Pacific Northwest NATIONAL LABORATORY

PNNL-36330

Battery Energy Storage System Safety Report

Design Considerations for Electric Cooperatives

August 2024

Matthew Paiss
Vince Sprenkle
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U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99354

Summary

With the passage of the Bipartisan Infrastructure Law and the Inflation Reduction Act, as well as the falling costs of renewables, battery energy storage systems are becoming a more attractive generation and capacity source for many utilities. With more utilities adopting this technology, the benefits and challenges of commissioning these types of systems are becoming clearer, specifically around the area of safety. This report will provide an overview of the codes and standards that have been adopted in the last few years around stationary battery energy storage systems and provide rural electric utilities some considerations to think about as they deploy this technology.

Acknowledgments

This project was supported by funding from the Department of Energy's Office of Electricity, Energy Storage Program. The authors of this report would like to thank Lauren Khair and Michael Leitman (National Rural Electric Cooperatives Association), Vince Sprinkle (Pacific Northwest National Laboratory), and Dr. Mohammed Kamaludeen (Department of Energy) for their support.

Acronyms and Abbreviations

AFB	Air Force Base
AHJ	Authority Having Jurisdiction
BESS	Battery Energy Storage Systems
C&S	codes and standards
DOE	Department of Energy
DoD	Department of Defense
G&T	generation and transmission
IBC	International Building Code
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
NFPA	National Fire Protection Association
NRECA	National Rural Electric Cooperatives Association
OSHA	Occupational Safety & Health Administration
PNNL	Pacific Northwest National Laboratory
RESDP	Rural Energy Storage Deployment Program
RFP	request for proposal
UFC	United Facilities Criteria
UL	Underwriters Laboratories
U.S.	United States
WREA	West River Electric Association

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1.0 Introduction

The National Rural Electric Cooperative Association (NRECA) is the national trade association representing nearly 900 electric cooperatives and other rural electric utilities. America's electric cooperatives are locally owned by the people that they serve and compose a unique sector of the electric industry. From growing regions to remote farming communities, electric cooperatives power 1 in 8 Americans and serve as engines of economic development for 42 million people in 48 states, serving across 56 percent of the nation's landmass. Electric cooperatives operate at cost and without a profit incentive. NRECA's member cooperatives include 64 generation and transmission (G&T) cooperatives and 832 distribution cooperatives. The G&Ts purchase, generate, and transmit wholesale power to distribution cooperatives that provide retail electric service to the consumer-members at the end of the line. Collectively, cooperative G&Ts generate and transmit power to nearly 80 percent of the distribution cooperatives in the nation.

Pacific Northwest National Laboratory (PNNL) is one of 17 national laboratories funded by the Department of Energy (DOE) to solve some of the most difficult challenges in our world. With its over 6,000 scientists and engineers, PNNL connects cutting-edge fundamental scientists with end-use domain experts to discover and develop new energy storage technologies that can support a future decarbonized world, including a clean, resilient electric grid. PNNL research provides a clear understanding of the technology needs for integrating safe energy storage into the grid. Staff at PNNL work with utilities and broad stakeholders across industry to assess the optimal role for energy storage installations under local operational and market conditions. With expertise in materials development for a wide range of battery chemistries, grid controls, codes and standards support for system safety, and techno-economic assessments, PNNL is one of the leading national laboratories working to modernize the grid.

National investment in clean energy deployments, workforce development, and domestic supply will see significant growth in the coming years. The provisions of the Infrastructure Investment and Jobs Act call out energy storage codes and standards (C&S) specifically as areas of interest to guide the safe deployment of battery energy storage systems (BESS) at scale. Further investment as a result of the $369 billion Inflation Reduction Act, including new tax credits for energy storage and support for domestic manufacturing and supply chain, will also significantly boost energy battery deployments. Rural electric utilities are newer to the battery energy storage area. As of the beginning of 2024, more than 50 NRECA member utilities across the country have deployed one or more BESS projects, many of these installed along with other technologies as part of hybrid generation plants (either owned or under a power purchase contract) or as part of a microgrid.

The goal of this document is to provide an overview of battery energy storage safety codes for lithium-ion BESS, especially in light of the significant amount of federal funding that is available for these types of demonstration projects to utilities.

2.0 State of Battery Energy Storage System Safety

While rare, incidents related to stationary BESS have resulted in significant public attention, loss of confidence, and increasing resistance to BESS project development. Association with the numerous failures of often unlisted consumer devices are connected to the safety of utility-scale BESS installations, a guilt-by-association that warrants more education. Nevertheless, there have been several very public incidents that have resulted in large property loss, as well as injuries and fatalities to emergency responders. Advancements in code, as well as maturity of manufacturer products, are improving the safety of BESSs as highlighted in a recent report by the Electric Power Research Institute, *Analysis of Failure Root Cause*.[1] Stationary BESSs have experienced tremendous growth in the past five years for both behind-the-meter as well as in-front-of-the-meter locations. According to the DOE's Energy Information Administration, total cumulative installed utility-scale (1 MW+) battery storage capacity was expected to reach about 16 GW by the end of 2023, with total deployed capacity expected to nearly double to exceed 30 GW by the end of 2024.

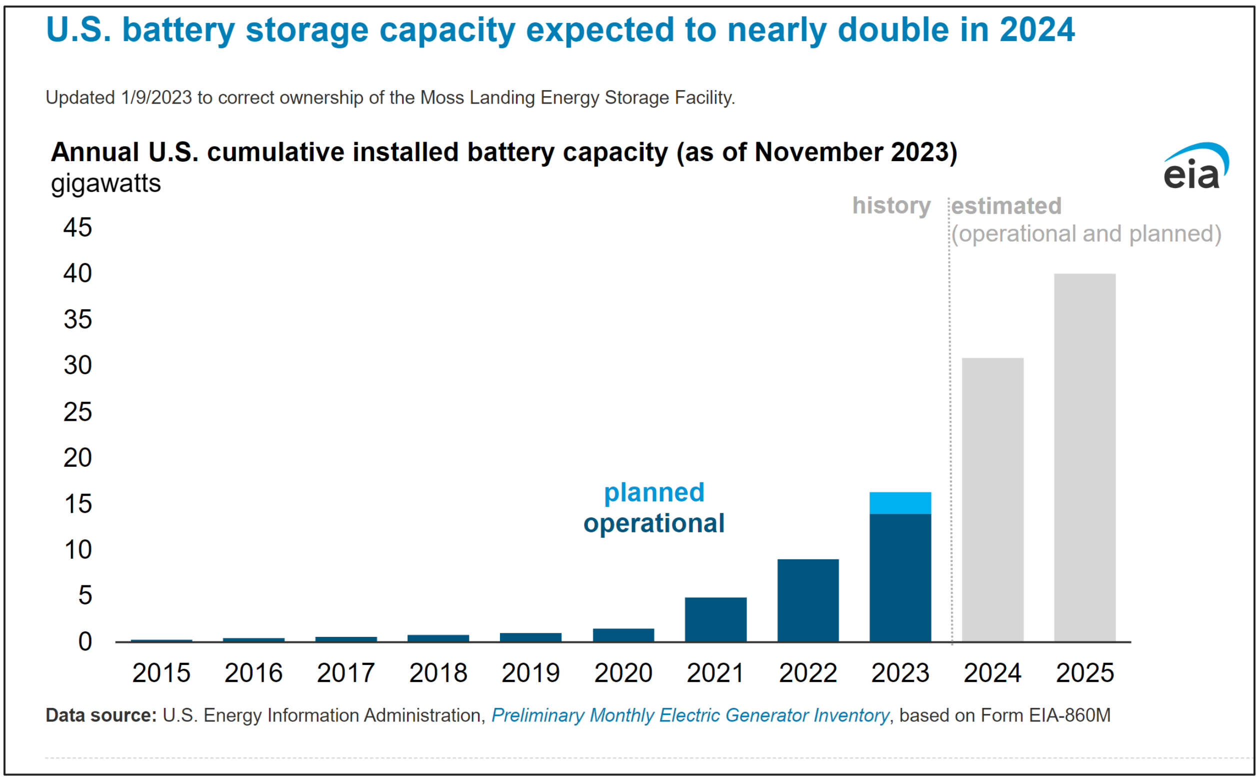

Figure 1. Cumulative U.S. Installed Battery Capacity

With local, state, and federal goals for decarbonization of the grid, federal funding of projects is growing at the fastest levels seen in history. While the term "energy storage" includes a broad family of technologies capable of storing electricity for delivery at a later time, this paper will focus specifically on electrochemical BESSs. There are multiple chemistries within this electrochemical family, as depicted in Table 1.

[1] https://www.epri.com/research/products/000000003002030360

Table 1. Common Lithium-ion Chemistries

Acronyms	Name
NMX	High Nickel Manganese
NMC	Nickel Manganese Cobalt
NCA	Nickel Cobalt Aluminum
LFMP	Lithium Manganese Iron Phosphate
LFP	Lithium Iron Phosphate
LMO	Lithium Manganese Oxide
LTO	Lithium Titanate

Lithium-ion chemistry is the most common electrochemical battery technology being installed today, bringing with it certain safety concerns due to the flammable organic electrolyte used as an ion transport medium between the cathode and anode of the battery. There are a number of different anode/cathode chemistries, yet the potential for separator failure leading to direct short circuit is possible with each chemistry.

There are a number of different failure modes that can result in an overheating condition commonly called thermal runaway. This refers to an exothermic reaction resulting in venting of flammable gases, jet flames, and risks of deflagration. These failure modes will be discussed in more detail in Section 4.0.

The safety of a BESS requires a systems approach. Simply utilizing a cell from a reputable Tier 1 supplier will not ensure safe operation, as demonstrated by various failures in recent years aggregated in the Electric Power Research Institute BESS Failure Database.[2] Key components of the full system design, including thermal and environmental management, battery management system, power conversion system, enclosure, grounding, communications, workmanship, and operations and maintenance, each play a key role in the safe life cycle of a lithium-ion BESS. Key factors among this list are quality/compatibility of integration and workmanship.

The growing number of examples of system failures in the database serve as both data points for improvements in design gaps as well as lessons learned to inform C&S. The application of these lessons is critical to reduce risk and should be incorporated at the earliest steps in a BESS project. The following sections will provide details in each area where safety has touchpoints and will include recommendations to assist in project development.

[2] https://storagewiki.epri.com/index.php/BESS_Failure_Event_Database

3.0 Overview of Codes and Standards

C&S are the documents that guide the installation, operation, and minimum safety requirements of performance for BESS.[3,4] They include fire codes, electrical codes, and BESS-specific product safety and installation standards. The C&S for stationary BESS have seen gradual refinement with each revision of the relevant documents.

There are several opportunities to facilitate a clear path for key stakeholders including manufacturers, utilities, authorities having jurisdiction (AHJ), and emergency responders. One of these is adopting the most current edition of model fire codes and product safety standards. Another is the education of these stakeholders in the requirements of these C&S, as well as any technology-specific emergency response recommendations. BESS manufacturers should be designing, installing, and operating to the best practices or in the most current published code, not the minimum locally adopted requirements.

The key C&S relevant to stationary BESS and adopted in the U.S. are found in the graphic in Figure 2.

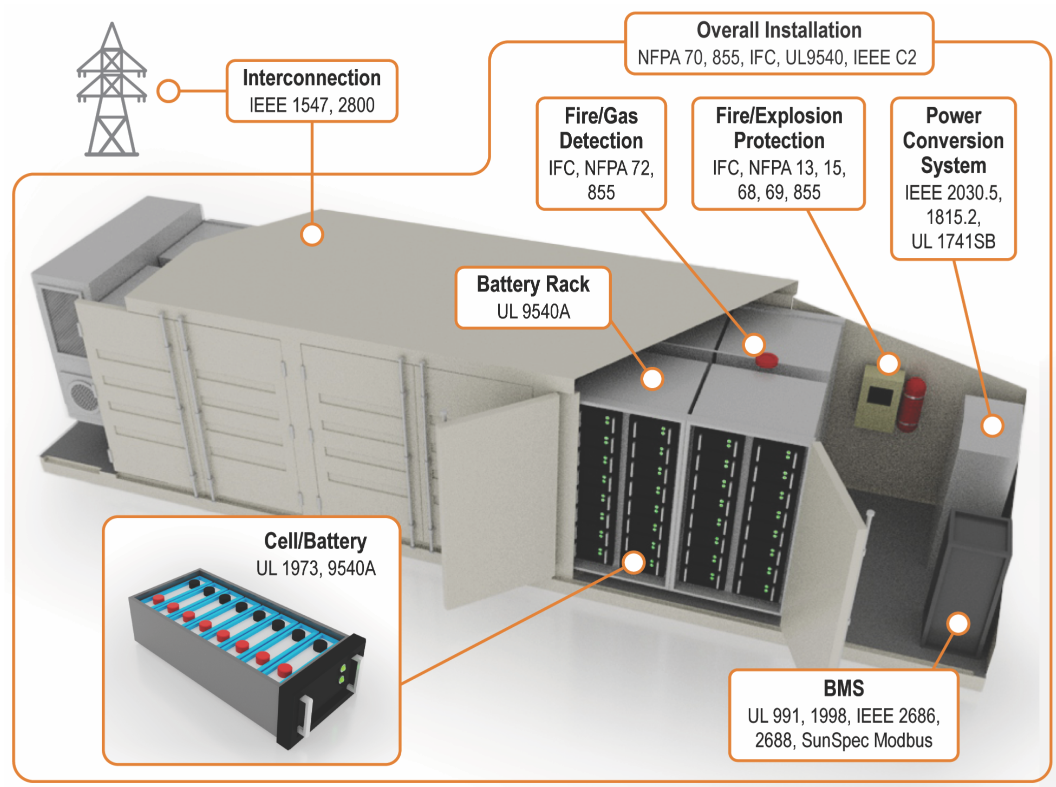

Figure 2. Key Codes & Standards Graphic

[3] Vartanian, C., Paiss, M., Viswanathan, V. *et al.* Review of Codes and Standards for Energy Storage Systems. *Curr Sustainable Renewable Energy Rep* **8,** 138–148 (2021). https://doi.org/10.1007/s40518-021-00182-8

[4] M.D. Paiss, R. J. Franks, C.G. Searles, J.B. Twitchell, C.K. Vartanian, M. Ropp, V.L. Sprinkle. 2022. “Study of Codes & Standards for Stationary Energy Storage Systems: A Report to Congress” PNNL-32789

The items in the box "Overall Installation" are the overarching C&S that address the requirements for complete BESS design and installation, which include the following Standards Development Organizations:

- The National Fire Protection Association (NFPA)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Code Council, which publishes the International Fire Code (IFC).
- UL Solutions, which publishes product safety standards.

The key documents from these organizations related to BESS include:

- NFPA 70 – National Electric Code
- IEEE C2 – National Electric Safety Code
- IFC – International Fire Code
- NFPA 855 – Standard for Installation of Stationary BESS
- UL 9540/9540A – Standard for Safety: Energy Storage Systems & Equipment.

Table 2 below is a descriptive compilation of key Codes & Standards.[5]

Table 2. Key Codes & Standards

ESS Topic	Recommended Codes and Standards
Fire and smoke detection, fire suppression, fire, and smoke containment	NFPA 1, NFPA 13, NFPA 15, NFPA 101, NFPA 850, NFPA 851, NFPA 855, IBC, and IFC
Ventilation, exhaust, thermal management, and mitigation of the generation of hydrogen or other hazardous or combustible gases or fluids	NFPA 1, NFPA 855, NFPA 68, NFPA 69, IEEE 1635/ASHRAE21, IFC, IMC, NFPA 70
Egress and access (normal operations and emergency), physical security, and illumination	NFPA 1, NFPA 855, NFPA 101, IBC, IFC, and local zoning codes
Electrical safety, emergency shutoff, workings pace, and electrical connections/installation for installations on the *customer side* of the meter	NFPA 70 and 70E
Electrical safety, emergency shutoff, working space, electrical connections/installation for installations on the *utility side* of the meter	IEEE C2
Anchoring and protection from natural disasters (seismic, flood, etc.) and the elements (rain, snow, wind, etc.)	IEC 60529, IEEE 1375, IEEE 693, UL 96A, IBC, IFC, NFPA 70, and NFPA 780
Signage	ANSI Z535, NFPA 1, NFPA 70, NFPA 70E, NFPA 101, NFPA 704, NFPA 855, IBC, and IFC
Spill containment, neutralizing, and disposal	NFPA 1, IPC, IFC, and IEEE 1578
Communications networks and management systems	NFPA 855, IEC 61850

[5] P.C. Cole, D.C. Conover, Energy Storage System Guide for Compliance with Safety Codes and Standards. 2016, Pacific Northwest National Laboratory, Sandia National Laboratories

These documents are enforced through adoption of a model code or by being referenced in an adopted code. Adoption is on a federal, state, or local basis, and the frequency of updates varies. The IFC and NFPA standards are updated every 3 years, with adoption of the most current edition typically taking place between 1 and 6 years later. BESSs on federal property may follow the Unified Facilities Criteria (UFC 3-600-01 Fire Protection Engineering for Facilities).

Figure 3 provides an example of the patchwork effect of inconsistently adopting the IFC across the U.S. This is clearly a challenging environment for manufacturers seeking to meet the requirements in each state they install product in. Additionally, from a safety perspective, having a state enforcing language that was created 5 years prior is clearly a challenge in a rapidly developing industry.

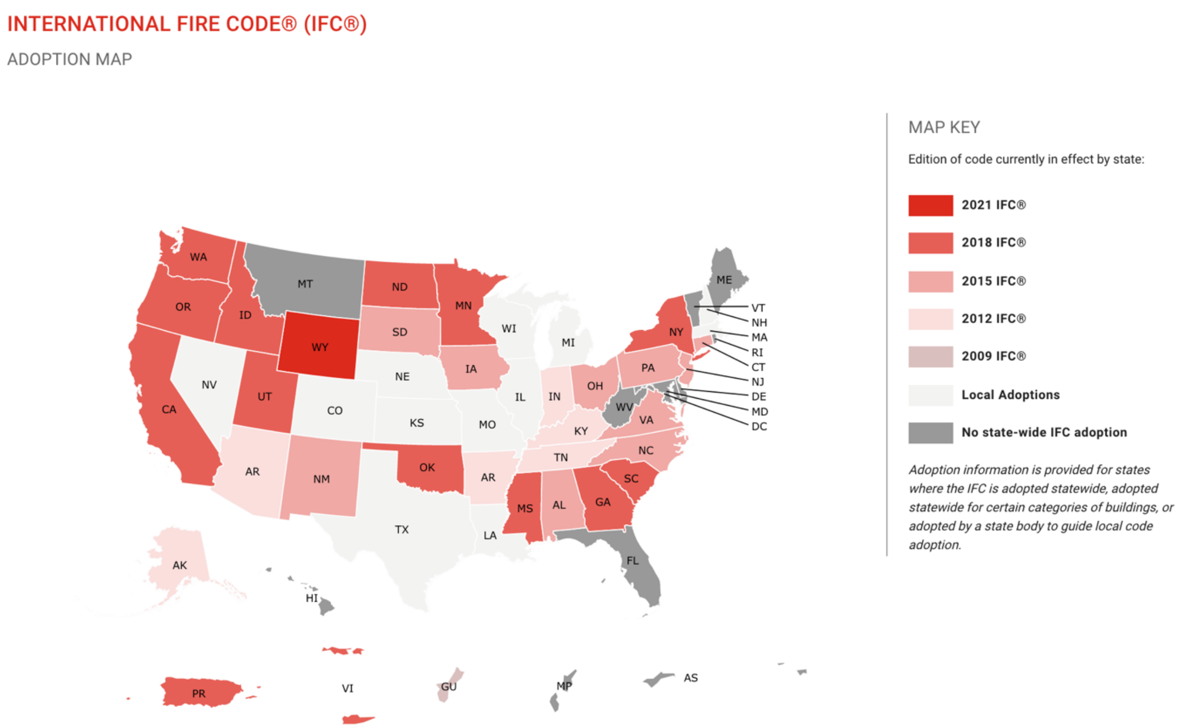

Figure 3. State Adoption by Code Edition

States that do not adopt on a state-wide basis create an even more challenging regulatory landscape. On top of the inconsistent adoptions are changes made to the codes through a process called amendments. This is a process where sections of the model code are modified or removed from the final adoption, in some cases due to industry lobbying. One example is states that have consistently removed requirements for automatic sprinklers in residential structures at the encouragement of home builders based on cost rather than safety concerns.

The key BESS product safety standards include UL 9540, UL 1973, UL 1741, and IEC 62933. In the U.S., certification to UL 9540 is cited in both NFPA 855 and the IFC as a requirement for all BESS. There are minor exemptions for some select chemistries and occupancies such as lead-acid and Ni-Cd in telecom and utility applications. Because the key model codes published by the International Code Council and NFPA are updated triennially, there are often periods of adoption where changes to one code are not reflected in another, causing confusion and interpretation challenges.

For utilities that have federally owned property in their service area, there are often different sets of building and fire codes than those adopted outside the gates of those properties. An example with ESS is that NFPA 855 or the UFC may be the enforceable code on a Department of Defense (DoD) base, while the IFC is enforced in other utility service areas. **The key is to determine the enforced code for the local jurisdiction.**

3.0 UL 9540 Listing

The product safety standard for BESS is UL 9540: Standard for Safety Energy Storage Systems and Equipment. The document is in its third edition published in 2023. This standard covers batteries listed to UL 1973, inverters listed to UL 1741, and assesses the full integration and operation of the complete BESS. This will include the construction, mechanical tests, environmental tests, and manufacturing and production tests. BESS integrated into an enclosure will include fire and explosion protection, which is based on data derived in the UL9540A Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems. This document is in its fourth edition published in 2019.


ANSI/CAN/UL 9540:2023

JOINT CANADA-UNITED STATES NATIONAL STANDARD

STANDARD FOR SAFETY

Energy Storage Systems and Equipment

ANSI/UL 9540-2023

BESSs that can discharge more than 50 kWh or that are placed closer than 3 feet from other BESSs are required to undergo fire testing. This series of fire tests characterizes the fire and explosion risks of an electrochemical battery and provides valuable data for the manufacturer and fire protection engineers to address safe designs and complete installations. The testing is done at the cell, module, unit (or rack), and installation level if needed. Because this is a series of destructive tests, it is important to perform the tests on representative samples of cells, modules, or units. **The complete fire test data should be provided to the AHJ from their vendor and/or integrator.**


ANSI/CAN/UL 9540A:2019

JOINT CANADA-UNITED STATES NATIONAL STANDARD

STANDARD FOR SAFETY

Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

ANSI/UL 9540A-2019

Standards Council of Canada Conseil canadien des normes

Fire testing does not produce a certification or listing, but it is often a requirement to receive the UL 9540 listing. The testing lab will produce a UL 9540A report that is often provided to fire protection engineering firms to assist in the design of fire and explosion protection systems, or to code officials to approve projects.

NFPA 855 requires that BESSs be listed to UL9540. This is different than having equipment field listed and labeled as meeting the requirements of UL9540. A “field listing” does not include factory inspections for quality assurance, and there are increasing numbers of AHJs that will not accept a field evaluation in lieu of product certification.

There are a number of qualified testing labs that can complete certification and testing to UL standards.

4.0 Fire and Explosion Protection

As discussed in Section 2.0, all current lithium-ion chemistries that are available on the market today are prone to thermal runaway. Risks for fire or explosions exist for all chemistry families. There are some chemistries that are more heat tolerant and are therefore less prone to experience this type of failure—however, with sufficient heat, these will eventually enter thermal runaway and emit large volumes of flammable gases. The process can begin when a cell reaches between 80–120 °C, at which point the liquid electrolyte will start vaporizing. When pressure inside the cell is high enough, the cell will vent the gases. Further heating will then cause degradation of the cathode, leading to further heating and ultimately the plastic separator between the anode and cathode beginning to melt. Initially, this will stop the ions from passing through and is identified by a collapse in the cell voltage. Continued separator melting will result in a direct shorting of the anode and cathode, and all energy in the cell will be rapidly released in an exothermic reaction. This will produce significant amounts of flammable gases, heat, and possible jet flames of considerable length. If not ignited, the risk of a vapor cloud explosion, also known as a deflagration, becomes a significant hazard.

Preventing an explosion begins with passive protections in the module that will limit the failure of one cell to propagate throughout the module. However, with larger format cells, there is the potential for explosions in smaller enclosures with only a single cell failure.

The IFC and NFPA 855 require fire-suppression systems for battery types where flames extended outside the unit during a unit-level fire. Non-residential systems must be evaluated in the "Installation Level Test," which includes target units to evaluate temperature rise and potential for elevated temperatures to the enclosure walls or the room where they will be installed.

Explosion controls are also required in the IFC, with two options to meet this requirement:

1. **Deflagration venting designed to NFPA 68.** This is commonly known as blow-out or pressure vents designed to direct fire balls and pressure waves away from people or exposures and to protect the integrity of the enclosure or building. This option may be removed in the next edition of NFPA 855 as a sole solution due to concerns over build-up of flammable gases.
2. **Deflagration prevention designed to NFPA 69.** This is a mechanical exhaust system that must keep flammable gases below 25% of the lower explosive level of the gas mixture. These systems must operate very quickly, move large amounts of air, and have backup power for the duration of the incident (which may be an extended period based on data from recent incidents).
3. **NFPA 855 includes a third option.** Where approved, ESS cabinets designed to make sure that no hazardous pressure waves, debris, shrapnel, or enclosure pieces are ejected, as validated by installation-level fire and explosion testing and an engineering evaluation compliant with 9.1.5 that includes the cabinet, shall be permitted in lieu of providing explosion control that complies with NFPA 68 or NFPA 69.

   An example of the above could be a system where the cabinet doors are designed to open when triggered by gas, smoke, or heat detection to allow passive exhausting of gases, such as the IntelliVent™ system from PNNL.[6] This approach offers many advantages over

[6] https://www.pnnl.gov/available-technologies/intellivent

mechanical exhaust systems and may still be designed to meet requirements of NFPA 69 (deflagration prevention).

A few of the benefits of utilizing doors for deflagration prevention include:

- Rapid gas removal at a very early stage in the incident with no continual power requirements for long-term ventilation system support.
- Visual confirmation of conditions in cabinets without a close approach.
- Remote manual activation to open doors from a safe distance.
- Fail safe design. Loss of power results in all doors opening.

5.0 Lessons Learned

In 2020 with funding from the DOE's Office of Electricity, NRECA Research started the Rural Energy Storage Deployment Program (RESDP) to deploy BESSs in collaboration with rural electric cooperatives to increase resilience at critical infrastructure across the United States. Rural electric cooperatives have limited but growing experience deploying BESSs, with over 75 energy storage systems deployed in the United States. NRECA Research has been able to utilize technical assistance from PNNL and Sandia National Laboratories to support the cooperatives participating in RESDP through the planning and commissioning of their battery projects.

This technical assistance in energy storage C&S has been critical to the success of RESDP, and lessons learned can be illustrated through the project at Ellsworth Air Force Base (AFB) in partnership with West River Electric Association (WREA). WREA is a small cooperative that serves about 13,000 members located near Rapid City, South Dakota. The cooperative has 55 employees and a service territory of about 4,500 square miles in the western part of the state. Ellsworth AFB is an economic engine for this area of South Dakota, employing many people in the surrounding communities. Given the base's importance, WREA is committed to making sure their member has the resilience it needs to meet its mission even though the co-op only serves a small portion of the total facility. This commitment led the cooperative to pursue its first battery energy storage project as part of the RESDP project.

The lessons learned started early in the project, with the process of developing a request for proposal (RFP) for a BESS. As was mentioned earlier in this document, the C&S for BESS have been evolving and continue to be improved through each iteration. In many RFP documents, there is a section asking bidders to state that their solution meets all applicable C&S that were listed in the RFP solicitation. As part of the documentation, WREA made sure that each required standard and code was listed in the RFP with the corresponding year and/or version—this ensured that, from the start, there was no interpretation needed from the bidders about what will be required for this project.

For example, because this project is located on federal property, there are additional C&S that utilities and BESS developers need to be aware of and comply with. The NFPA 855 installation code is one of the additional codes required. This code entails additional steps to ensure compliance for BESSs installed on federal property and is a new code for many in the energy storage industry. When this project was started in late 2020, NFPA 855 had been recently updated to include "cabinets" in the requirement for controls.[4]

This update identified a gap between the installation code (855) requirement and the product safety standard requirements in UL 9540. Explosion controls require data from the UL 9540A Large Scale Fire that are used by fire protection engineers to design the system. A BESS cabinet may have received its "listing" to UL 9540, but if it was being installed in an area where NFPA 855 was enforced (as is the case for many federal facilities), then the cabinet would be required to have an approved method of preventing or controlling an explosion should thermal runaway occur within the ESS.

This was the first time that many manufacturers were seeing this new design requirement and provided an educational opportunity for all parties in the project. This additional compliance step necessitated additional time and cost on the manufacturer's part, causing significant delays in the project's timeline to achieve compliance. Additionally, it required the battery energy storage integrator to work closely with their battery manufacturer to collect data on the cell, module, and unit tests that are required to make sure that the fire is controlled in the case of a thermal runaway event.

Another key document that affected this installation was the Unified Facilities Criteria – Fire Protection Engineering (UFC 3-600-01). This is essentially the Fire Code for DoD facilities and included updates that required unoccupied structures to be separated 100 feet away from occupied structures. DoD, like the rest of the utility industry, has been updating their C&S to meet new industry needs, so it is important that any utility that is considering deploying a new BESS on federal land check with their AHJ.

WREA's small step of explicitly placing the version and/or year of the code and standard in all procurement documents helped avoid the need for substantial change orders for the project and avoided any additional financial burden on their small not-for-profit cooperative. As utilities continue to plan for battery energy storage projects, it is important that they are familiar with the new C&S that govern BESS deployments and use the most up-to-date C&S in their procurement documents. Doing so will make sure they are clear with their vendors about their requirements and are deploying systems that use the best available compliance standards, correct for their jurisdiction, to help mitigate any disagreement that could cause delay or increased costs.

For more information on what rural electric utilities should know about BESS procurement, please visit our guide at:https://www.cooperative.com/programs-services/bts/Documents/Reports/Battery-Energy-Storage-Procurement-Guide-June-2021.pdf.

6.0 Commissioning/Decommissioning

Commissioning is a very important phase of the project life cycle that focuses on the verification and documentation of all the systems and assemblies planned, designed, installed, tested, and maintained to meet the owner's project requirements.

The benefits of commissioning include but are not limited to:

1. Verifying that systems are installed correctly and functioning as intended on site;
2. Making sure that safety systems and controls are installed correctly and functioning as intended;
3. Identifying defects before they go out of warranty; and
4. Confirming that the owner has thorough documentation for ongoing operations and for any future maintenance/troubleshooting.

Commissioning During Project Phases

As shown in Figure 4 below, commissioning activities span the planning, procurement, deployment and integration, and operation and maintenance phases of the project. Commissioning responsibilities are split between the supplier and the project owner. However, it is beneficial to engage a commissioning professional who will be responsible for tasks such as:

1. Reviewing owner project requirements and basis of design;
2. Developing construction checklists and verifying proper completion; and
3. Maintaining an issues log.

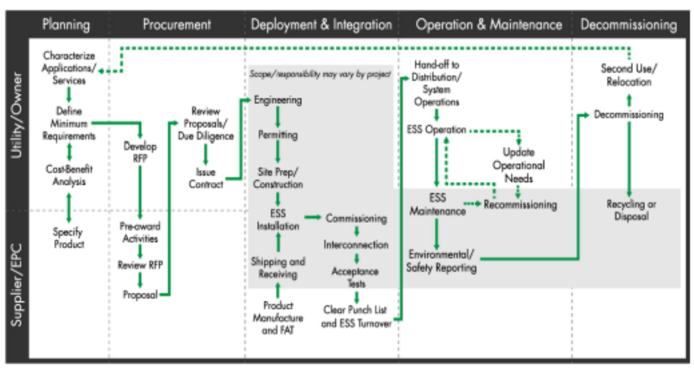

Figure 4. Project Activities Timeline

Decommissioning

At the end of life of one or more components of the BESS, or if the system is no longer needed to serve the grid at its current location, the system will have to be decommissioned. A qualified team of multidisciplinary experts are essential for a successful decommissioning process.

A decommissioning plan that includes a decommissioning scope, objective, end state, and strategy; a risk management assessment; a safety plan; an environmental assessment; and recycling and disposal considerations are also essential to the success of the process. NFPA 855 requires the plan be submitted to the AHJ before work commencing.

It is important to discuss the difference between a planned and unplanned decommissioning. An unplanned decommissioning is often the result of a system failure and may involve multiple agencies depending on the scale of the incident. Additional challenges may include forensic investigations, hazard mitigations, and stranded energy risks.

6.1 Training

Those handling lithium-ion batteries and responding to safety events are encouraged and sometimes required to complete specialized training. Education for emergency responders should address battery incidents for the variety of applications and locations where they will be found. Additionally, any emergency response includes proper handling and disposal of the HazMat. All of these trainings cover the many dangers of lithium-ion batteries including electrical hazards, thermal runaway (depending on battery configuration), responding to damaged batteries, exposure to battery chemicals, battery fire, exposure to dangerous fumes, and compressed gases. The emergency response trainings cover many scenarios for lithium-ion events including standard residential and workplace responses, electric vehicle crashes and fires, and BESS fires and explosions. These emergency response trainings are typically set up to address fire codes surrounding lithium-ion battery fires.

There are trainings directly addressing the more standard National Fire Protection Association codes pertaining to battery storage—NFPA 70E, which addresses safe work practices for protection personnel by reducing exposure to electrical hazards, is a common offering on many training websites.[7] Because the Occupational Safety & Health Administration (OSHA) 1910 Subpart S and 1926 Subpart K address this code to reduce workplace injuries due to shock, electrocution, and arcing, OSHA offers online and in-person trainings to cover this code. In fact, OSHA offers course OSH 254, which directly addresses lithium-ion batteries in the workplace—however, this training is more focused on safe handling, storage, and shipment of batteries not in a battery storage context.[8]

NFPA 855 directly addresses batteries in a stationary battery storage arrangement, providing the minimum requirements for mitigating hazards associated with BESS. In the NFPA *Energy Storage and Solar System Safety Training Course*, trainees will learn basic battery and electrical theory, types of batteries, failure modes and hazards, pre-incident planning, and emergency response procedures. Emergencies emulated include electrolyte releases, overheated batteries, battery fires, and environmental events.

UL's Fire Safety Research Institute also offers a *Fire Service Considerations with Lithium-Ion Battery ESS* course. This course is designed based on lessons learned from the 2020 deflagration incident in Surprise, Arizona[7]. Contractors with experience in the battery storage field are offering more in-depth training by involving other stakeholders. The International Association of Fire Chiefs has produced a set of resources on their website dedicated to the fire service education.[8]

The Interstate Renewable Energy Council (IREC) has created a series of educational tools aimed at the inspector and firefighting communities via a DOE funding grant creating the MPOWERED/Clean Energy Clearinghouse Project:

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[7] https://fsri.org/research-update/report-four-firefighters-injured-lithium-ion-battery-energy-storage-system
[8] https://www.iafc.org/topics-and-tools/lithium-ion-and-energy-storage-systems

> The IREC clean energy clearinghouse will help fill knowledge gaps for professionals interacting with clean energy technologies to improve safety and increase consumer confidence. The three-year, $2.1 million project, funded by the DOE's Office of Energy Efficiency and Renewable Energy, will reduce barriers to widespread adoption of distributed energy resources by providing education and resources to expand the knowledge of 30,000 professionals." [9]

Many other BESS trainings exist on the market, though they are broader in scope outlining all BESS components and project life cycle, safety risks and mitigations are only a section of the total agenda. Individual battery manufacturers also conduct trainings related to their products. For example, Fluence, a manufacturer of batteries for grid-scale and commercial applications, offers a customer training course that covers safety and reactive maintenance, among other topics.

PNNL will be offering a suite of energy storage curriculum under the Grid Storage Launchpad education program in collaboration with top-tier higher educational organizations starting in 2025.

In summary, while training is the last section in this document, all successful projects begin with training across all stakeholders. Training and education should be a present priority at all stages of BESS deployment across the grid. From educating the local community groups that may have questions and concerns related to projects proposed in their communities, to developing a skilled workforce to support safe systems installations, training is key. Training support for emergency responders to understand the unique hazards and response, are equally important in the success of energy storage deployment.

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