Update on and Overview of Model Codes and Standards for Energy Storage System Safety

David Conover

Pacific Northwest National Laboratory

902 Battelle Blvd, Richland, WA 99354, United States

Abstract- **Myriad energy storage system (ESS) technologies are being deployed and developed for future deployment. Successful ESS design, construction, installation, and use in the built environment must address a number of issues—the foremost being safety. Safety is documented and validated through codes, standards, and regulations (CSR). The provisions in these documents typically lag technology development and initial deployment. Until these documents are updated, it can be more challenging to secure approval for an ESS[1] installation because no uniform, consistent, and acceptable means of documenting and validating its safety, in addition to ensuring its continued safety during operation and when decommissioned, is available. This paper provides foundational information for understanding why CSR are important to technology deployment, what CSR are relevant to ESS, and how they are being developed, updated and adopted so stakeholders involved in any way with ESS can further ensure ESS safety in relation to the dynamic nature of ESS development and deployment.**

Keywords- **safety, codes, standards, technology acceptance, regulations.**

I. Update on and Overview of Model Codes and Standards for Energy Storage System Safety

This paper provides an overview of the topic of codes and standards as related to energy storage systems (ESS) and a little history to provide a framework for understanding how these documents can impact the timely acceptance of ESS while ensuring public safety. Safety-related issues associated with ESS are identified; the documents addressing those issues are highlighted, along with how they are developed and adopted. Finally, information is provided on keeping those documents updated and current as ESS technology evolves and applications increase over time.

United States (U.S.) model codes and standards are developed, published, and regularly updated by voluntary sector (e.g., non-governmental) standards development organizations (SDOs). When adopted, they represent the body of criteria that must be satisfied to design, construct, commission, rehabilitate, operate, maintain, repair, and decommission components of the built environment such as buildings, facilities, products, systems, and equipment therein. This body of adopted criteria is referred to as codes, standards, and regulations (CSR). These criteria are not static but are very dynamic, needing revision and enhancement as new technologies are developed and new issues arise that impact their deployment and use.

The Electricity Storage Handbook (DOE/EPRI 2013) indicates that one of the three biggest challenges hindering adoption of energy storage systems (ESSs) is codes and standards. They directly affect ESS technology (product) and its intended installation/application. Although CSR can focus on other issues such as performance, the acceptability of an ESS from a safety standpoint directly affects whether it can be manufactured and deployed and, if so, how and under what conditions. The administration of CSR and time to approval issues (e.g., documenting and validating compliance) affect the ability to construct and install ESSs in a timely manner. The absence of criteria for evaluation, documentation, and validation of ESS safety can adversely affect those seeking to move ESSs into the market and those responsible for public safety. They have little basis on which to consistently and confidently qualify a system and its installation as being "safe." This 'time lag' between technology development and deployment and the availability and application of CSR that provide needed and relevant criteria poses an ongoing challenge. Existing model codes and standards need to be updated and/or new ones developed to specifically address the range of ESS technologies and installations. After their publication, they have to be adopted as CSR as a basis for uniformly documenting what is safe and determining what can be approved in a consistent and timely manner. In some instances, the lack of specificity limits progress until appropriate safety-related criteria are available; in others, "outdated" criteria can be conservatively applied to the technology, thereby affecting the cost of an ESS installation or limiting the application of an ESS.

Fig. 1 provides a view of how CSR can affect technology development and deployment. All scenarios (A, B, and C) involve up-front investment to bring the technology to market

[1] For the purposes of this paper, ESSs are stationary and can store energy through thermal, mechanical, or electrochemical means for applications in the built environment (e.g., buildings, facilities, industrial processes). Mobile ESSs used for disaster relief and other temporary uses can also be considered "stationary" for the purpose of ensuring system safety.

(negative slope) and then in going to market the generation of income (positive slope). In a “typical” business model (B) where there is some awareness of CSR, while there are no “show stoppers,” there is little proactive effort to enhance consideration of the subject technology in CSR. Where CSR are not considered (C), additional investment in technology development and/or generation of research to document technology safety is needed. This increases the time to market, which affects the availability of the technology and requires additional investment. In worst-case situations, CSR can impede the use of the technology because they compromise a basic safety tenet or indirectly by requiring additional unplanned safety considerations. A response to this “time lag” is for the proponents of a technology, in this case ESS, to collaborate early on in development of CSR to conduct needed research to support new CSR criteria in parallel with technology development, as shown in scenario (A). That investment is more than recouped because the necessary CSR are developed and deployed at or near the time the technology enters the market.

When CSR are updated to address new ESS technologies and applications, they can provide a specific, uniform, and repeatable basis for documenting and validating the safety of the ESS technology and its installation (i.e., prescriptive). Note that most CSR allow an approach to compliance by showing that what is proposed is no more hazardous, nor less safe, and performs at least as well as other technologies specifically covered by the CSR (i.e., equivalent performance). While affording a path to approval until the CSR are updated, this path can necessitate the development of criteria by which each entity enforcing the adopted CSR can determine “equivalent safety” associated with a proposed ESS. This can result in proponents of an ESS installation having to provide a customized or “one-off” documentation package for each jurisdiction (approval authority) where an ESS is desired on the customer side of the meter or for each utility on the grid side. In addition, authorities having jurisdiction (AHJs) also may be less inclined to accept this path to compliance because they would have to develop the criteria on which to base “equivalent performance”, or consider and approve those suggested by the ESS proponent, and then have to assess the documentation provided by the ESS proponent. The availability of updated and specific CSR to document and validate ESS safety is clearly preferable. That said, it takes time to develop model codes and standards and adopt them as CSR.

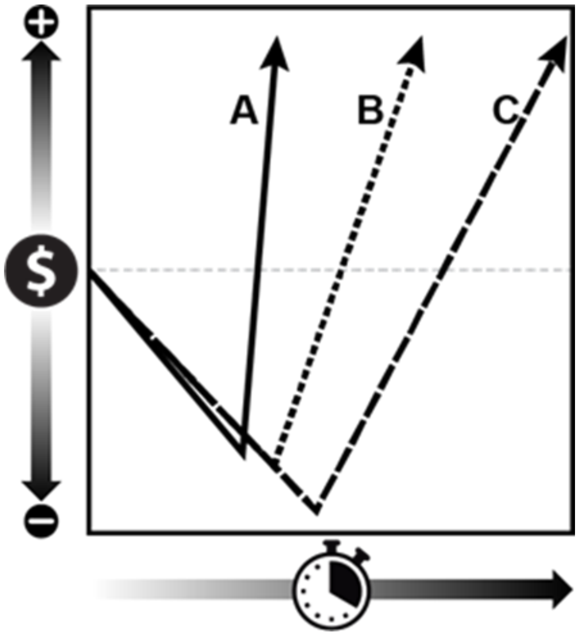

Fig. 1. The value of addressing CSR.

II. Short History of ESSs Relative to CSR

Energy storage has been an integral part of daily life for decades, even centuries. With the advent of electricity, Benjamin Franklin coined the term “battery” to convey the concept of electrical storage. Buildings have historically used batteries to support standby or emergency power requirements. More recently, buildings are using batteries to store electrical energy from renewable energy sources, such as wind and photovoltaic systems, as well as thermal energy from solar or waste heat sources and mechanical energy in flywheels. Although battery safety has been addressed in documents such as the National Electrical Code (NFPA 70), Fire Code (NFPA 1), International Fire Code (ICC IFC), and Underwriters Laboratories standards (UL 1973), until recently they only provided criteria for vented lead-acid batteries. More recent model codes and standards provide criteria for a wider range of batteries and now complete ESSs that include a wide range of ESS technologies. Even with updated model codes and standards available for adoption, the adoption process does take time. Consequently, those adopting them as CSR may still be using older versions of these model codes and standards.

Current U.S. energy, environmental, and economic challenges, coupled with increased globalization of technology, are supporting a very dynamic evolution of new storage technologies and applications. While updated CSR are needed, the development of model codes and standards and their adoption as CSR can be challenging to “speed up,” especially when the results of safety-related testing and analysis are needed to form a basis for the criteria in those documents.

In the U.S., the existence of CSR typically occurs through adoption of criteria developed by private sector SDOs. The process involves all stakeholders, including potential adopters, but adopters of these documents can and do develop their own “home grown” CSR. Adoption can occur through governmental vehicles at the federal, state, local, territorial, or tribal levels; through private sector vehicles such as insurance policies, contracts, or incentive programs; and through utilities with respect to equipment that is part of their grid equipment or connected to the grid. After adoption of the CSR, those seeking approval must document compliance with what is adopted to the AHJs having authority for validating compliance (e.g., enforcing the CSR). This introduces another process component—conformity assessment, which focuses on documenting compliance with the criteria that are adopted and then validating that the criteria are satisfied. While adopting entities have the authority to validate compliance and will undertake the necessary enforcement activities to ensure compliance, they will also rely on documentation from third-parties (e.g., testing and listing of products by “approved” agencies or plans and specifications prepared by a registered design professional). This is especially true with respect to ESS products or components manufactured in a single place, then shipped to various sites for installation. Safety issues (traditional and new, due to advances in ESS technology and/or applications) will continue to arise and will have to be addressed.

In summary, the optimum outcome is that CSR provide specific criteria on which to document and validate the safety of ESS at the point in time that ESS initially enters the market. Achieving that outcome, short of drastically changing how the U.S. system of CSR development, adoption and application functions, requires collaboration by all ESS proponents and stakeholders and their participation in the updating of CSR and fostering their adoption and application in parallel to ESS technology development and deployment. A key component of that collaboration is identifying safety issues associated with ESS, conducting research and analysis to develop solutions to those issues and then memorializing those solutions in CSR.

III. Safety Issues Associated With ESSs

A number of safety-related issues are associated with ESSs in general; others are unique to specific ESS technologies (types, chemistries, and capacities/sizes) and their applications. The following application scenarios will affect whether and to what degree a particular safety issue is relevant:

- Location of the ESS in relation to the grid (e.g., customer meter) and whether it is grid-connected
- Location of the ESS in relation to buildings and facilities (e.g., indoors, outdoors, rooftop, below grade, enclosed, etc.)
- Type of building or facility in which an ESS may be located or installed on or adjacent to i.e., single family dwelling, hotel, parking structure, business, industrial)
- Nature of the installation (i.e., rural/remote, urban)
- Application is associated with a new building or an existing building
- ESS is stationary, mobile but “stationary” (i.e., on wheels), or portable.

These systems can be “brand new” or existing systems that may undergo repair, renewal, refurbishment, and recommissioning

The safety issues include:

- Clearances and working space
- Shocks and arc flash
- Structural loading
- Protection against natural and manmade disasters
- Spill control
- Impact protection
- Access to and egress from the ESS area
- Smoke and fire detection and fire suppression
- Separation of ESSs from each other and from other spaces/areas
- Ventilation and exhaust to address temperature and environmental concerns.

The range of ESS technology types, chemistries, sizes/capacities, and potential applications is needed to identify the safety issues associated with each scenario (e.g., technology type, size/capacity, and application), and the research needed to determine how to best ensure the safety issues for each scenario are addressed (e.g., there will be no safety-related incident, or if there is, how it will be effectively managed). When a specific solution(s) is known, model codes and standards can be updated to provide a basis for uniformly implementing the solution(s). When an ESS has been documented and validated as satisfying the criteria in CSR, then its installation can be deemed “safe.” Safety includes the minimization of an incident occurring and the ability to effectively address an incident if it does occur.

Safety-related criteria in model codes and standards can be presented in several formats:

- Prescriptive format (e.g., locate the ESS x ft from something)
- Component performance format in which a particular component or portion of the system must provide a particular outcome without specifying

how that is to be achieved (e.g., the ventilation system shall be designed to keep the ESS room temperature during normal operation below x ºF)

- More complete performance format without specifying how it is to be achieved (e.g., the ESS shall be designed and constructed to eliminate all possible electrical shock hazards).

As noted above, the availability of model codes and standards to fully address the safety of any technology or its application in the built environment always lags new technology development and deployment (or even new application of existing technology). It takes time to conduct the necessary research to answer safety-related questions (e.g., how far is a safe x ft clearance or how much ventilation is sufficient?). Even when a complete performance goal is established, it takes time to develop a standard to guide how to uniformly document and verify (through testing and/or analysis) that the goal has been successfully realized. Even though research results and experiences with the technology can inform the development of model codes and standards, there is lag time between their finalization and adoption. Continued growth in ESS technologies and applications drive the ongoing cycle of research, analysis, knowledge, and model codes and standards development and adoption. Hence, all ESS proponents and stakeholders who would collaborate as suggested above to shorten the gap between ESS technology, in relation to CSR that have been adopted and are being applied, need to know the 'target' model codes and standards on which to focus their efforts.

III. What Model Codes and Standards Apply to ESSs and How

Information about model codes, standards, and other related documents can be organized by document scope relative to ESSs from the "macro to the micro" level (Table I). The more "macro" documents are likely to adopt by reference the more "micro" documents. In aggregate, these documents form the basis for documenting and validating the safety of ESSs with respect to the issues noted above, available technologies and today's anticipated applications. These documents will continue to be updated pursuant to SDO-specific processes, which are described on SDO websites and provide every opportunity for input from all interested parties. As noted above it takes time for these documents to be updated and revised and then adopted. Paralleling development of new ESS technologies and applications with these activities can foster timelier and less burdensome ESS deployment. Fig. 2 shows an ESS installation and the relative scope of each of these types of documents.

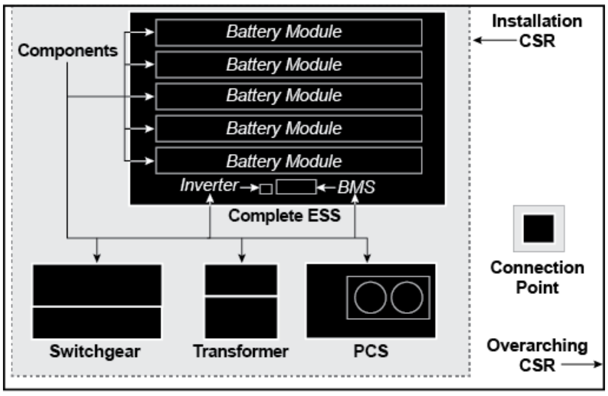

Fig. 2. ESS installation

III. Codes and Standards That Apply to ESSs

Table I identifies documents that enjoy widespread adoption as CSR or are likely to when completed. (See the SDO websites for more detailed information about all the documents included in Table I.)

TABLE I

MODEL CODES, STANDARDS, AND OTHER RELATED DOCUMENTS

Category	Model Codes, Standards, and Related Documents
Overarching codes and standards – the built environment at large that includes, but is not limited to, ESSs	• NFPA 1-2018 (Fire Code). The 2018 edition is finalized and Chapter 52 includes requirements related to ESSs. Public inputs for the 2021 edition will be due in mid-2018. • NFPA 70-2017 (National Electrical Code [NEC]). Article 706 applies to ESSs and Article 480 applies to batteries, in addition to other criteria in the NEC relevant to electrical equipment and installations. A revision process that will lead to the 2020 edition is underway. • 2018 IFC (International Fire Code). Chapter 12 of the IFC covers energy systems and Section 1206 in that chapter covers electrical ESSs. Proposed changes are due January 8, 2018, and the outcome of the code development process, which will occur during 2018, will be the 2021 edition of the IFC. • 2018 IRC (International Residential Code). A section of the IRC covers ESSs and possible changes to that section can be submitted and considered as described above under the IFC. • IEEE C2-2017 (National Electric Safety Code [NESC]). The NESC covers electrical safety for utility systems and equipment. The final date to receive change proposals from the public for revision of the 2017 edition is July 15, 2018. The outcome of the revision process will be the 2022 edition of the NESC. • DNVGL-RP-0043, October 2017 (Safety, Operation and Performance of Grid-connected Energy Storage Systems). This document provides a comprehensive set of recommendations (not a code or standard per se) for grid-connected ESSs.
Codes and standards for ESS installations – the installation of the ESSs relative to other systems and parts of the built environment	• NFPA 855-20XX (Standard for the Installation of Stationary Energy Storage Systems). This standard will cover the safety of all ESSs and their installation in the built environment. It has been drafted and was out for first public input in September 2017. Final approval of NFPA 855 is targeted for June 2018. • NECA 416-2016 (Recommended Practice for Installing Stored Energy Systems). This document describes installation practices for ESSs such as battery systems, flywheels, ultra-capacitors, and smart chargers used for electric vehicle (EV) and vehicle-to-grid applications. It has been published and a new appendix containing a compliance checklist is under development. • FM Global Property Loss Prevention Data Sheet # 5-33 January 2017 (Electrical Energy Storage Systems). This data sheet describes loss prevention recommendations for the design, operation, protection, inspection, maintenance, and testing of electrical ESSs. It focuses primarily on lithium-ion battery technology. Development of an interim revision is planned for 2018 with publication expected in 2019.
Codes and standards for a complete ESS – the entire ESS in the aggregate	• UL 9540[2] (Energy Storage Systems and Equipment). This is a product safety standard for an ESS and was first published November 21, 2016. UL is in the process of creating a bulletin for circulation that includes revision to the standard, and which would include a reference to a newly published UL 9540A – Test Methods for Evaluating Thermal Runaway Fire Propagation in Battery ESS. • ASME TES-1 (Safety Standard for Thermal Energy Storage Systems). This standard provides safety-related criteria for molten salt ESSs. The document has been approved for public review that will close in late February 2018.
Codes and standards for ESS components – components associated with the ESS	• IEEE P1679.1 -2017(Guide for the Characterization and Evaluation of Lithium-Based Batteries in Stationary Applications). This new standard provides appropriate information about safety attributes and operating conditions related to stationary applications of lithium-based batteries. IEEE P1679.2 (Guide for the Characterization and Evaluation of Sodium-Beta Batteries in Stationary Applications). This proposed new standard provides appropriate information about safety attributes and operating conditions related to stationary applications of sodium-beta batteries. • UL 1973 (Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail Applications). A new edition will be published in January 2018. UL 1974 (Evaluation for Repurposing Batteries). The new standard will cover use of repurposed EV batteries for stationary applications and the processes used in such repurposing. A bulletin for the first edition of UL 1974 is expected in early 2018. • UL 810A (Electrochemical Capacitors). The standard covers the safety of electrochemical capacitors, which can be used as an energy source in ESSs. The first edition was published on October 7, 2008, and reaffirmed on March 28, 2017.

[2] UL standards are under continuous maintenance and are updated as warranted.

IV. How Model Codes and Standards Are Developed and Adopted

In the U.S., model codes and standards are developed in the voluntary sector by one SDO or through a co-sponsorship agreement between multiple SDOs. The SDO does not author them; rather it establishes and oversees a process whereby all interested and affected parties, stakeholders, or interested entities, including representatives from all levels of government, can participate in their development. Most SDOs subscribe to the American National Standards Institute (ANSI) essential requirements, which are intended to ensure the SDO provides fair and due process to all interested and affected parties.

The process by which each SDO develops model codes and/or standards is available from each SDO. In general, a process meeting the ANSI essential requirements can be summarized as shown in Fig. 3. After model codes or standards are developed in the voluntary sector, they are available for adoption. Adoption is simply a decision by any decision-making entity that compliance with the adopted model codes or standards is mandatory.

Adoption can occur in many ways, including the following:

- Legislative or regulatory action by a governmental entity (i.e., federal, state, local, Indian Tribe) as a mandatory requirement in all cases or as a condition for program funding
- Action by a utility under its operation as controlled by a Public Utility Commission and acting as the AHJ for systems on the grid side of the meter or simply as the entity connecting to an ESS on the customer side of the meter
- Requirement by an insurance carrier as a condition for insurance coverage
- Condition for licensing (e.g., a state contractor licensing board that adopts and applies particular technical requirements and compliance with those as a condition for licensure)
- Reference in building specifications issued by a building owner/developer or financial institution backing a project
- Anyone considering the application and use of energy storage that, in the absence of any other means of adoption, elects to apply model codes or standards to their project (e.g., self-adoption).

How these adopting agencies or entities exercise their authority varies widely, as does their pre-emptive authority over other bodies or entities and the scope of what they "regulate." While they may adopt model codes and standards and have the authority to amend them (e.g., increase stringency and/or add provisions), they also may choose to develop their own home-grown provisions in lieu of or in addition to the model codes and standards. Ideally, all stakeholders affecting ESS safety can collaborate in the development of model codes and standards and fully support their timely adoption and application in a uniform and consistent manner. The alternative can be a "crazy quilt" of differing requirements that can work against addressing EHS safety in a comprehensive and more timely manner, because those responsible for public safety, in the face of increased ESS deployments and not finding their CSR needs addressed, will generate their own requirements; or worse, be less willing to approve ESS applications until those CSR are updated and available for adoption.

V. Keeping Model Codes and Standards and CSR "Fresh" as ESS Technology and Deployments Grow and More is Learned to Better Address Safety

Multiple initiatives are under way separately within the range of ESS development and deployment and development of model codes and standards and their adoption as CSR. These are typically carried out in series, instead of in parallel as suggested above, and hence can have an impact on the timely acceptance of safe ESSs. While it is very challenging to conduct all the necessary activities (research and development, model code and standard development, and then their adoption and implementation as CSR) in parallel, they can and should be carried out in a coordinated manner that fosters their being addressed in parallel as much as possible. Closing this gap between ESS development and deployment and the availability of CSR needed to document and validate ESS safety can be done but requires collaboration by all ESS proponents and safety stakeholders. Such collaboration can be facilitated by following the ESS safety roadmap, whose goal is to "foster confidence in the safety and reliability of energy storage systems."

The need for a new model code or standard is identified (e.g., one does not exist) by a committee associated with the SDO, an interested and affected party, stakeholder or any entity with an interest in seeing a model code or standard developed. Where a model code or standard already exists, it is updated on a regular schedule as established by the SDO.

The proponents of the new model code or standard prepare relevant documentation for submittal to the SDO for consideration in establishing a new model code or standards project. Where a model code or standard already exists, any interested and affected party can submit proposed changes to the SDO. They are considered in accordance with the SDO procedures. Changes that are approved are included in the next edition of the model code or standard.

The SDO processes the request for a new code or standard through their codes and standards development procedures and either approves, disapproves, or requests additional information.

When approved, the SDO will provide notification of their intent to establish a new model code or standard so that the public can comment on the intended action. If no adverse comments are received, the SDO will initiate development of the new model code or standard, starting with a call for committee members that will be responsible for the development of an initial draft of the model code or standard.

Fig. 3. Summary of the model codes and standards development process.

IV. Summary and Conclusion

ESSs and their potential applications and interrelationships with the built environment will continue to evolve. This will drive the need for more research, testing, and analysis to document safety, and it could raise new safety-related issues. Model codes and standards will continue to be developed and updated regularly to address new technologies and to respond to new information and experiences. They will continue to be available for adoption as CSR, eliminating the need for document adopters to each separately and in parallel conduct the same developmental and updating efforts. Then adopting proponents of ESSs will have to document compliance, and AHJs will have to validate compliance. This process does not end when an ESS is initially commissioned; it continues throughout its first and any subsequent lives—through system renewal, and ultimately, its decommissioning and disposal.

Moving forward requires establishment of an ESS development and deployment goal focused on safety that is respectful of time, identification and satisfaction of information gaps. This has been done through the U.S. Department of Energy OE ESS Safety Roadmap. The realization of a safety related goal requires knowledge of and collaborative involvement in this entire process by all interested and affected parties. As outlined in the safety roadmap this is a dynamic process that is founded on communication and collaboration. On an ongoing basis, all interested parties must have a common and robust understanding of the CSR process and be committed to interacting in that process to foster development and adoption of needed CSR provisions. Concurrently, safety issues need to be identified that are associated with both new technologies being developed and safety-related observations and instances associated with existing ESS installations. Solutions to those issues need to be found and can include research, testing, and analysis, as well as needed modifications to ESS technology designs or installation specifications. Those solutions, in turn, must be memorialized in model codes and standards in as timely a manner as possible, within the processes associated with the relevant SDOs, in addition to making those solutions readily available for application and use in parallel to their consideration in those SDO processes.

The process associated with technology development and deployment and the process associated with the development, adoption, and implementation of CSR are not likely to change drastically. That said, knowing how they each function can go a long way to bridging the gap between ESS technology and CSR criteria. With that knowledge and collaboration in support of a goal, as outlined in the safety roadmap, that gap can be further bridged by addressing technology development and deployment efforts, needed research, analysis and documentation, and development of CSR criteria in parallel. Although challenging, when all stakeholders communicate and collaborate on the needed activities the goal can be achieved.

References

[1] D. R. Conover, “Overview of development and deployment of codes, standards and regulations affecting energy storage safety in the United States,” Pacific Northwest National Lab., Richland, WA, Rep. no. PNNL-23578, Aug. 2014. Available: https://energymaterials.pnnl.gov/pdf/PNNL-23578.pdf

[2] D. R. Conover, “Inventory of safety-related codes and standards for Energy Storage Systems,” Pacific Northwest National Laboratory, Richland, WA, Rep. no. PNNL-23618, Sept. 2014. [Online]. Available: https://www.sandia.gov/ess-ssl/docs/safety/ESS_Inventory_9-15-14_PNNL_23618.pdf

[3] D. R. Conover, “DOE OE Energy Storage Systems safety roadmap focus on codes and standards,” Pacific Northwest National Laboratory, Richland, WA, Rep. no. PNNL-27189, Dec. 2017. [Online]. Available: https://www.sandia.gov/ess-ssl/publications/EnergyStorage_safetyroadmap_2017.pdf

[4] Pacific Northwest National Laboratory and Sandia National Laboratories, “DOE OE Energy Storage Systems safety roadmap,” Pacific Northwest National Lab. and Sandia National Labs., Richland, WA and Albuquerque, NM, Rep. no. PNNL-SA-126115/SAND2017-5140 R, May 2017. [Online]. Available: https://www.sandia.gov/ess-ssl/publications/EnergyStorage_safetyroadmap_2017.pdf