Town of Medway

Battery Energy Storage System (BESS)

Research and Best Practices Summary

Reference: Issue

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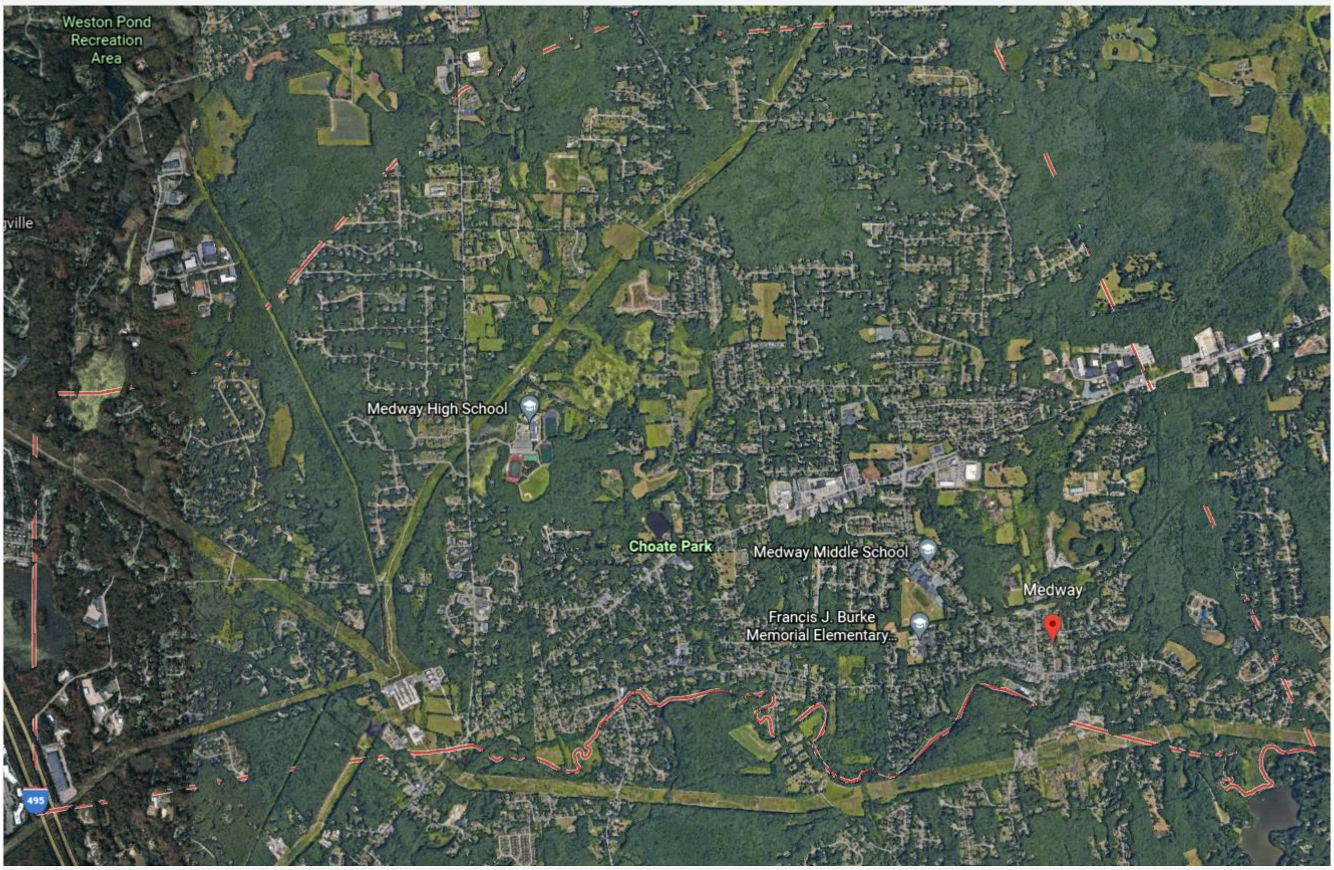

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Contents

Tables

Figures

Appendices

Executive Summary

As part of the Town of Medway's ongoing efforts to enhance their knowledge of Battery Energy Storage Systems (BESS), this report has been prepared to summarize important best practices and technical information about the energy storage industry. The objective of the report is to provide technical information which the Town can reference when determining how to implement BESS within their community. This information includes National and Federal Code reviews, Massachusetts state regulation, similar projects, and industry-leading manufacturers.

Although this report provides technical information, it builds off other work that has been performed and is not intended to be a complete reference. Additional work will likely be needed to aid the Town with BESS implementation. The Town of Medway has identified the following knowledge gaps, which will be covered in separate reports:

- Summary of technical considerations relating to BESS siting.
- Summary of technical matters for the Town of Medway to consider as they look to modify the existing zoning bylaws for the Energy Resource district.

BESS installations are highly configurable and can be coordinated to provide stakeholders with a multitude of benefits. Like all energy infrastructure improvements, BESS units do have challenges which should be considered during the design and planning phases.

Key benefits of BESS can include:

- Increased **reliability** of electrical power supply and ability to match supply and demand from intermittent sources
- Increased **stability** and flexibility for the power grid
- Supports **decarbonization** goals
- BESS site serves as **taxable revenue** for the local jurisdiction
- BESS could prove **economically** beneficial when purchasing energy at lower rates and discharged during high demand
- Increased **resiliency** and ability to supply power during black-outs and major outages
- Aids in **reducing congestion** on the network resulting in reduction or elimination of the need to invest in new transmission lines

Key challenges of BESS include:

- Planning for **space** requirements for BESS when developing a project
- There is an upfront **capital cost** associated with BESS infrastructure
- Fire testing data required for BESS systems > 50 kWh will require **detailed review** by local Authorities Having Jurisdiction (AHJ)
- Initial phase **permitting** process can be lengthy and complex
- Potential for **environmental** impacts

The report serves primarily as a review of lithium-ion (li-ion) batteries but will also touch on other battery chemistries where relevant to provide context.

Definitions

Batteries, Electricity, and Related Terms:

Anode: The electrode in a battery system on which oxidation occurs. A battery contains both a cathode and anode to complete the transfer of electrons.

Array: A physical grouping of batteries. Sometimes referred to as a “cluster”. The capacity of batteries in an array is considered on a cumulative basis. See **Figure 1**.[1]

Battery Energy Storage System (BESS): A type of ESS consisting of an array of batteries intended to provide electrical power during outages and supplement available resources during times of high demand.

Battery Management System (BMS): A system that monitors, controls, and optimizes performance of an individual or multiple battery modules in an energy storage system and has the ability to control the disconnection of the module(s) from the system in the event of abnormal conditions.

Cathode: The electrode in a battery system on which a reduction reaction occurs. A battery contains both a cathode and anode to complete the transfer of electrons.

Cell: The basic electrochemical unit, characterized by an anode and a cathode, used to receive, store, and deliver electrical energy.[2] See **Figure 2**[3]

Container: The physical enclosure surrounding ESS battery arrays. Personnel only enter this space to maintain, test, or service the equipment. See **Figure 4**. [4]

Energy Density: The volume of energy stored in a battery, expressed in Watt-hours per liter (Wh-l)

Energy Storage System (ESS): One or more devices, assembled together, capable of storing energy in order to supply electrical energy at a future time to the local power loads, to the utility grid, or for grid support[5]

Module: A battery cell, including any exterior casing. See **Figure 3**. [6]

Figure 1: Battery Array

Figure 2: Battery Cell

[1] https://energy-storage.news/wp-content/uploads/2021/08/Powin_BatteryStack_iso.jpg
[2] 2020 NFPA 855 3.3.4
[3] https://www.dnkpower.com/battery-cell-selection/prismatic-lithium-battery-cell/
[4] NFPA Journal - Energy Storage Systems, May June 2018
[5] 2020 NFPA 855 3.3.9
[6] FIAAM.jpg (640×426) (capricasolar.co.za)

Substation: An assembly of equipment through which electric energy is passed for the purpose of distribution, switching, or modifying its characteristics.[7] See **Figure 5**.[8]

Figure 3: Battery Module

Figure 4: Battery Container

Figure 5: Substation

[7] 2020 NEC 2.00

[8] Choreographing electrons and the hidden sophistication of the US electric grid (freeingenergy.com)

Switchgear: An assembly containing primary power circuit switching, interrupting devices, or both, with electrical buses and connections. The assembly may include control and auxiliary devices. Access to the interior of the enclosure is provided by doors, removable covers, or both. Electrical equipment that supports BESS.[3] See **Figure 6**. [9]

Thermal Runaway: The condition when an electrochemical cell increases its temperature through self-heating in an uncontrollable fashion and progresses when the cell's heat generation is at a higher rate than it can dissipate, potentially leading to off-gassing, fire, or explosion.[10]

Transformer (XFMR): An electrical component that transfers electrical energy from one circuit to another. It can be used to increase or decrease voltage between circuits. Electrical equipment that supports BESS. See **Figure 7**. [11]

Figure 6: Switchgear

Figure 7: Transformer

[9] lv+switchgear.jpg (1000×849) (powersonicgroup.com)
[10] 2020 NFPA 855 3.3.20
[11] https://www.miracle.net.in/blog/electrical-transformers-need-know/

Standards, Organizations, and Related Terms:

Factory Mutual (FM): Certification organization that provides evaluation standards and testing. Author of Data Sheet 5-33 on Electrical Energy Storage Systems, focused on loss prevention recommendations.

International Electrotechnical Commission (IEC): Organization that prepares and publishes standards for electrical and electronic technologies. Author of internationally recognized standards for safety, design, and integration of a wide variety of products, processes, and systems, including battery components.

Institute of Electrical and Electronic Engineers (IEEE): Professional organization that provides technical standards. Author of the electrical installation standard that is utilized by U.S. public utility companies.

Listed: Equipment, materials, or services included in a list published by an organization that is acceptable to the authority having jurisdiction (AHJ) and concerned with evaluation of products or services, whose listing states that either the equipment, material, or service meets appropriate designated standards or has been tested and found suitable for a specified purpose.[16]

Massachusetts Comprehensive Fire Safety Code (MFSC): The MFSC is the applicable fire code in the state of Massachusetts and is based on the model fire code, NFPA 1, *Fire Code*. Massachusetts adopts the base 2015 edition NFPA 1 code language and incorporates amendments applicable specifically to jurisdictions in Massachusetts.

National Electrical Code (NEC): NFPA 70, *National Electrical Code*. Massachusetts adopts the base 2020 edition NEC code language and incorporates amendments applicable specifically to jurisdictions in Massachusetts, for all electrical installations.

National Fire Protection Association (NFPA): Non-profit organization that provides various fire protection and life safety standards and guidelines. Codes and standards of note include: NFPA 1, *Fire Code*; NFPA 70, *National Electrical Code*; NFPA 855, *Standard for the Installation of Stationary Energy Storage Systems*.

Underwriters Laboratories (UL): U.S. certification organization that provides evaluation standards and testing for a variety of products and systems, including battery components and systems. Standards of note include: UL 9540, *Energy Storage System (ESS) Requirements*; UL 9540A, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*.

[16] 2020 NFPA 855 3.2.4

Other Definitions.

Authority Having Jurisdiction (AHJ): An organization, office, or individual responsible for enforcing the requirements of a code or standard, or for approving equipment, materials, an installation, or a procedure.[17]

Failure Modes and Effects Analysis (FMEA): A systematic technique for failure analysis. An FMEA is often the first step of a system reliability study and involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes and their causes and effects. For each component, the failure modes, and their resulting effects on the rest of the system are recorded.[18]

Lower Flammability Limit (LFL) / Lower Explosive Limit (LEL): The minimum volume of vapor / gas in air that is needed to support combustion for a specific flammable vapor / gas.

Modified Accelerated Cost Recovery System (MACRS): The tax depreciation system used in the U.S. Under this system, assets have an accelerated depreciation in the earlier years.

[17] Massachusetts Comprehensive Fire Safety Code (MFSC) 3.2.2
[18] 2020 NFPA 855 A.4.1.4.1

1. Introduction

A battery energy storage system (BESS) is an array of batteries intended to provide electrical power during outages and supplement available resources during times of high demand. Currently, peaks in power demand are addressed by "peaker" plants, power plants that are only operated during these high demand time periods, but as electrical demand grows, so does the need for a more stabilized and reliable power grid that moves away from the non-renewable sources that have been relied on in the past.

BESS provides a grid-scale energy storage solution for short-term and localized grid demand challenges. The planning, development, design, operation, and maintenance of BESS involve many stakeholders who will need to work together to develop a comprehensive BESS project that serves the goals that have been set for it. BESS facilities come in a wide range of sizes, typically measured in electrical capacity (megawatt, MW, or megawatt per hour, MW/h) that serve a wide range of purposes. Of note, **Table 1** provides estimated capacity ranges for various BESS applications.

Table 1: Approximate Capacity by BESS Application

BESS Application	Approximate Anticipated Capacity Ranges
Investor-owned public utility	5-500 MW / 10-1,000 MW/h
Municipality-owned utility	5-50 MW / 10-100 MWh
Private landowner	0.25-2 MW / 0.5 – 8 MWh
Private residential	0.002-0.005 MW / 0.005-0.015 MWh

The following report provides a summary of the key considerations for BESS technology and infrastructure and is intended to serve the Town of Medway as an educational resource on BESS.

1.1 BESS Economics

1.1.1 BESS Revenue Streams

There are several incentives and revenue streams available for BESS systems that can be claimed by the owner of the system depending on the design. A few of the key revenue streams are outlined here, but a comprehensive list can be found via the Massachusetts Energy Storage Factsheet, specifically in Table 3 of the Factsheet.[20]

For systems paired with Solar PV:

- Federal Investment Tax Credit (ITC) - % of total installed cost realized via tax credit
- MACRS Depreciation – Accelerated tax deductions taken in earlier years of an asset and less in the later years
- The Solar Massachusetts Renewable Target (SMART) program – $/kWh incentive for each unit of energy generated on a Solar PV system that is co-located with a BESS

[20] Massachusetts Energy Storage Factsheet; https://files-cdn.masscec.com/Energy%20Storage%20Factsheet.pdf

For any systems paired with a load, such as a building or consumer facility for which the BESS is powering directly:

- Demand reduction programs:
  - Connected Solutions – Demand charge incentive program focused on shaving the peak during June-September that pays based on average performance
  - Clean Peak Standard – Massachusetts Department of Energy Resources (DOER) program that pays an incentive based on peak shaved during afternoon windows of high grid demand, seasonally dependent, typically in mid to late afternoon
- On bill demand charge savings for behind-the-meter (BTM) systems:
  - BESS systems can be dispatched to reduce monthly peak demand charges
  - Installed Capacity (ICAP) savings: Installed capacity charges are built into end-user energy purchase contracts and are based on a user's share of total grid load during the peak hour of the year. Dispatching the BESS during this window can yield significant savings during billing cycles in subsequent years.
- Ancillary Grid Services:
  - Frequency regulation
  - Voltage support
  - Operating reserves
  - Black start

Compensation for the above services is based on the market participation rules and ancillary services managed by the Independent System Operator (ISO) and are based on market conditions and certain Locational Marginal Pricing (LMP).

The revenue streams above generally accrue to the system owner, or meter account holder for BTM systems, and are included in the system owner or developer's initial project financial analysis.

1.1.2 BESS Estimated Capital Costs

BESS pricing has been rapidly trending down as technology and manufacturing advancements have streamlined product costs. However, there is significant market volatility and supply chain constraints which affect pricing. Typical BESS installed costs range between $400-600/kW, or $800-1,200/kWh for utility-scale systems.

Overall costs are driven by the following:

- **Li-Ion battery storage system** (e.g. Li-Ion racks; containers (or buildings); warranty and guarantee; power conversion system (PCS); control system; commissioning; pad mounted transformers)
- **Foundations** (e.g. containers pads; transformer pads; substation foundation)
- **Electrical balance of plant** (e.g. underground cables; grounding; pull wire; BESS controls system; project substation and step-up transformers)
- **Site works** (e.g. site prep; site management during construction)
- **O&M building**
- **Grid interconnection**
- **Testing and energization**

- **Owners' development costs** (e.g. land acquisition; permitting; financing; engineering / procurement; insurance)

2. Benchmark BESS

2.1 Massachusetts Project – Cranberry Point Energy Storage, LLC – Carver, MA

Cranberry Point Energy Storage, LLC (Cranberry Point) is a proposed 150 MW / 300 MWh battery energy storage system with adjacent electrical equipment located on a 6-acre residential/agricultural zone district at 31R Main Street in Carver, Massachusetts. Cranberry Point is proposed to use lithium-ion batteries located inside above-ground, self-contained enclosures; the dimensions of a single enclosure would be approximately 23.5 feet long, 5.4 feet wide, and 8.3 feet tall. Cranberry Point would initially install approximately 116 enclosures, with space open at the end of each enclosure to accommodate additional battery units in the future as the initial set of batteries lose capacity over time. Cranberry Point is shown in **Figure 9** and has a public website to provide information to the public.[21]

Figure 9 – Cranberry Point Energy Storage LLC Rendering

Cranberry Point submitted to the Town of Carver for a Special Permit and Site Plan Review pursuant to the town's zoning by-laws. The project was heard at three Planning Board public meetings and received a Condition Approval with 21 Conditions and 4 Waivers from the Office of Planning and Community Development on March 26, 2019.[22]

[21] Cranberry Point Energy Storage LLC, Project Website, https://cranberrypointenergystorage.com/

[22] Town of Carver, MA, Planning Board Meeting Minutes 3/26/2019
https://www.carverma.gov/sites/g/files/vyhlif4221/f/minutes/planning_board_meeting_3-26-19.pdf

Cranberry Point has made a petition filing with the Massachusetts Energy Facilities Siting Board (EFSB) on August 27, 2021. The project is currently responding to the received EFSB information request.[23]

2.2 Massachusetts Project – Reading Municipal Light Department – Reading, MA

The 5 MW / 10 MWh BESS is owned by NextEra Energy Resources and is operated under an energy storage agreement with Reading Municipal Light Department (RMLD). The system is located at RMLD's North Reading substation and became operational on June 1, 2019.

Figure 10 - RMLP BESS (Courtesy Public Power)[24]

NextEra and RMLD received a $1 million grant from the Baker-Polito Administration's Energy Storage Initiative (ESI) Advancing Commonwealth Energy Storage (ACES) program, funded by the Massachusetts Department of Energy Resources (DOER) and administered by the Massachusetts Clean Energy Center (MassCEC). The unit will be dispatched to reduce RMLD's peak load and has been integrated into their power supply portfolio, focused on providing reliable electricity and allowing for cleaner energy resources.

The BESS will be charged during off-peak hours and discharged during peak events to reduce RMLD's peak load. The BESS is co-located with RMLD's 2.5 MA Distributed Generator, which is also used for peak reduction. [25]

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[23]Massachusetts, EFSB Project website for Cranberry Point Energy Storage, LLC https://eeaonline.eea.state.ma.us/DPU/Fileroom/dockets/bynumber/EFSB21-02

[24] Massachusetts lawmakers tour Reading Municipal Light Department battery storage system https://www.publicpower.org/periodical/article/massachusetts-lawmakers-tour-reading-municipal-light-department-battery-storage-system

[25] BESS Makes Powerful Statement At Ribbon Cutting Ceremony https://patch.com/massachusetts/reading/bess-makes-powerful-statement-ribbon-cutting-ceremony

3. Battery Energy Storage System Technical Overview

3.1 Overview

Large-scale, stationary, BESS is a relatively new technology which is growing rapidly throughout the world and is seen as a means of stabilizing a future power grid that is driven by renewable energies which are often less consistent in production than current gas, coal, and nuclear power plants.

The following sections provide an overview of battery technologies seen in the industry today.

3.2 Battery Chemistries

There are many different battery technologies used in BESS. Lithium ion (li-ion) and lead-acid are the two most common types of batteries used in BESS. Flow batteries are seen less frequently. However, other battery energy storage chemistries and technologies are used in some circumstances. Each type has advantages and disadvantages depending on the demands of the application. Below are the most common types seen in BESS the commercial or residential markets.

3.2.1 Lithium-Ion

Lithium ion (li-ion) batteries are a type of rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging. A diagram of the li-ion battery process is shown in **Figure 11**.

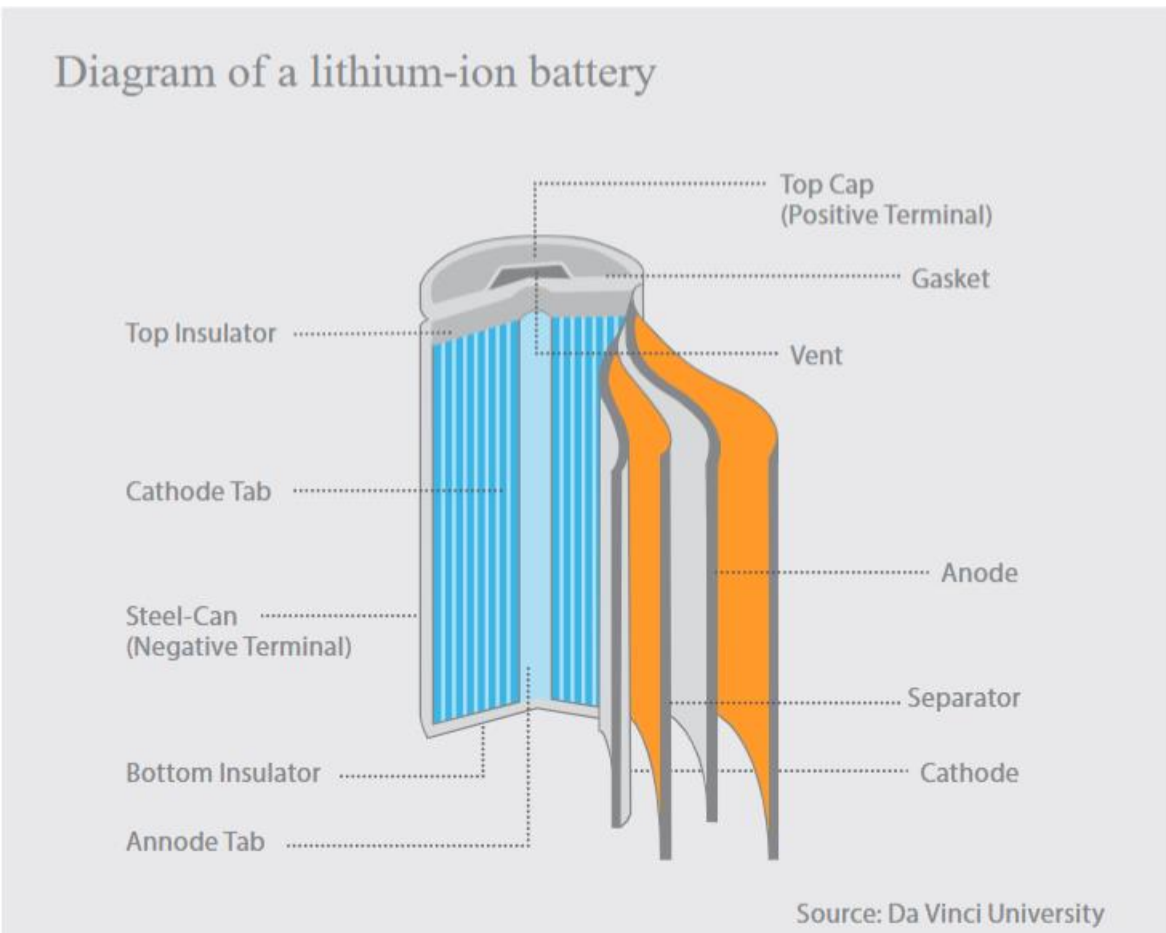

Figure 11: Lithium-Ion Process Diagram

Lithium metal is a water-reactive material, meaning that it either reacts violently with water or will readily produce a flammable gas product when reacting with water. Unlike lithium metal, lithium-ion batteries are not water reactive.

Li-ion batteries are the most popular emerging battery technology and are commonly used in consumer electronic products, where a high energy density is required, meaning the ability to provide high amounts of energy over a longer duration. The technology can be scaled up to distribution scale size and is commonly used in electric vehicles. The development of li-ion batteries is expected to drive down cost and improve technical performance of the batteries, increasing their ability to provide energy over a wide range of conditions and improve efficiency by decreasing the energy losses during charging and discharging.

Li-ion batteries are commonly used in:

- Small electronics (laptops, smartphones, etc.)
- Electronic car batteries
- Power backups / Uninterruptible Power Supplies (UPS)

Figure 12: Common Applications of Li-Ion Batteries[26]

Li-ion BESS systems are comprised of individual cells which are grouped together. An overview of a BESS system is provided in **Figure 13**.

[26] https://static.wikia.nocookie.net/creepypasta/images/e/e4/Last.jpg/revision/latest?cb=20110713100422

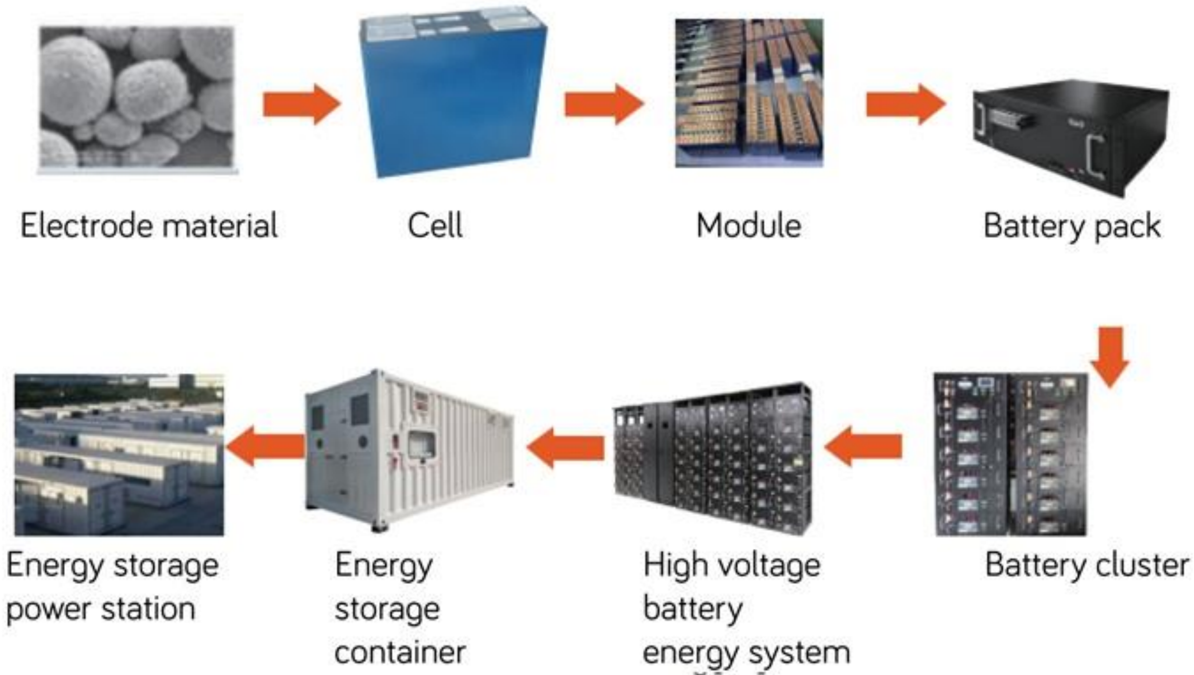

Figure 13: Li-ion BESS Component Overview

Advantages of li-ion batteries include:

- Extremely high energy density, on the order of 400 Wh/l, meaning that the batteries produce a significant amount of energy for a smaller number of batteries compared to other technologies
- Able to tolerate more discharge cycles than other technologies
- High efficiency due to high density, fast discharge, and smaller energy losses compared to other technologies
- Does not release flammable gas during normal operation
- Retains charge well
- Good high temperature performance

Disadvantages include:

- Higher cost than other technologies
- Physical or electrical damage can cause thermal runaway
- Complex control circuitry (Battery Management System)
- Electrolyte and electrodes are combustible
- Raw materials include rarer elements
- Complex construction of mixed materials causes little to no recycling

3.2.2 Lithium Iron Phosphate

Lithium iron phosphate batteries are a type of li-ion battery that utilizes lithium iron phosphate as the cathode.[27] They are commonly used as a substitute for li-ion batteries for stationary applications that can accommodate a bulkier load, and for applications that do not require as high of energy density, meaning it is able to emit larger amounts of power over longer periods of time. Lithium iron phosphate batteries are attractive because of their increased thermal stability and non-hazardous materials, specifically for battery disposal.

Common examples of lithium iron phosphate batteries include existing technology that historically used li-ion batteries and are now switching to lithium iron phosphate, including:

- Electronic car batteries
- Emergency lighting
- Solar energy storage

Advantages include:

- Higher thermal and chemical stability than li-ion, stays cool at higher temperatures
- Less prone to thermal runaway
- Non-hazardous materials
- Higher discharge rates than li-ion
- Longer life cycle / discharge cycle than li-ion
- Stable and maintains charge when stored for long period of time

Disadvantages are:

- Lower energy density than li-ion
- Heavier and bulkier than li-ion
- Not as commercially available or developed as li-ion

[27] Beck, Anton; EPEC Engineered Technologies; Lithium Iron Phosphate vs Lithium-Ion Differences and Advantages; https://blog.epectec.com/lithium-iron-phosphate-vs-lithium-ion-differences-and-advantages

3.2.3 Lead-acid

Lead acid battery technology is historically the most established battery technology. An example of a lead-acid battery is a standard 12-volt car battery. Advanced lead acid batteries have been developed and are particularly suited to energy storage applications. A diagram of a lead-acid battery is shown in **Figure 14**.

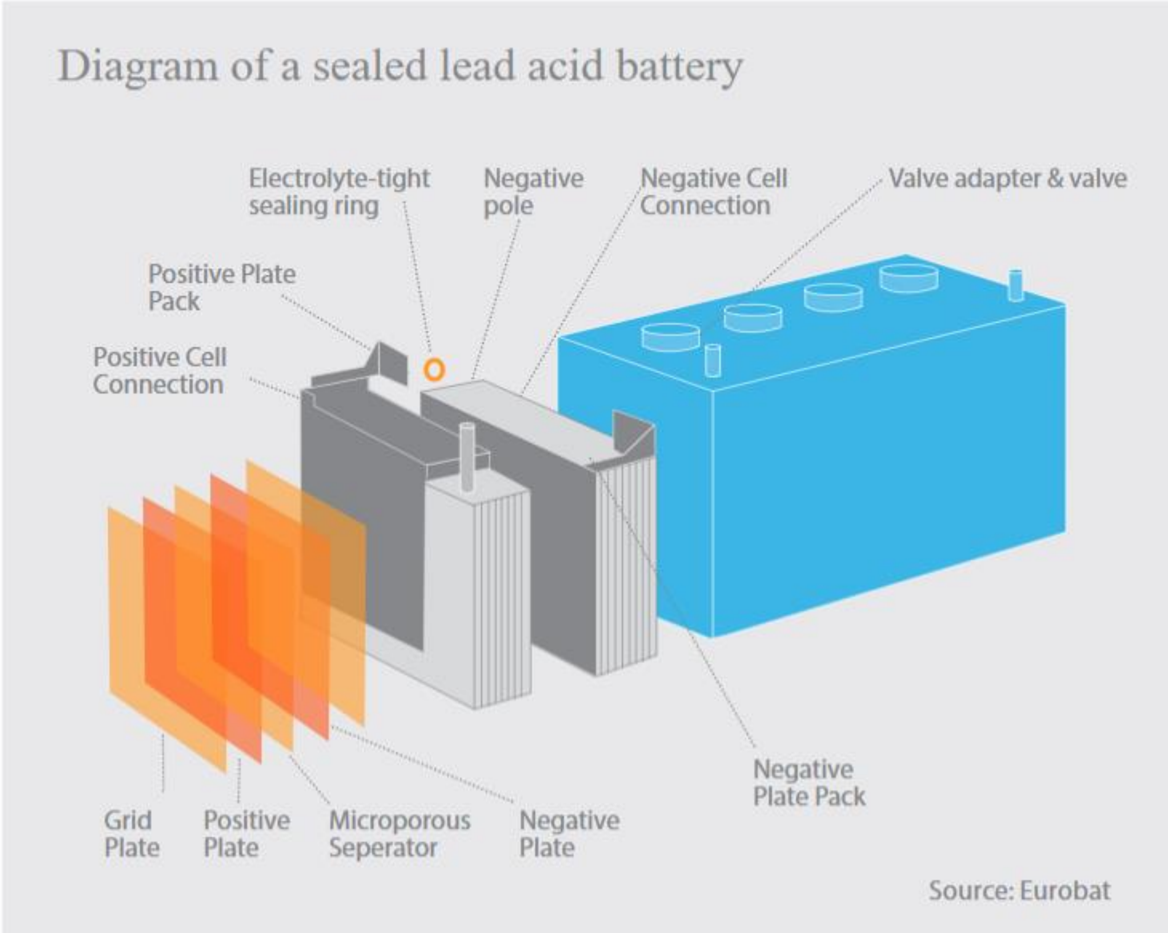

Figure 14: Lead-Acid Process Diagram

Lead-acid batteries are commonly used in:

- Standard car batteries
- Other types of electronic vehicles, including fork trucks, golf carts, and wheelchairs
- Backup power supplies for smaller electronic systems such as alarms or computers.

Figure 15: Common Applications of Lead-Acid Batteries[28]

[28] the-auto-warehouse-car-battery-replacement-myths-and-facts.jpg (848×565) (theautowarehouse.com)

Lead-acid batteries have many advantages including:

- Mature technology with over 150 years of experience; existing infrastructure for end-of-life recycling is already in place due to the automotive industry
- Good low temperature performance
- Stable and reliable
- Low self-discharge rates
- Adaptable to a wide range of discharge scenarios
- Raw materials are relatively common
- Recyclable
- Electrolyte and electrodes are non-combustible

Disadvantages include:

- Lower energy density than li-ion (e.g., more batteries are needed for same amount of power)
- Fewer cycles (e.g, battery can be discharged and recharged fewer times)
- Some off gassing during normal operation
- Can off gas large amounts hydrogen if charging system does not operate correctly
- Usually requires ventilation or air conditioning of storage location

The electrolyte (i.e., sulfuric acid) is corrosive and lead has chronic toxicity potential. During regular use, these hazards are largely contained. However, the recycling of the batteries requires safeguards.

3.2.4 Flow

Flow batteries are a rechargeable battery using two liquid electrolytes, one positively charged and one negative, as the energy carriers. The electrolytes are separated using an ion-selective membrane, which under charging and discharging conditions allows selected ions to pass and complete chemical reactions. The electrolyte is stored in separate tanks and is pumped into the battery when required. The storage capacity of flow batteries can be increased by simply utilizing larger storage tanks for the electrolyte. A diagram of a flow battery is shown in **Figure 16**.

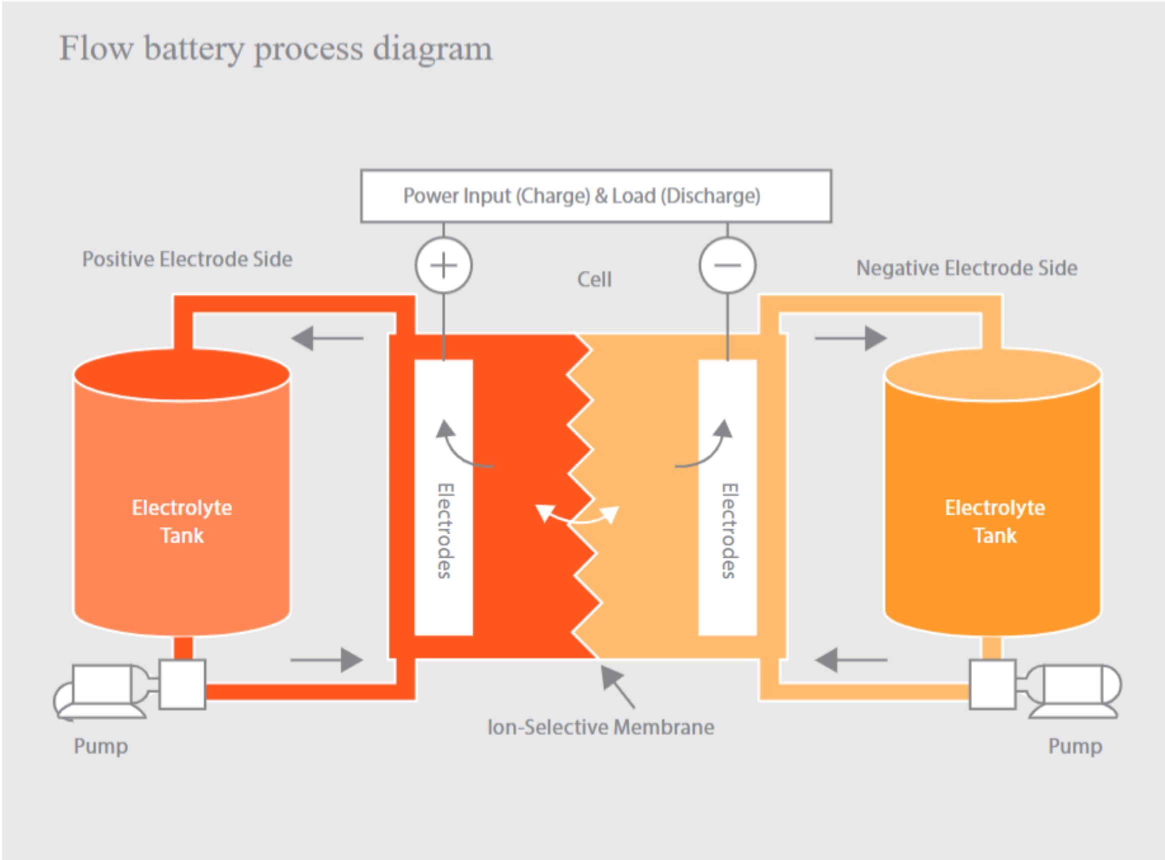

Figure 16: Flow Battery Process Diagram

Flow batteries differ from other batteries in not relying on changing chemicals to generate electricity. Flow batteries rely on the transfer of electrons between compounds to generate electricity. For purposes of this discussion flow battery is meant to refer to inorganic redox flow batteries which are the most common type commercially.

Flow batteries are commonly used in:

- Primary use in electrical grid storage to meet peaks in power demand
- Some types of electric vehicles

Advantages include:

- Able to tolerate a large number of charge/discharge cycles
- Reduced likelihood of the cells output being reduced to that of the lowest performing cellfoo
- Virtually unlimited capacity and long life as the chemistry does not 'wear out' due to inefficiencies
- No maintenance charging and minimal maintenance.
- Non-flammable

Disadvantages are:

- Low energy density
- Slower charging and discharging
- Not commercially mature

3.3 Electrical Balance of Plant Equipment

Space and consideration should be given to the various pieces of electrical equipment needed to support BESS incorporation into the power grid. A diagram of typical electrical components needed to support large-scale BESS sites is provided in **Figure 17**. The exact quantities and configurations of each piece of equipment are governed by the overall power rating and configuration of the BESS.

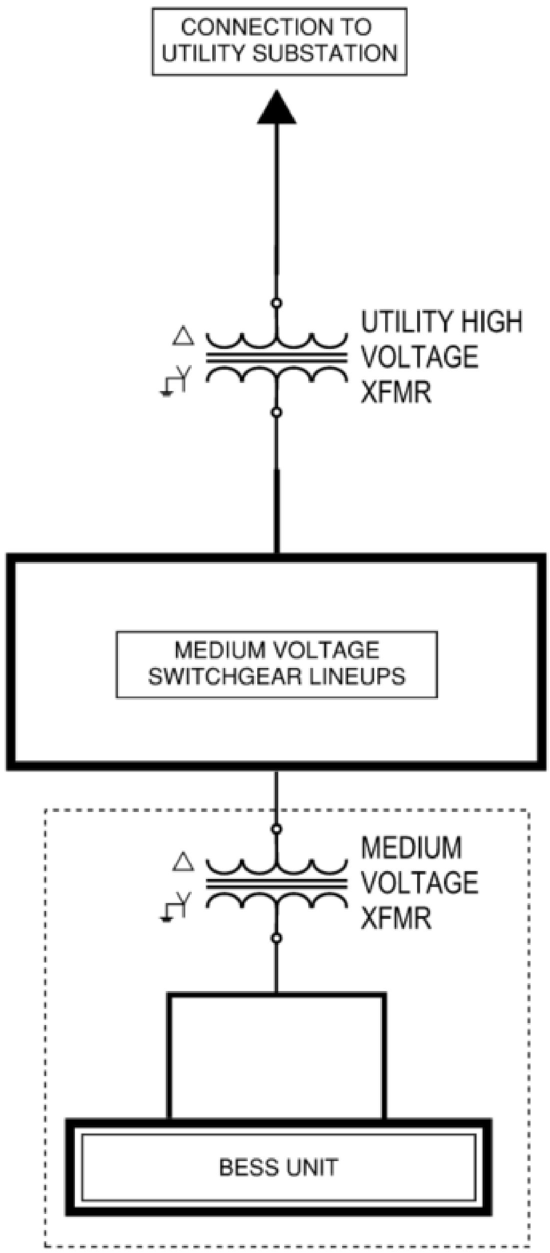

Figure 17: Representative Electrical Block Diagram for BESS Installation[29]

[29] Electrical transformer (XFMR)

4. Regulations and Available Guidance

4.1 Massachusetts BESS Applicable Codes and Standards

527 CMR 1.00, the Massachusetts Comprehensive Fire Safety Code (MFSC), regulates BESS installations. The MFSC is based on the 2015 edition of NFPA 1, *Fire Code*, with Massachusetts amendments. Massachusetts amended the fire code in October of 2020 to include Chapter 52, Energy Storage Systems, which is a chapter taken from the 2018 edition of NFPA 1. These are the requirements that apply to BESS installed and permitted in Massachusetts today. Enforcement of the MFSC is the responsibility of local fire departments.

4.2 National Fire Protection Association (NFPA) Codes and Standards

4.2.1 NFPA 855, Standard for the Installation of Stationary Energy Storage Systems

NFPA 855, *Standard for the Installation of Stationary Energy Storage Systems*, 2020 Edition, is the primary fire safety standard for BESS that is referenced in the United States. Though the Massachusetts state building and fire codes have not yet been revised to formally reference NFPA 855, NFPA 855 is thought of as a key best-practice design and safety standard and is often referenced and adopted voluntarily on projects in Massachusetts.

The 2020 Edition of NFPA 855 is the first edition of the Code and is in part based on the language that was developed for Chapter 52 of the 2018 edition NFPA 1, currently adopted as part of the base fire code in Massachusetts (MFSC).

Scope

NFPA 855 excludes a number of ESS systems from the requirements of the code. Of note, the following ESS are excluded:

- BESS having capacities (measured in kWh) less than those identified in the code, presented in **Table 2**; any large-scale BESS facility is expected to exceed the threshold capacities of the code. Therefore, it is expected that BESS will comply with NFPA 855 where they are permitted within jurisdictions where NFPA 855 is officially adopted.
- ESS installed in one- and two-family homes and townhouses are only required to comply with NFPA 855 Chapter 15, One- and Two-Family Dwellings and Townhouses;
- Mobile ESS deployed at an electric utility substation or generation facility for 90 days or less, where used exclusively during periods where the facility's primary BESS is being tested, repaired, retrofitted, or replaced. NFPA 855 Section 4.5 contains specific requirements for mobile ESS that also apply.

Table 2: NFPA 855 Threshold Quantities

Battery ESS Technology Type	Aggregate Capacity (kWh)
Lead-acid, all types	70
Nickel (Ni-Cad, Ni-MH, Ni-Zn)	70
Lithium-ion	20
Sodium nickel chloride	20
Flow batteries	20
Batteries in one- and two-family houses & townhouses	1

The table above are NFPA 855 threshold capacities for BESS based on various battery technologies. The Town of Medway could reference NFPA 855 threshold when determining if regulation by the Town is warranted.

It should be noted that NFPA 855 does not apply retroactively to existing BESS permitted prior to the effective date of the NFPA 855 standard.

Upcoming Changes

One of the most debated issues during the original NFPA 855 development cycle was whether or not the Code should apply to BESS owned and operated by public utilities.[30] On one side of the argument, utilities are federally regulated and adhere to their own set of design and safety standards, and, for these reasons, have historically been granted exclusions to similar safety regulations for other applications. On the other side, BESS hazards remain the same and fire departments are expected to respond to BESS fires regardless of who owns and operates them, therefore all BESS should fall under the scope of NFPA 855.

The 2020 Edition of NFPA 855 was issued without an official scope as this discussion had yet to be resolved by the end of the development cycle, but it is expected that this topic will take center stage again during the 2023 Edition development cycle meetings, beginning in 2022.

4.2.2 NFPA 855 Code Development

The development of NFPA 855 first began in 2016 to create a safety standard for the rapidly developing BESS technology. Each NFPA code is developed by a technical committee of members from the industry. The NFPA technical committees serve as consensus bodies that are responsible for developing and updating the NFPA codes and standards. They are made up of members of the public from a variety of groups to maintain a balance of affected individuals from the industry.

The NFPA 855 technical committee is comprised of the following groups in **Table 3**, categorized per NFPA's classification of committee members. A full list of principal members can be found on the NFPA 855 website.[31]

[30] NFPA Journal; Roman, Jesse; "Power Struggle"; https://www.nfpa.org/News-and-Research/Publications-and-media/NFPA-Journal/2021/Fall-2021/Features/ESS/Sidebar-1

[31] www.nfpa.org/855

Table 3: NFPA Committee Membership Classifications

NFPA Committee Member Classifications
Manufacturer (M) [32]
User (U)
Installer / Maintainer (I/M)
Labor (L)
Applied Research / Testing Laboratory (R/T)
Enforcing Authority (E) [33]
Insurance (I) [34]
Consumer (C)
Special Expert (SE) [35]

NFPA revises all their codes and standards on a three- to five-year basis using a designated public code development process.[36] Once the technical committee for a new code has been appointed, the committee drafts the initial code language, and it enters the four fundamental steps in the NFPA standards development process:

1. Public input
2. Public comment
3. NFPA technical meeting
4. Standards council action

Once the draft is published, it enters a robust public review and comment period where any member of the public may submit requests to add, remove, or revise content. The NFPA technical meeting serves as a live forum to further review the proposed revisions made during the public input and comment periods, and the standards council action acts as the final approval required in order to formally issue the code or standard.

A diagrammatic of the NFPA standard development process can be found in **Figure 18**.

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[32] Manufacturer (M) notable principal members include: Tesla; Panasonic Energy of North America (PENA); Eaton Corporation; Siemens

[33] Enforcing Authority (E) notable principal members include: Cambridge (MA) Fire Department; Fire Department of New York City (FDNY); Phoenix Fire Department

[34] Insurance (I) notable principal members include: FM Global

[35] Special Expert (SE) notable principal members include: Pacific Northwest National Laboratory (PNNL)

[36] NFPA; How the NFPA Standards Development Process Works; https://www.nfpa.org/Codes-and-Standards/Standards-Development/How-the-process-works

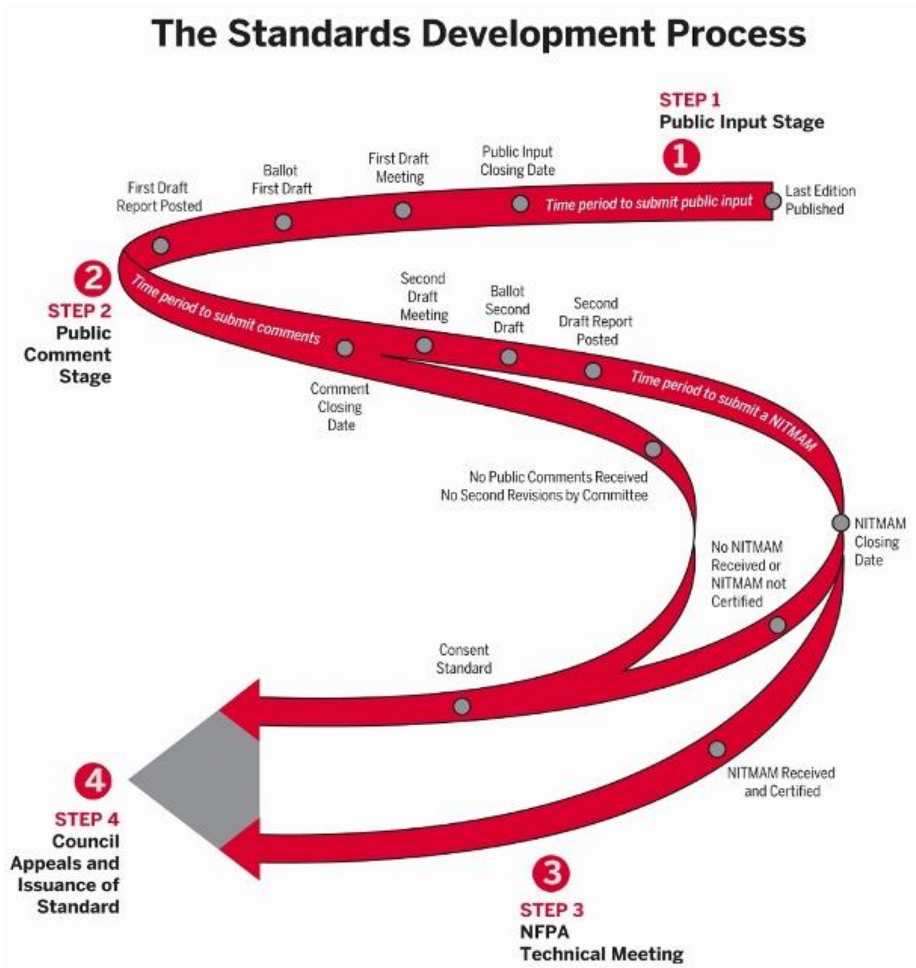

Figure 18: NFPA Standards Development Cycle[37]

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The technical committee for NFPA 855 is currently developing the next edition of the code with an anticipated release date in 2023.

4.2.3 NFPA 70, National Electrical Code

NFPA 70, *National Electrical Code* (NEC), is the national standard for electrical installations. The 2020 Edition of the NEC is adopted by Massachusetts with state amendments.

Article 706 of the 2020 Edition NEC covers electrical design and installation for Energy Storage Systems (ESS). The NEC applies to BESS other than those owned by investor-owned public utility companies. All BESS installations are expected to comply with the electrical installation requirements of the NEC, where the code is formally adopted within the specific jurisdiction.

4.3 FM Global Datasheet 5-33

Factory Mutual (FM Global) is one of the largest commercial property insurers in the United States. They develop and maintain a series of Property Loss Prevention Data Sheets, which are often utilized as best-practice design standards.

[37] Figure Reference: NFPA; How the NFPA Standards Development Process Works; https://www.nfpa.org/Codes-and-Standards/Standards-Development/How-the-process-works

It is important to note that compliance with all or of part of specific FM data sheets is not required by state or local jurisdictions but may be implemented by a project either voluntarily or via discussion with FM Global as the property insurer, if applicable.

FM Data Sheet 5-33 is the applicable data sheet for Electrical Energy Storage Systems. Originally published in January of 2017, the data sheet has since undergone a significant revision and was re-issued in April of 2020. The scope of the data sheet is specifically for lithium-ion battery chemistries only and does not apply to other battery chemistries including flow batteries or lead-acid.

4.4 IEEE C2, National Electrical Safety Code

Similar to how the NEC provides requirements for the electrical design and interconnectivity of privately-owned BESS, Institute of Electrical and Electronic Engineers (IEEE) C2, National Electrical Safety Code, is the electrical installation standard that is utilized by utility companies. Investor-owned public BESS and BESS owned by public municipalities are expected to be installed in accordance with IEEE C2.

5. Component Selection, Testing, and Listings

In the United States, when a product, component, or system is "listed," it means that it has been tested by a Nationally Recognized Testing Laboratory (NRTL) and has passed the appropriate acceptance criteria for that certification. BESS and the components that make up the system are no different from a standard hair drier in that it has an applicable certification that it has been tested against to certify that it meets a designated level of safety.

United Laboratories (UL) is one of the most recognized NRTL in the United States and is the industry standard for BESS testing and certification.

5.1 Component Standards

The applicable listing for battery cells that are part of BESS is UL 1642, *Lithium Batteries*. Even if individual battery cells carry the appropriate UL 1642 listing, and the electrical design and interconnectivity of the ESS is installed in accordance with the NEC, the various system components may not coordinate properly together. That is where UL 9540, *Energy Storage Systems and Equipment*, steps in, which tests the ESS as a whole.

UL 9540, most recently revised in April 2021, specifies that BESS units listed per the certification are limited to a maximum of 50 kWh. Where BESS units exceed this capacity, they are required to be tested in accordance with UL 9540's companion fire test performance criteria, UL 9540A, *Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems*.

UL 9540A tests a battery module from cell to unit and tests for thermal runaway. A diagram of the UL 9540A test method is provided in **Figure 19**.

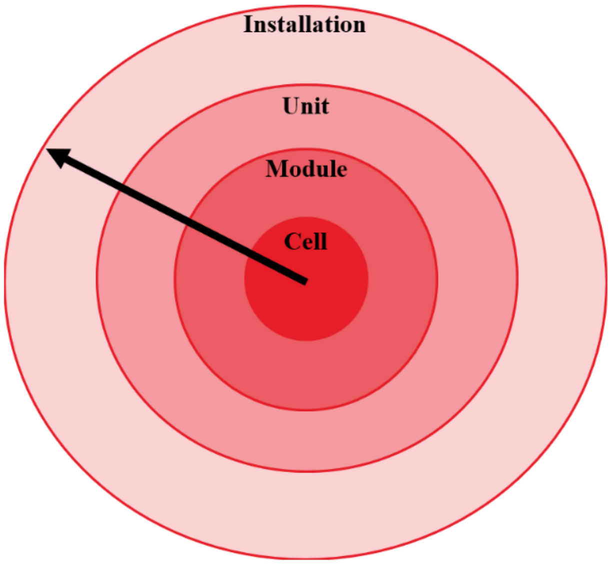

Figure 19: UL 9540A Test Method

UL 9540A Test Method

- Testing begins at cell level
- If thermal runaway is not observed, testing does not continue to the next level
- If thermal runaway is observed, testing continues to the next level

Key Information: UL 9540A test results provide the technical justification necessary for designers, safety reviewers, and Authorities Having Jurisdiction (AHJs) to determine capacity, location, and other important metrics when BESS exceed the minimum parameters of UL 9540 and other installation standards such as NFPA 855

The significance of the minimum UL 9540 listing criteria is that it requires any BESS of capacities > 50 kWh to be tested in accordance with UL 9540A. Without the minimum criteria, for example, it would be possible to obtain a listing for a 300 kWh BESS without it needing to be tested per UL 9540A.

UL 9540 – Listing for BESS System

UL 9540A – Testing Method for BESS System

Similarly, NFPA 855 requires BESS larger than 50 kWh to be tested per UL 9540A. Additionally, where BESS installations seek to exceed the minimum requirements provided in NFPA 855, they are required to support the exceedance with large-scale fire testing, or UL 9540A testing.

5.2 Minimum Massachusetts Requirements

For BESS projects in Massachusetts, the following listings can be expected.

Table 4: Massachusetts BESS Listings

Listed Pre-Engineered BESS System Capacity	Expected Listings
Storage batteries	UL 1973 listed *
Individual Array Capacity ≤ 50 kWh	UL 9540 listed
Overall Capacity ≤ 250 kWh	UL 9540 listed
Individual Array Capacity > 50 kWh	UL 9540 listed + UL 9540A tested
Overall Capacity > 250 kWh	UL 9540 listed + UL 9540A tested

* For li-ion battery cells, it is also common for the batteries to be listed per UL 1642, *Lithium Ion Batteries*.

Massachusetts adopts the 2020 edition of the National Electrical Code (NEC) for all electrical installations. Article 706 of the NEC requires ESS to be listed, which is a significant change from previous editions of the code where it was only required to have individual components of the ESS listed, but not the system as a whole. Now that UL 9540 offers a comprehensive listing for the energy storage systems, this listing is prescriptively required.

6. Siting Considerations

Key design parameters for BESS installations include where they are located, how far away from nearby adjacencies they need to be spaced, how high the capacity of the BESS can be as it relates to site layout, and environmental considerations. A primary consideration regarding siting, and one of the key drivers for this scope of work, is that a BESS site must comply with the zoning allowances of the local jurisdiction.

As part of this effort on behalf of the Town of Medway, two future scopes of work are forthcoming:

- Summary of technical considerations relating to BESS siting
- Summary of technical matters for the Town of Medway to consider as they look to modify the existing zoning bylaws for the Energy Resource district.

6.1 Permissible Locations

BESS may be located in accordance with the installation code(s) applicable within the state and local jurisdiction. Permissible locations can be categorized as depicted in **Figure 20**.

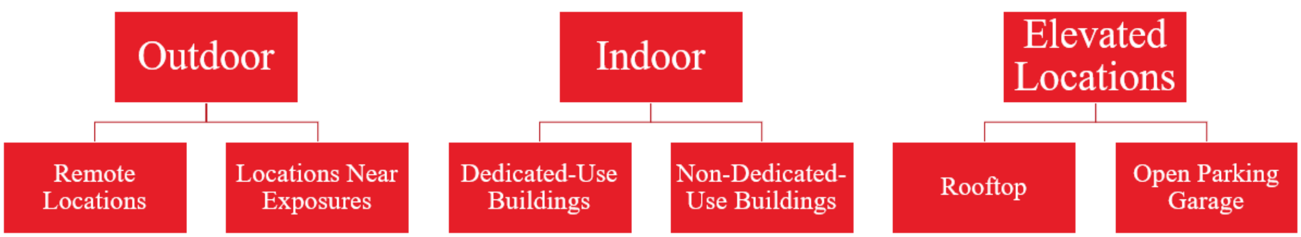

Figure 20: BESS Permissible Locations

Remote Locations are considered those located more than 100 feet from all of the following, defined as *exposures*:[38]

- Buildings
- Lot lines that can be built upon
- Public roads
- Stored combustible materials, such as ancillary outdoor storage or trash collection areas
- Other exposure hazards not associated with electrical grid infrastructure

The current MFSC requirements for BESS locations are provided in **Table 5**.

[38] NFPA 855 4.4.3.1

Table 5: MFSC Permissible Locations

Location	Permitted in Massachusetts?
Outdoor Installations	Yes
Indoor Installations	Yes, where either of the following conditions apply: • In a dedicated room designed as a high-hazard (Group H) occupancy meeting the robust design requirements of the building and fire code • In a dedicated room separated by either 1-hour or 2-hour fire barriers, depending on the relative hazard of the building occupancy
Rooftop Installations	Only where the floor level is 75ft or less above the lowest level of fire department access Rooftop installations > 75ft above the lowest level of fire department access may be permitted when approved by the AHJ
Below-grade Installations	Only where the floor level is 30ft or less below the lowest level of fire department access

6.1.1 Additional Guidance

FM Global provides a hierarchy of preferred installed locations, beginning from outdoor installations to dedicated cutoff rooms of various configurations. **Figure 21** is taken from FM Global DS 5-33 and shows the preferred installed locations.

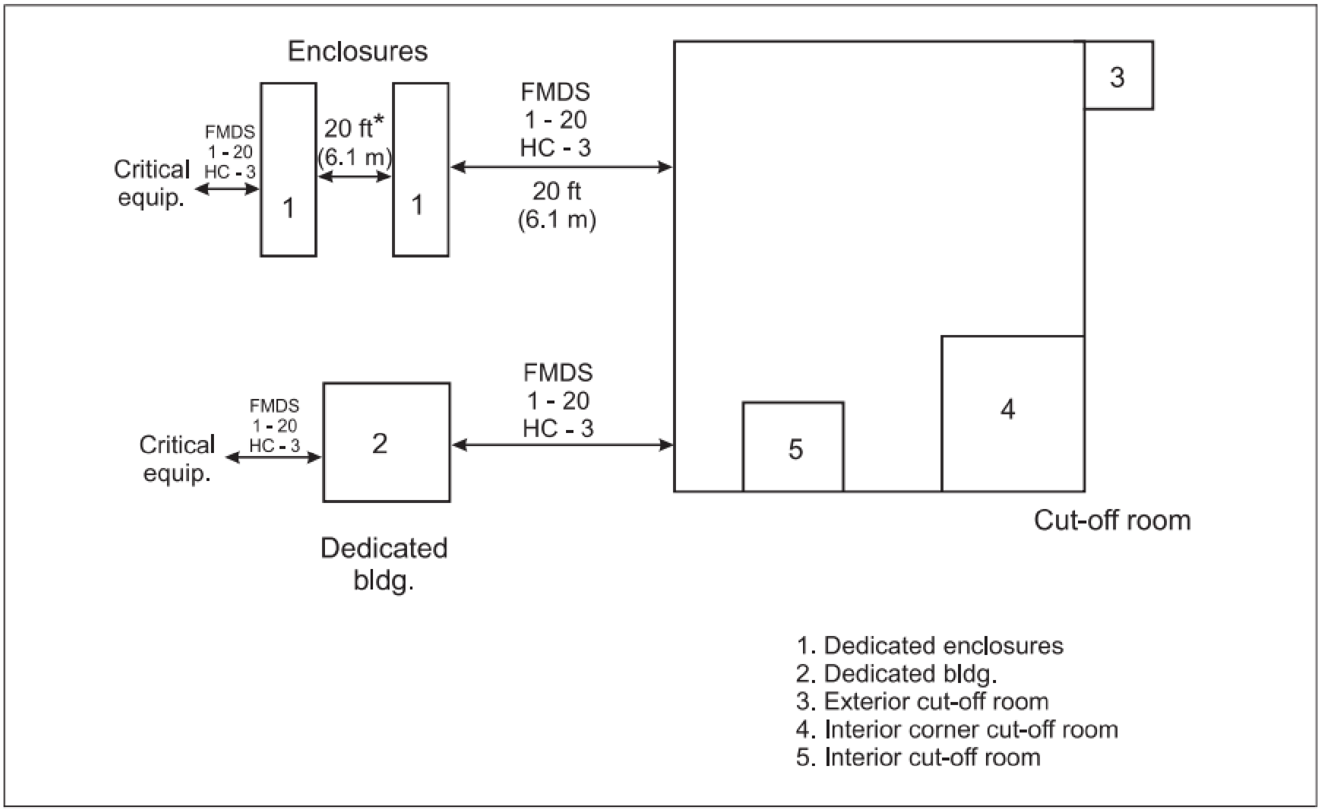

Figure 21: FM Global DS 5-33 Fig. 2.3.1 Preferred Locations Hierarchy

6.2 Maximum Stored Energy

The MFSC limits indoor BESS installations to the following maximum allowable capacities:[39]

Table 6: MFSC Maximum Capacities for Indoor BESS Installations

Battery Technology	Maximum Capacity
Lithium ion	600 kWh
Sodium batteries	600 kWh
Flow batteries	600 kWh
Other battery technologies	200 kWh

BESS installations are limited to arrays of no greater than 50 kWh with the associated 3-foot clearance in between arrays.

Where deviations from the maximum capacities outlined above are required, the AHJ is permitted to approve alternate and/or larger capacities or array groupings beyond the maximum code limits with support from large-scale fire testing in accordance with UL 9540A and a hazard analysis. Hazard analysis is typically performed in accordance with a Failure Modes and Effects Analysis (FMEA), and is described further in Appendix A.

Listed, pre-engineered li-ion BESS systems will fall under either of the following two categories:

Table 7: Listed Pre-Engineered Li-ion BESS Categories

Listed, Pre-Engineered Li-Ion BESS Categories	
Individual array capacity ≤ 50 kWh Maximum capacity ≤ 600 kWh	Systems are expected to carry a UL 9540 listing but are not expected to be provided with UL 9540A fire test data Individual array capacities of ≤ 50 kWh are small and often difficult to achieve
Individual array capacity > 50 kWh Maximum capacity > 600 kWh	Systems are expected to carry a UL 9540 listing and are also expected to be provided with UL 9540A fire test results showing failure data for the BESS-specific array capacity, overall capacity and spacing. Most BESS systems exceed one or both of the maximum capacities and therefore would be expected to provide UL 9540A fire test data as part of the BESS project

6.2.1 Additional Guidance

Beyond the MFSC capacity limits for indoor applications, NFPA 855 limits the capacity of BESS installations in the following locations:[40]

1. Indoor: Non-Dedicated-Use buildings
2. Outdoor: Locations Near Exposures (as defined in Section 7.1, Permissible Locations)
3. Open Parking Garages

[39] MFSC §52.3
[40] NFPA 855 §4.8

4. Rooftops

Similar to the capacities found in the MFSC, NFPA 855 contains the following boundaries for BESS capacities where BESS based on the type of battery chemistry:

Table 8: NFPA 855 BESS Maximum Capacities

Battery Technology	Maximum Capacity
Lead-acid	Unlimited
Nickel	Unlimited
Lithium ion	600 kWh
Sodium nickel chloride	600 kWh
Flow batteries	600 kWh
Other battery technologies	200 kWh

Mirroring the requirements of MFSC, all groups of batteries for all types of BESS installations are limited to a maximum capacity of 50 kWh, matching with the maximum capacity after which UL 9540 requires fire testing in accordance with UL 9540A. A minimum clearance of 3 feet is required between 50 kWh groupings, and between 50 kWh groupings and walls, including walls of outdoor BESS walk-in containers.

Where deviations from the maximum capacities outlined above are required:

- Where battery groups exceed 50 kWh, large-scale fire testing in accordance with UL 9540A is required to support the justification for the manufacturer-specific BESS installation.
- Where the maximum stored energy is exceeded for designated indoor or outdoor locations as outlined in **Table 8**, large-scale fire testing in accordance with UL 9540A is required for the manufacturer-specific BESS installation, as well as a hazard analysis (typically in FMEA format, see Appendix A) to support exceeding the maximum stored energy of the system.

Listed, pre-engineered BESS systems typically exceed the individual array capacity and support larger capacities and/or smaller separation distances via large-scale fire testing in accordance with UL 9540A.

FM Global does not limit the maximum capacity of BESS installations but contains more robust requirements for the protection of indoor BESS systems and outdoor BESS enclosures.

6.3 Size and Separation Distances between Outdoor BESS Units

For outdoor BESS, MFSC requires the following minimum clearances to be provided between the BESS units and exposures.[41]

Table 9: MFSC Outdoor BESS Minimum Setback Distances

Exposure Type	Minimum Required Clearance
Buildings	5 feet
Property lines	5 feet
Public roads	5 feet
Stored combustible materials, such as ancillary outdoor storage or trash collection areas	5 feet
Other exposure hazards not associated with electrical grid infrastructure	5 feet
Means of egress	10 feet

Other considerations for providing clearance between outdoor walk-in containers include maintaining clear working space around electrical equipment and providing space between containers such that fire-fighting operations can occur, and first responders can access BESS units that may sit in the middle of a larger array of units.

Relating to the clearances required between BESS walk-in units, MFSC requires battery arrays > 50 kWh in combustible containers to be spaced at least 3 feet from container walls. Noncombustible containers are more common for outdoor BESS, so this requirement is largely not a concern.

It should be noted that other guidance including NFPA 855 does not include this exception to omit the separation between arrays and container walls, so large-scale fire testing per UL 9540A would be required to omit the 3-foot separation which largely serves to reduce the size of outdoor walk-in containers and therefore the overall size of the BESS site.

For outdoor installations, a typical walk-in container is depicted in **Figure 22**. Note that the container is shown for diagrammatical purposes only and does not represent the type or aesthetics of a BESS outdoor container, and that exact sizes and configurations vary by manufacturer and product.

[41] MFSC §52.3.2.1.4.3

Figure 22: Typical Outdoor BESS Container Dimensions

6.3.1 Additional Guidance

NFPA 855 requires clearances between outdoor BESS and exposures (lot lines, buildings, roads, etc.) of at least 10 feet.[42]

FM Global recommends providing 20 feet of clear distance between outdoor BESS walk-in units or constructing a fire-rated barrier between units where the 20-foot clearance is not met. FM also treats any outdoor container that is more than 500ft^2 as a building.

6.4 Environmental Considerations

There are several environmental considerations for BESS designers to review, giving thought to the specific BESS technology and existing location, including:

- Noise control
- Light pollution
- Control of hazardous material spills
- Fire water containment
- Ground water control

As part of this effort on behalf of the Town of Medway, a summary of technical considerations relating to BESS siting is forthcoming.

7. Fire Remediation Actions and Response

Though installation codes, standards, and testing guidelines seek to reduce the likelihood of fire events from occurring in battery technologies, there is no feasible way to eliminate the risk all together. Pre-incident planning and emergency response are critical components of a comprehensive BESS safety plan to address foreseeable hazards when they occur on site. Emergency responder training ensures that first responders are aware of the potential hazards they may face when arriving at the site and are informed of the appropriate fire-fighting measures to be taken.

[42] NFPA 855 §4.4.3.3

7.1 Pre-incident Planning

An Emergency Responder Pre-Incident Plan should outline the emergency response protocols for the facility staff and for the local fire department for various types of incidents.[43] A pre-incident plan should cover the following topics:

- Primary hazards associated with BESS (thermal runaway, electrical fires), including outlining that BESS fires are capable of re-igniting after initial extinguishment
- Understanding the response and reporting capabilities of the provided Battery Management System (BMS)
- Identify provided safety systems including thermal runaway management systems, fire suppression, and fire detection
- Identify shutdown procedures for the BESS system specific to the battery technology, including the location of electrical disconnects
- Identify the appropriate manual fire-fighting response for the specific battery technology
- Damaged BESS component removal procedures

Additionally, FM Global recommends that the pre-incident plan for the facility include:[44]

- Manual disconnection
- Access routes
- Manual fire protection methods
- Manual smoke ventilation (if provided)
- Safety Data Sheet (SDS) for battery cells with key information such as chemical composition, recommended fire suppression agents, and reactivity of the battery cell with various materials

Pre-incident plans are a joint effort created by the BESS developer with input from the BESS operator and local fire department for emergency response.

7.2 Fire Department Response

Best practice guidelines for fire department response begin with standard hazmat response, including:

- Isolating the area to all personnel
- Confirming location and type of alarm
- Performing air monitoring
- Managing ventilation and exhaust
- Suppressing fires

Regarding air monitoring, toxic gas monitoring should be used for li-ion, lead acid, and flow battery chemistries because when the battery decomposes, it generates toxic gases. The specific gases to be monitored for should be part of the emergency responder pre-incident plan for the specific BESS site.

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[43] NFPA 855 Annex C

[44] FM DS 5-33 2.8.2

Full Personal Protective Equipment (PPE) and Self-Contained Breathing Apparatus (SCBA) gear should be utilized by the fire department when responding to a BESS incident.

FM Global recommends that a fire watch is present until all potentially damaged BESS equipment is removed from the area after a fire event and the fire protection water supply, if provided, is replenished.

7.3 Overheated Battery Response

Prior to a fire event, the Battery Management System (BMS) may detect a cell that has heated beyond the specified operating temperature, indicating that the cell is in a damaged or compromised condition. It is important that the facility has a designated plan to respond to such an event to keep the cell from progressing to thermal runaway.

8. Summary

BESS provides a grid-scale energy storage solution for short-term and localized grid demand challenges. The planning, development, design, operation, and maintenance of BESS involve many stakeholders who will need to work together to develop a comprehensive BESS project that serves the goals that have been set for it.

Key benefits of BESS can include:

- Increased **reliability** of electrical power supply and ability to match supply and demand from intermittent sources
- Increased **stability** and flexibility for the power grid
- Supports **decarbonization** goals
- BESS site serves as **taxable revenue** for the local jurisdiction
- BESS could prove **economically** beneficial when purchasing energy at lower rates and discharged during high demand
- Increased **resiliency** and ability to supply power during black-outs and major outages
- Aids in **reducing congestion** on the network resulting in reduction or elimination of the need to invest in new transmission lines

When siting a BESS facility, it must be located within the allowances of state and local building and fire codes, as well as local zoning regulations. Engineered safety systems, such as those described in Appendix A of this report, pre-incident planning, and emergency response are all critical components of a comprehensive BESS safety plan to address foreseeable hazards when they occur on site.

The findings in this report are intended to aid the Town of Medway in determining how to implement BESS within their community. Although this report provides technical information, it builds off other work that has been performed and is not intended to be a complete reference. Additional work will likely be needed to aid the Town with BESS implementation. The Town of Medway has identified the following knowledge gaps, which will be covered in separate reports:

- Summary of technical considerations relating to BESS siting.
- Summary of technical matters for the Town of Medway to consider as they look to modify the existing zoning bylaws for the Energy Resource district.

Appendix A

Additional BESS Design Considerations

A.1 Overview of Hazards

While there are safety concerns for BESS, installation and testing codes and standards have made significant strides in recent years to understand the primary hazard of BESS and protect against them.

BESS is an emerging technology, which means that battery chemistries are evolving and could change the source, intensity, and/or likelihood of fire events beyond those which are understood and identified by current codes. That being said, installation codes such as NFPA 855 address emerging technologies by requiring the full gambit of protection systems for battery technologies that fall outside of the common chemistry types (e.g. lead-acid, flow, li-ion). Full-scale fire testing will continue to play a critical role in understanding the nature of safety risks associating with emerging battery technologies, and with the recent editions to codes and standards requiring UL 9504A testing for BESS units greater than 50 kWh, availability of UL 9540A testing has quickly become the industry expectation for BESS units.

There are two primary hazards associated with BESS: thermal runaway and electrical fires.[45]

A.1.1 Thermal Runaway

Thermal runaway is a condition in which a battery generates sufficient internal heat to cause sustained breakdown of the battery. It most often occurs when a battery cell has sustained physical or electrical damage, and usually results in a fire. Some battery types are more susceptible to thermal runaway. Typical flow batteries are not as susceptible to thermal runaway as the battery requires the electrolyte to be pumped to function, therefore once supply of the electrolyte has stopped, so has the risk of thermal runaway.

During a thermal runaway event, the cell produces flammable gas that builds up within the cell enclosure or the room where ESS are installed. Hot vented gas, when directed toward adjacent cells, may propagate thermal runaway to those cells and continue to adjacent cells.

A.1.2 Electrical Fire

Electrical fires are a risk with any electrical installation, particularly of the high voltage observed for grid-scale installations. Design and installation in accordance with safety standards, including NFPA 70, *National Electrical Code*, work to prevent electrical fires from occurring.

A.2 Electrical Interconnection

A key consideration when siting BESS installations is positioning relative to substations. Where the BESS can be located close to the point of interconnection into a substation, the extension of power lines can be minimized.

Where power lines are required to traverse multiple plots of land before reaching the substation, the likelihood that the power lines can be run primarily underground diminishes. Underground power lines are not subject to the same types of environmental risks as overhead power lines and are therefore the more desirable option to provide resiliency for the power transmission lines connecting BESS sites with substations.

Consideration should also be given to providing redundant pathways to the substation, especially for larger capacity BESS sites, to avoid a single point of failure being able to disconnect the BESS from the power grid.

[45] FM Global Data Sheet 5-33, *Electrical Energy Storage Systems*

A.3 Risk Analysis and Mitigation

Where BESS are not able to meet the prescriptive requirements of safety standards including NFPA 855, a hazard analysis is required to support alternate approaches.

For BESS, a Failure Mode and Effects Analysis (FMEA) is the preferred and most common risk analysis approach.

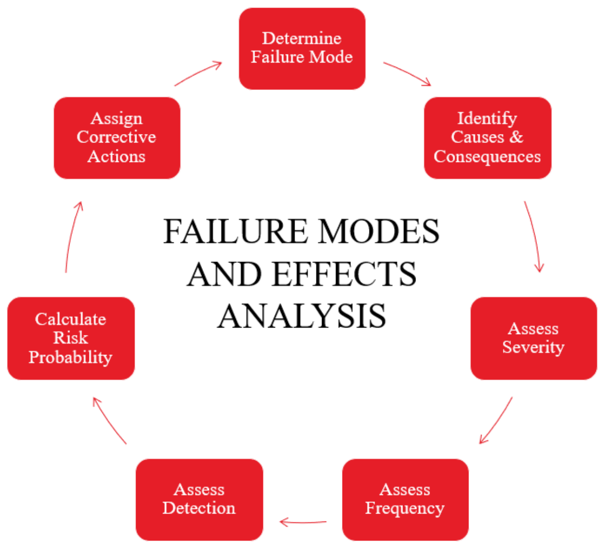

Figure 23: FMEA Overview

Failure Modes and Effects Analysis (FMEA)

A FMEA is designed to:[46]

1. Identify and fully understand potential failure modes and their causes, and the effects of failure on the system or end users, for a given product or process
2. Assess the risk associated with the identified failure modes, effects, and causes, and prioritize issues for corrective action
3. Identify and carry out corrective actions to address the most serious concerns

Though not required, FMEAs are typically performed in accordance with the guidelines set by IEC 60812, *Failure Modes and Effects Analysis*, issued by the International Electrotechnical Commission. IEC standards are internationally recognized standards for safety, design, and integration of a wide variety of products, processes, and systems.

The FMEA is typically conducted by a third-party company or individual qualified and experienced in conducting hazard assessments and can be provided to the local authority having jurisdiction over the design project and/or local fire department if specifically requested.

A.4 Battery Management System

A Battery Management System (BMS) is the first line of defense against fire incidents including thermal runaway. A BMS as defined by NFPA 855 is:[47] A system that monitors, controls, and optimizes performance of an individual or multiple battery modules in an energy storage system and has the ability to control the disconnection of the module(s) from the system in the event of abnormal conditions.

The design of BMS is individual to the BESS installation, with designs differing based on BESS size, location, cell configuration, and more. A BMS provides two key forms of protection and control: electrical protection and thermal protection. Electrical protection ensures that battery cells are not operating outside their designated

[46] Carlson, Carl S.; *Effective FMEAs;* 2012 John Wiley & Sons, Inc.

[47] NFPA 855 §3.3.3

specification regarding metrics such as voltage output, and thermal protection which provides temperature control to bring the battery cells back into the desired temperature specification range to maximize output.

The BMS has the ability to shut down a specific module by transmitting an off-specification cell and can transmit these readings to off-site personnel for notification. FM Global recommends that the BMS is programmed to monitor the state of health of li-ion battery cells, as li-ion cells degrade over time, increasing in resistance, decreasing in capacity, and becoming more susceptible to thermal runaway.

BMS not only provide invaluable data on the day-to-day operation of the BESS but they are also the first means of detecting off-specification batteries and disconnecting them from the system before they lead to a potential thermal runaway scenario.

A.4.1 Minimum Massachusetts Requirements

MFSC requires a BMS for all li-ion BESS installations. The BMS is required to:

1. Monitor and balance cell voltages, currents, and temperatures within the BESS manufacturer's specifications
2. Transmit an alarm signal to an approved location if potentially hazardous temperatures or other conditions including short circuits, overvoltage (overcharge), or under voltage (over discharge) are detected

A.5 Thermal Runaway Detection and Safety Caps

A.5.1 Thermal Runaway Detection

Thermal runaway is a condition in which a battery generates sufficient internal heat to cause sustained breakdown of the battery. It most often occurs when a battery cell has sustained physical or electrical damage, and usually results in a fire. Some battery types are more susceptible to thermal runaway. Flow batteries are mostly not susceptible to thermal runaway as the battery requires the electrolyte to be pumped to function, therefore once supply of the electrolyte has stopped, so has the risk of thermal runaway.

A.5.2 Safety Caps

A part of the battery cell design common to most battery types. The purpose of the safety cap is to allow a battery jar to release excess internal pressure without rupturing. Different battery chemistries will have different tendencies to evolve gas (usually during the charging process) due to inefficiencies in converting electrical energy to chemical energy.

A.6 Fire Detection and Alarm

BESS systems rely on smoke detection to provide detection in the event of a fire. Smoke detectors are typically interlocked into other safety and control systems, including the fire sprinkler system and Battery Management System (BMS), to provide comprehensive emergency detection and alarm.

Detection for BESS is being rapidly developed by the industry, seeking to provide early-warning indication about an impending fire or thermal event before it occurs. One of the leading detection technologies is off-gas detection, which detects the off gas that battery cells release when they begin to fail. Off-gas detection is then interlocked to the BMS to disconnect the failing battery or array before a thermal event begins to occur.

Off-gas detection is not currently required by any installation standards but is a consideration for BESS site designers.

A.7 Fire Suppression and Control

A.7.1 Fire Sprinkler Systems

Lithium metal is a water-reactive material, meaning that it either reacts violently with water or will readily produce a flammable gas product when reacting with water. Unlike lithium metal, lithium-ion batteries are not water reactive, meaning that it is safe, and even recommended, to utilize water as the primary suppressing agent.

The industry has spent time testing the effectiveness of different fire suppression agents on BESS and have found that the most suitable suppressant for li-ion batteries is large volumes of water which serve to cool the batteries and terminate the thermal runaway effect. Due to the dense nature of li-ion BESS systems, much of the water is unable to penetrate into the modules, hence the need for large water volumes.

Installation standards such as NFPA 855 require high-volume sprinkler systems for indoor BESS installations as well as for outdoor BESS installations where there is a risk of engaging nearby exposures (buildings, roads, vegetation, etc.) in a fire that spreads from the BESS unit.

A.7.2 Water Supply

One of the primary challenges to using water as a suppressant for li-ion fires is being able to apply water directly to the battery cells. Due to the nature of typical li-ion BESS walk-in units, without a fixed sprinkler system within the walk-in container the doors must be opened by fire departments in order to apply water directly to the battery cells, subjecting emergency responders to potentially hazardous environments within the containers. Outdoor installations make providing permanent fire sprinkler systems challenging, especially in remote or cold environments where the logistics of providing water to the site or preventing water from freezing surpasses the usefulness of the system.

Some types of li-ion BESS walk-in units are provided with sprinkler systems that can be easily supplied with water by the fire department during emergency response, but others are not.

A.7.3 Suppressing Agent Supply

Other types of battery chemistries work better with other types of suppression agents. Suppression should be tailored to the specific manufacturer, design, and chemistry of the BESS.

Where a different type of suppressant agent has been identified to be appropriate for the battery technology, the alternate suppression system is typically built into the containerized BESS system and tested as part of the UL 9540A large-scale fire testing. Where suppression systems other than water-based systems are proposed, they should be supported by UL 9540A test data.

A.7.4 Reduced Water Emerging Technologies

In a FM Global report issued April 2020 titled "Reducing Water Demands with Innovative Fire Protection Solutions," two emerging fire suppression technologies were reviewed for their effectiveness on fighting BESS fires:[48] Simultaneous Monitoring, Assessment and Response Technology (SMART) sprinklers, and Automated Water Cannons (AWC).

These types of water-based fire suppression systems are to this point not widely used in the BESS industry but could be considered if a reliable water supply for traditional fire sprinkler systems proves challenging.

[48] FM Global; April 2020; Reducing Water Demands with Innovating Fire Protection Solutions"; https://www.fmglobal.com/research-and-resources/research-and-testing/research-technical-reports

A.8 Spill Control and Fire Water Containment

A.8.1 Spill Control

Spill control should be integral to the overall BESS system. The purpose of spill control is to contain unintentional leaks from batteries or spills during maintenance operations. It is not intended to contain the entire volume of all batteries in a system or fire suppression water.

A.8.2 Fire Water Containment

Where water-based suppression systems are provided, or where infrastructure is added to facilitate fire department application of water suppressant, consideration should be given to the control of fire water.

Given the large volumes of water needed to cool and suppress a BESS event, consideration may be given to implementing controls to contain fire water to a designated area or to prevent the spill of fire water into adjacent areas. Specific controls to be implemented are discussed on a project-by-project basis.

A.8.3 Neutralization of Spills

Neutralization of spills is a technology-specific provision, generally only provided for certain types of lead-acid, nickel, and flow batteries due to the presence of liquid electrolyte.

The method of neutralization is determined by the BESS designer with the intent to balance the pH of electrolyte spills.

A.9 Ventilation

Ventilation is an important safety control for BESS because it removes potentially hazardous gases released from failed batteries and prevents them from accumulating in areas such as outdoor walk-in containers or indoor enclosures. Nearly all batteries will release hazardous gases during abnormal operating or emergency conditions.

Ventilation systems are typically designed to reduce flammable concentrations of gas within the space to less than 25% of what is referred to as the lower flammable limit (LFL), the minimum volume of the gas in air that is needed to support combustion.

Ventilation also serves as heat removal from enclosures, helping to prevent rapid progression of thermal runaway, and can serve as an integral component to explosion prevention systems, as referenced in the following section.

Given that ventilation is a critical safety component, BESS site designers should consider providing a reliable source of back-up power to maintain operation of the system during normal power outages or during failure of the BESS system it serves.

A.10 Explosion Control

Explosion control may be required depending on the chemistry and physical configuration of BESS. Where it is provided, the most common national design standards are NFPA 68, *Standard on Explosion Protection by Deflagration Venting*, and NFPA 69, *Standard on Explosion Prevention Systems*.

Where explosion deflagration venting is utilized, additional consideration should be given to providing setback distances to accommodate the hazard zone adjacent to the vent panels.