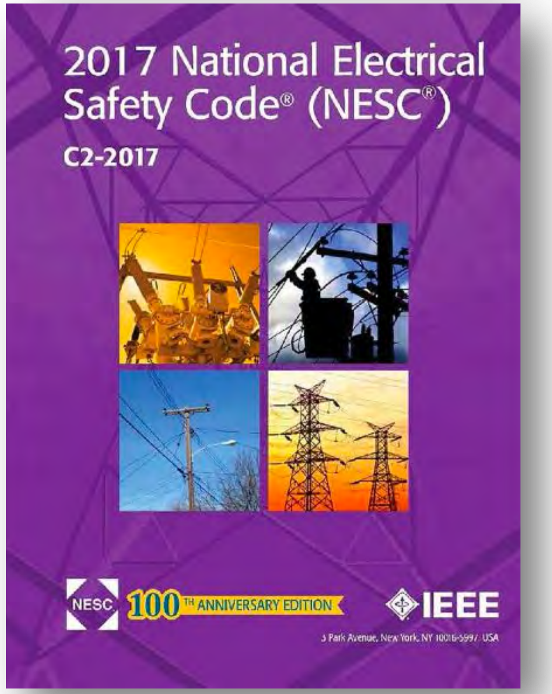
1. Poor ground fault protection
2. Inadequate HVAC
3. BMS Failures
4. Systems control failures

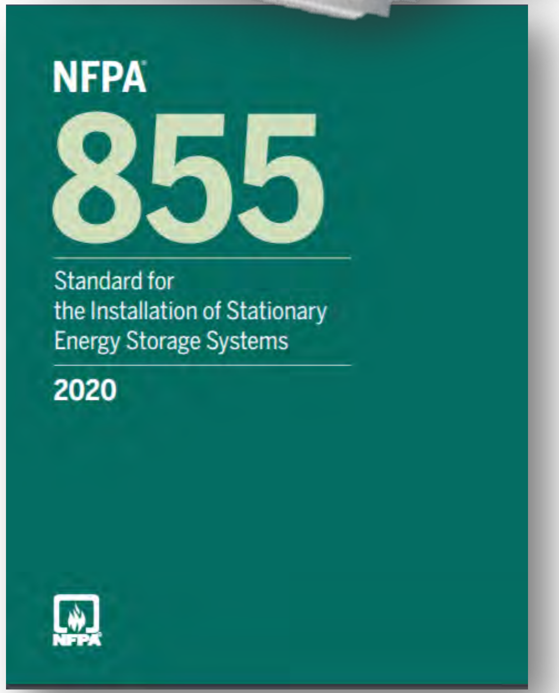
None listed to UL 9540

Pacific Northwest
NATIONAL LABORATORY

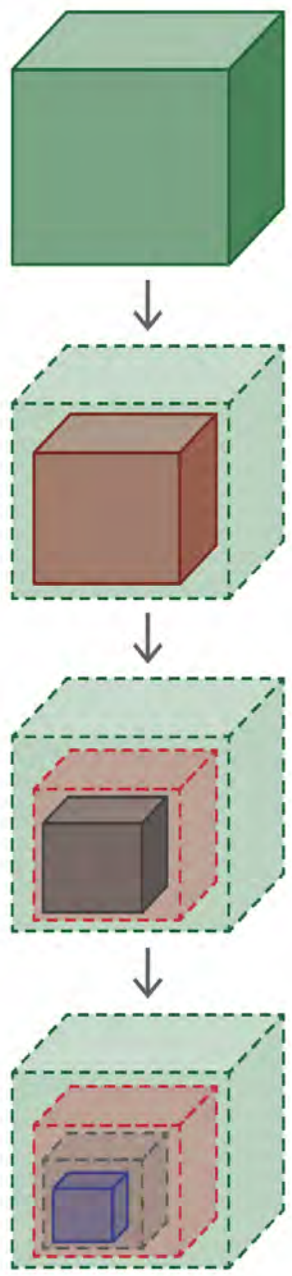
Codes & Standards







Standards and Model Codes Hierarchy



BUILT ENVIRONMENT

- ICC IFC, ICC IRC, ICC IBC
- NFPA 5000
- NFPA 1

INSTALLATION / APPLICATION

- NFPA 855
- NFPA 70
- UL 9540 A
- IEEE C2
- IEEE 1635/ASHRAE 21
- IEEE P1578
- DNVGL GRIDSTOR
- FM GLOBAL 5-33
- NECA 416 & 416

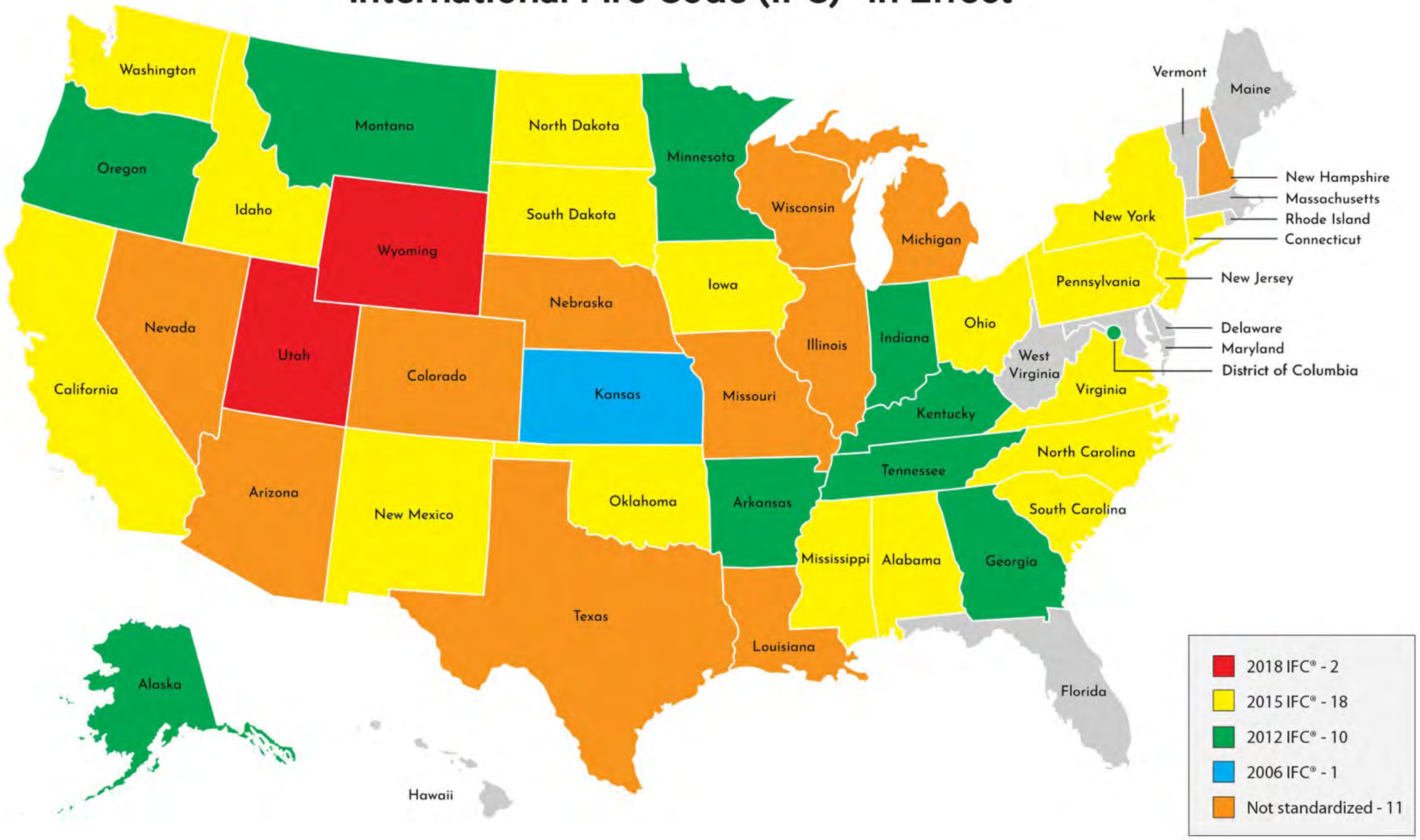
ENERGY STORAGE SYSTEMS

- UL 9540
- ASME TES-1
- NFPA 791

SYSTEM COMPONENTS

- UL 1973
- UL 1974
- UL 810A
- UL1741
- CSA 22.2 No. 340-201
- IEEE 1547
- IEEE 1679 Series

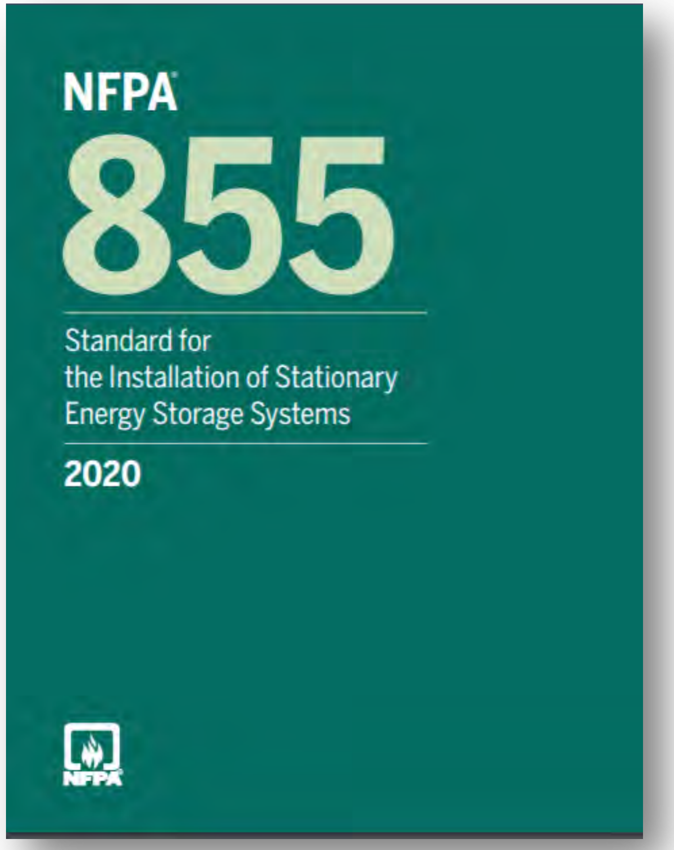
International Fire Code (IFC)® in Effect



https://www.iccsafe.org/wp-content/uploads/Master-I-Code-Adoption-Chart-OCT-2019.pdf

Codes & Standards – NFPA 855

- 2020 NFPA 855 Standard for the Installation of ESS
  - 1st Edition published
  - Scope reserved for next cycle based on appeal by utilities for exemptions.
  - Covers
    - ✓ Design
    - ✓ Commissioning
    - ✓ O & M
    - ✓ Deflagration Protection
    - ✓ Emergency Response
    - ✓ Decommissioning



Codes & Standards – IFC 2018

Example of some areas addressed:

- Hazard mitigation analysis
- Threshold & MAQ limits
- Size & Spacing requirements
- Explosion Protection
- Listed to UL 1973 or 9540
  - Modifications allowed based on large-scale fire testing (UL 9540a)

Codes & Standards – IFC 2021

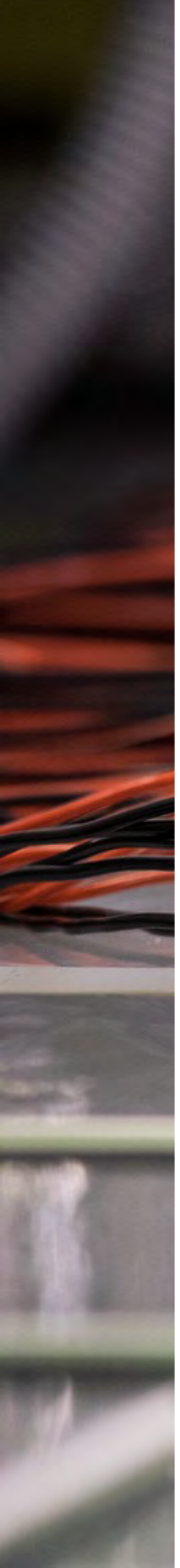
- Changes from 2018
  - Scope ads O&M, retrofit, commissioning, decommissioning
  - Exemption for telecom using Pb & NiCd @ < 60VDC
  - Suppression system based on 9540a
  - Dedicated/Non-dedicated use buildings
  - Explosion control: NFPA 68 or 69
  - Almost identical to NFPA 855

IFC Explosion Protection

Two options for meeting requirement:

1. NFPA 68 – Deflagration Venting.
   - Blow-out panels to protect structure from explosion based on max gas production in cell tests.

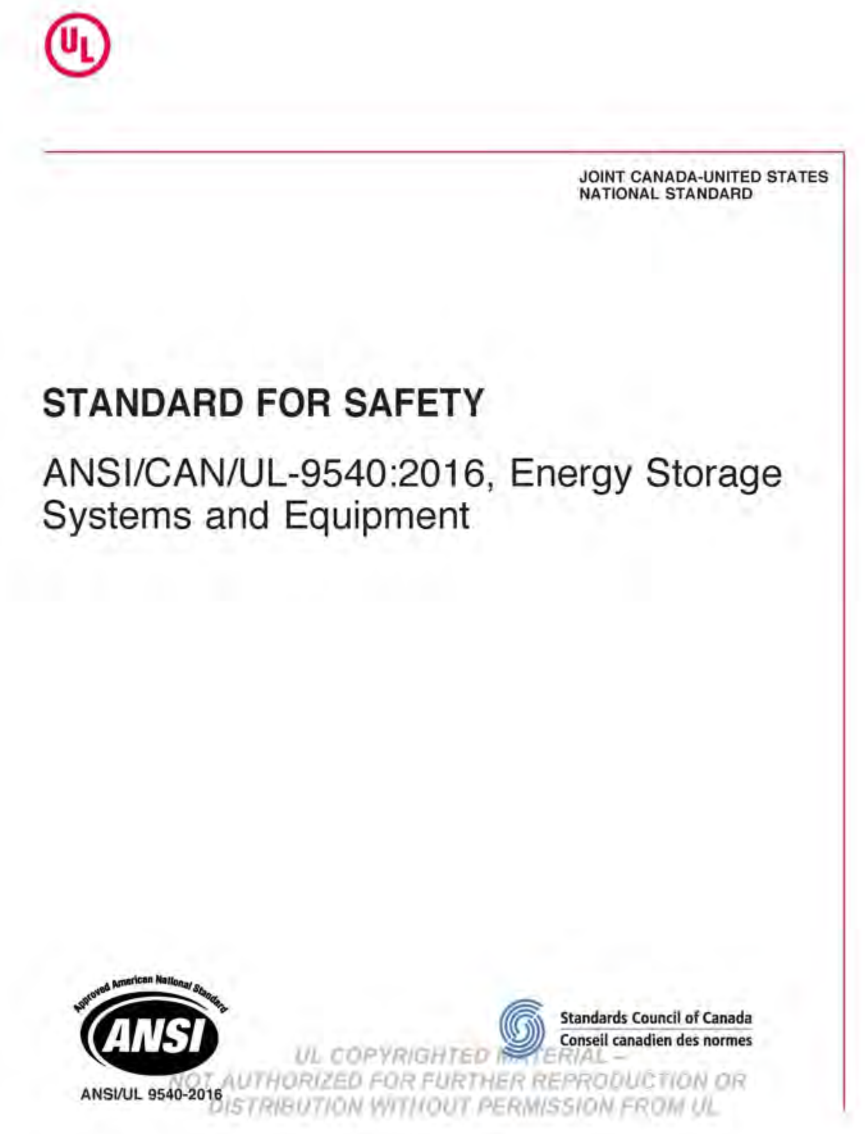
2. NFPA 69 – Deflagration Prevention.
   - Exhaust system designed to keep below 25% of LEL in area.



UL 9540A Test Method

Scope

- Evaluate fire characteristics of a battery ESS that undergoes thermal runaway.
- Artificially forces cells into thermal runaway (if possible)
- Evaluates/documents the resulting fire/explosion characteristics
- Test results used to determine fire and explosion protection required for an installation


JOINT CANADA-UNITED STATES
NATIONAL STANDARD

STANDARD FOR SAFETY

ANSI/CAN/UL-9540:2016, Energy Storage Systems and Equipment

Approved American National Standard
ANSI
ANSI/UL 9540-2016

Standards Council of Canada
Conseil canadien des normes

UL 9540A Test Methodology

- Evaluating/interpreting test results can be challenging

Credit: FM Global

Cell Level

↓

Module Level

↓

Unit Level

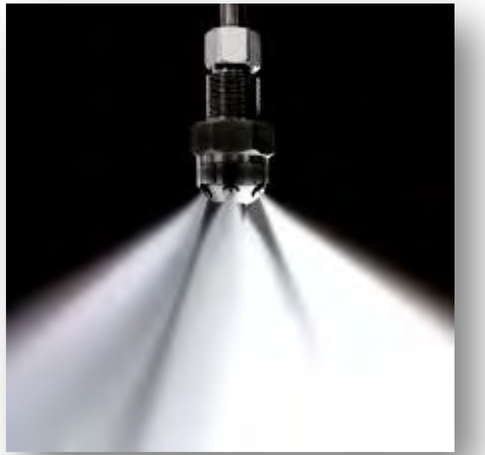
↓

Installation Level

Design Best Practices

- Design Best Practices
- System Design
- Warning Systems
- Incident Pre-Planning
- Incident Management

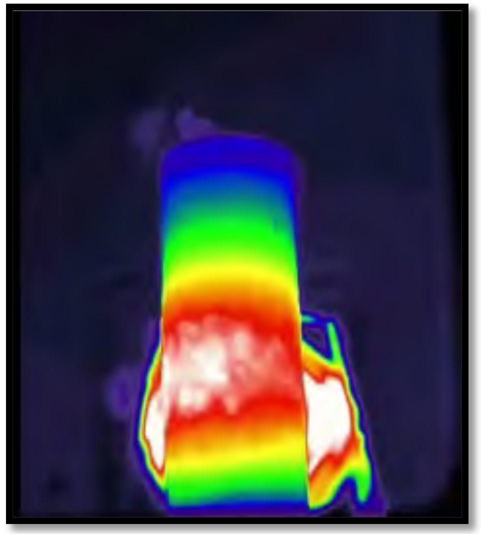
System Design
(dedicated use buildings)



- Exterior marking & visible alarm annunciation
- Gas detection
- 2-stage suppression (clean agent + water)
- Smoke & heat sensors for delayed detection post agent discharge
- Auto exhaust w/ sprinkler activation (exterior manual option available)

Warning systems

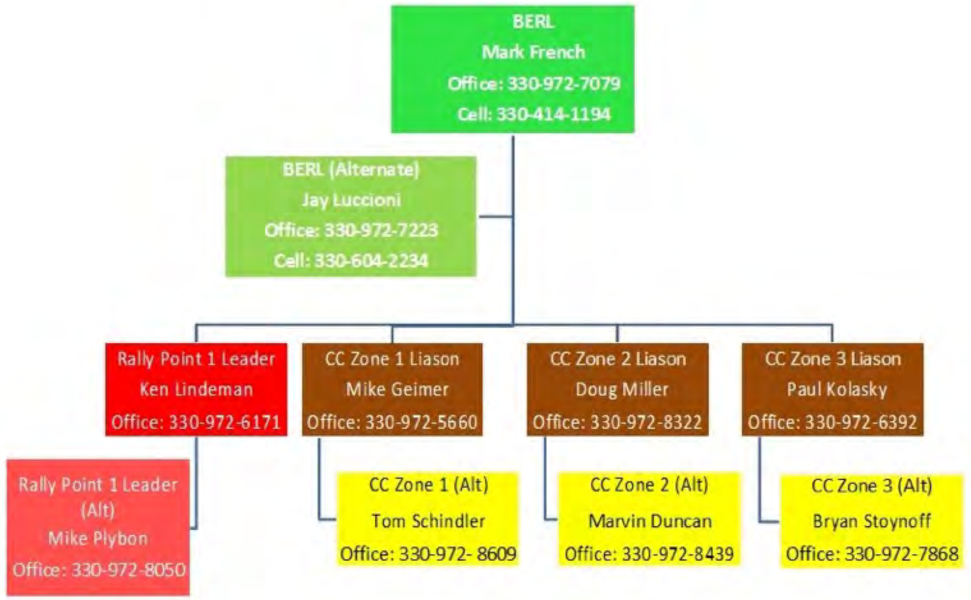
- BMS should remain powered and in communication with monitoring systems.
- Maintaining “eyes” on incident for long duration critical.
- Cell/module temperature & gas monitoring = key metrics



Incident Pre-Planning

- Provide local responders plans & locations of ESS.
- Plan for multiple scenario including decommissioning (detailed table-top exercises).
- Clear signage of hazards, disconnect locations, and contact info.

Emergency Contact List Phone Tree



Incident Management

- Life, property, environment are priorities.
- Rapid notification of 911
- Evacuate/shelter in place notifications as appropriate
- Identification of site manager to liaison with responders
- Decom/EOL, Emergency energy discharge

Pacific Northwest NATIONAL LABORATORY

Matthew Paiss, Technical Advisor
Battery Materials & Systems

Matthew.paiss@pnnl.gov

Thank you

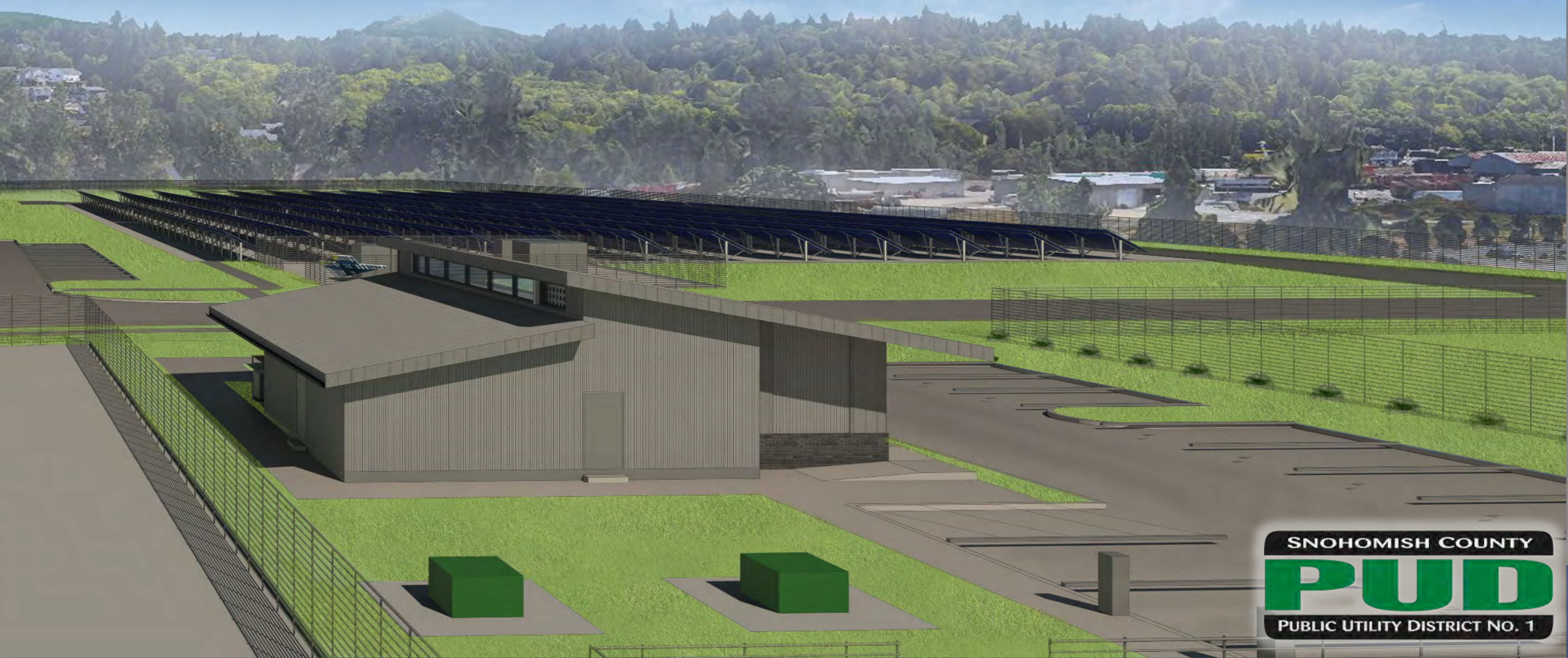
Dr. Imre Gyuk, DOE
Office of Electricity

U.S. DEPARTMENT OF ENERGY

PNNL-SA-152388

Energy Storage Digital Series - Solar Media Limited

Lithium Ion Battery Energy Storage Safety Lessons from Snohomish County PUD



SNOHOMISH COUNTY
PUD
PUBLIC UTILITY DISTRICT NO. 1

AGENDA

- Who is Snohomish PUD?
- PUD's Battery Energy Storage Systems
- Fire suppression - Basis of Design
- Fire suppression - Retrofits - MESA 1
- Fire suppression - New Construction - Arlington Microgrid
- Lessons learned so far…..
- Questions at the end

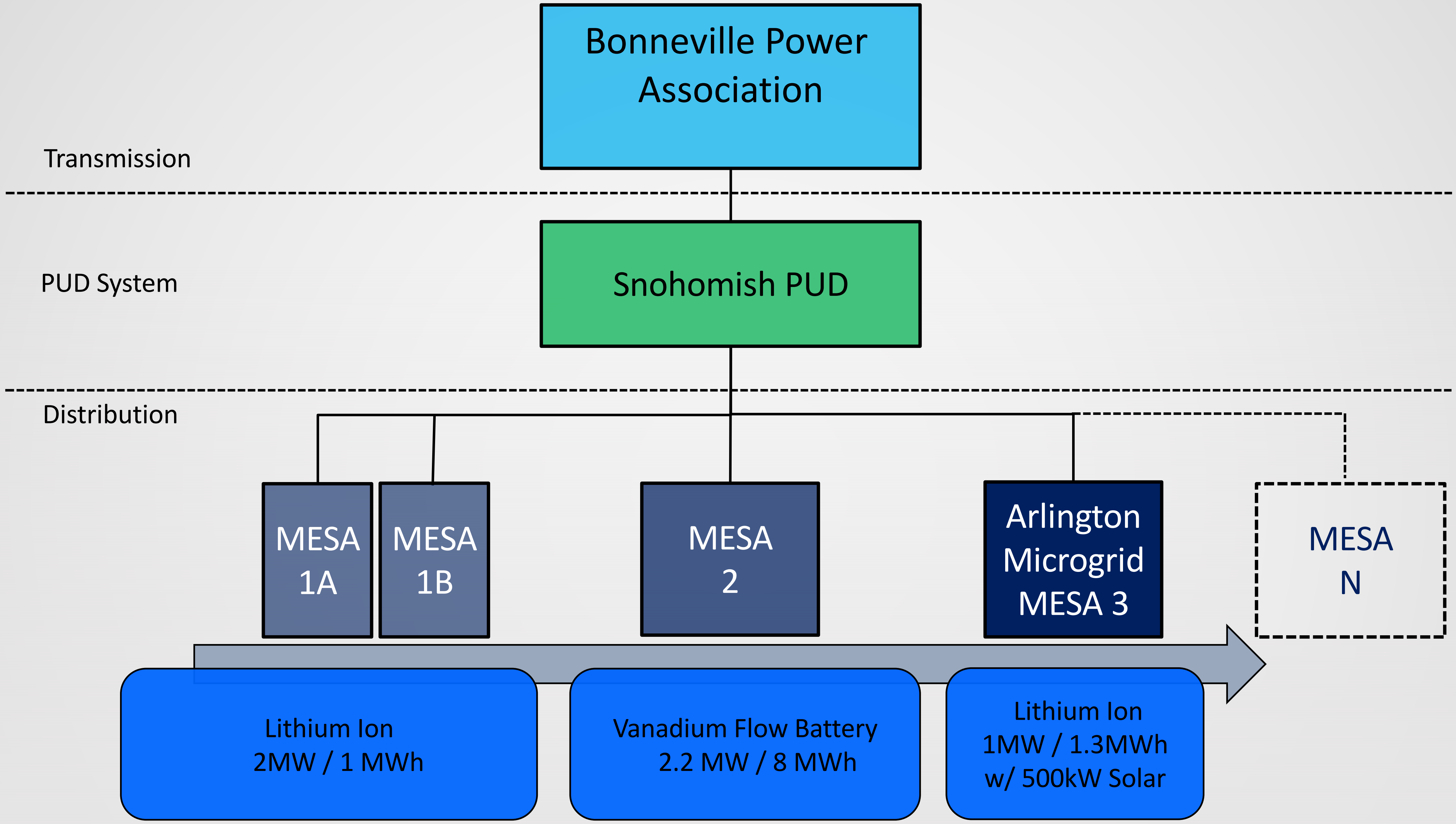
About Snohomish County PUD

- **Snohomish County & Camano Island**
- Second largest PUD in the state.
- **Began operation in 1949**
- Serves population of about 817,000
- **353,000 customers and growing**
- ~ 85% of our power is from BPA
- **3-Elected commissioners**

- **Five generation systems**
  - Jackson Hydroelectric Project – 100 MW
  - Young's Creek Hydro Project – 8 MW
  - Woods Creek Hydro Project – 650 kW
  - Hancock Creek and Calligan Creek – 6 MW each

- **Two existing battery storage systems** – MESA 1 and MESA 2

- **Third battery energy storage system**
  - The Arlington Microgrid



SNOHOMISH PUD
ARLINGTON MICROGRID

PUD's Energy Storage Portfolio

Fire Suppression System Basis of Design

- **DNV GL Final Report for Consolidated Edison, New York, NY**

  Considerations for ESS Fire Safety -

  Report No. OAPUS301WIKO (PP151894), Rev 3, January 18, 2017

- **New York Fire Department**

  608-01 **outdoor stationary battery systems** 4-23-19 publication draft.doc

  Notice of Public Hearing and Opportunity to Comment on Proposed Rule –

  Section 608-01 to Title 3 - Rules of the City of New York - Outdoor Stationary Battery Systems

DNV GL - ESS Fire Safety Report Summary

Because cooling is an inevitable need, a fixed suppression gas agent may reduce or mitigate flammability in an environment until ventilation and/or cooling strategies are implemented.

While the use of water demonstrates excellent cooling capability, it also potentially shorts out undamaged cells or neighboring modules. The use of water is a fully committed extinguishing tactic that is highly likely to result in a total loss of the asset.
Because it was noted that the aerosol test demonstrated extinguishment of the fire upon execution, aerosols can potentially serve as an initial attack for the fire followed by water as a backstop.

1 2

Therefore, DNV GL recommends the following:

- **Stage 1: If a system can limit cell cascading, a gas based suppression system may be considered for the first stage of fire fighting to extinguish a single cell fire and prevent flashover in a contained environment.**
- **Stage 2: If temperatures continue to rise or if an increasing level of smoke and gas is detected, forced ventilation and water extinguishing should be considered to cool the system and prevent further propagation of fire.**

Stage 1 provides an opportunity for avoiding collateral damage and total asset loss. Stage 2 provides a backstop for a situation when more than one battery cell is on fire. Both stages may also include some form of alarm or notification external to the battery system that notifies first responders of elevated risk.

- MESA 1A – Lithium Ion
  - Mitsubishi - GS Yuasa batteries
  - Parker Hannifin Power Conversion
  - 1MW/0.5MWh
  - Project Complete – July 2015
- MESA 1B – Lithium Ion
  - LG Chem batteries
  - Parker Hannifin Power Conversion
  - 1MW/0.5MWh
  - Project Complete – February 2016

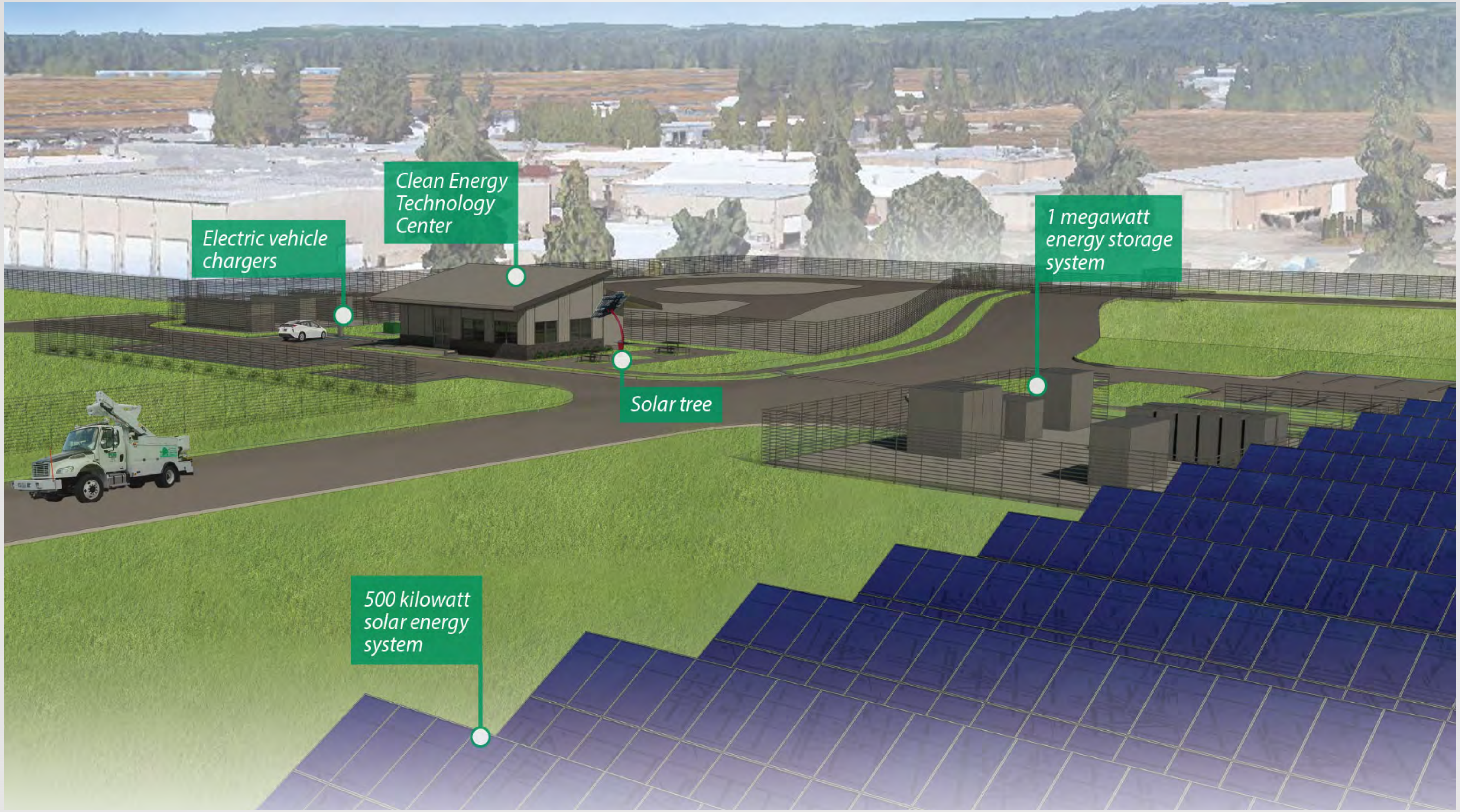
MESA 1 – Existing Fire Suppression Systems and Plan

- Four Smoke and Fire Detectors – hardwired to remote annunciator
- FM200 triggered if two detectors are activated
- Audible alarm and flashing light
- RTDs to provide battery temp to SCADA even when auxiliary power is lost.
- Arc-flash detection relaying
- Closed loop HVAC system to keep container at 72°F and constant humidity
- Reviewed by PUD’s insurance company and Fire Department
- Hazardous Material Management Plan – detail how to store, transport, monitor and respond to emergencies
- Training with PUD crews and local Fire Department

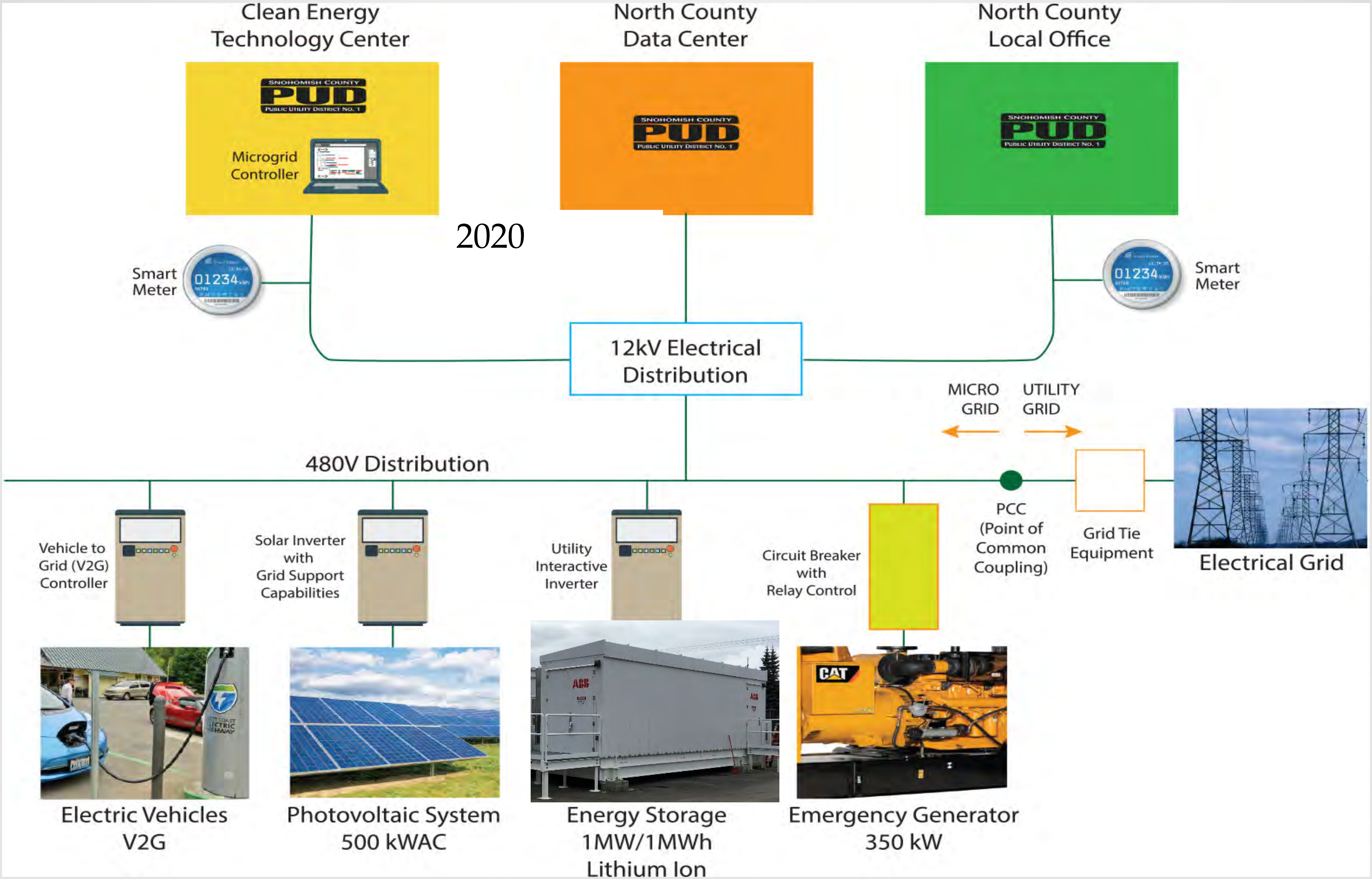
MESA 1 – Fire Suppression System Retrofit

- System design by fire technologies professional
- Automatic Venting control for prevention of deflagration gas build-up
  - (with 0-30 minute adjustable timer to start right after smoke alarm and FM200 triggered)
- Deluge system – Dry sprinkler system with Fire Department connection (FDC)
- Automatic Transfer Switch to allow for emergency power feed for critical functions such as cameras and monitoring.
- HMI displayed on laptop so systems can be viewed remotely by PUD crews and Fire Department prior to deluge activation
- Revised - Insurance company and Fire Department review
- Revised - Hazardous Material Management Plan
- Revised - Training with PUD crews and local Fire Department

Arlington Microgrid BESS – 1MW / 1.4MWh
ABB and Samsung SDI



SNOHOMISH PUD ARLINGTON MICROGRID



Mitsubishi & Nissan 2020

A&R Solar 2019

ABB 2020

SNOHOMISH PUD ARLINGTON MICROGRID

Microgrid BESS – New Construction - Fire Suppression System

<u>Three Stage System - based partially on DNV GL and NYFD reports and recommendations</u>

- **<u>First Stage:</u>**
  - Li-Ion Tamer - thermal run-away off-gas detection
  - Smoke and heat detector with horn strobe on the outside of container
  - Clean Agent Fire suppression system – Novec 1230

- **<u>Second Stage:</u>**
  - Timer to activate mechanical exhaust for removal of explosive gases with back-up manual switch.

- **<u>Third Stage:</u>**
  - Water – Fire Sprinkler Deluge System – dry pipe system connected to an FDC – Fire Department connection approximately 100’ away from containers. *Activate based on battery energy management (BEMS) fire data screen.*

Battery Energy Management System (BEMS) Display

- **The BEMS display is** located in the Clean Energy Center building fire control room.

- **At a minimum the screen shall display the following:**
  - Smoke and Heat detection system status
  - Stage 1 clean agent system status
  - Battery module and container temperatures
  - Gas Detection System status
  - Grid connection system status
  - Battery Stage of Charge (SOC)

  - A username and password shall not be required.

Lessons Learned so far ………

- Retrofits are difficult and expensive
- Deflagration Exhaust
  - Think about location and type?
  - Automatic (timer or via gas detection) – or - Manual?
- Deluge Water System
  - Dry or Wet type?
  - Automatic or with Fire Department connection ?
  - FDC should be located 100′ - 200′ away from container and within 50′ +/- of a hydrant
  - Do you need containment?
  - Will the doors hold water and how do you drain the container?
- Coordination and training with local agencies and fire department
- Training with internal crews
- Insurance company notification

Thank you!

Questions?

Matt Paiss (PNNL) & Scott Gibson (PUD)