ENERGY STORAGE SYSTEMS

BASED ON THE IBC®, IFC®, IRC® AND NEC®

IAEI
The Electrical Safety Leader

ICC
INTERNATIONAL CODE COUNCIL®

Energy Storage Systems: Based on the IBC®, IFC®, IRC® and NEC®

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Preface

Energy storage devices surround us and are an everyday part of our modern world, from cell phone and laptop batteries to thermal storage in passive solar homes. In the past few years, however, energy storage systems (ESS) have gained global attention as a key enabling technology to facilitate the shift to renewable energy sources, such as solar and wind power, for an ever-greater share of our electricity needs. ESS play a critical role in this transition, allowing for a variety of functions that provide much-needed support to the aging electrical grid, as well as providing the ability to store abundant renewable energy generated during periods of high sun or wind for later use. With the growing connectedness of electrical infrastructure, ESS are the glue that bind together variable resources and variable loads, providing the certainty that the average consumer expects when they turn on their oven that it will, in fact, have access to sufficient energy to operate.

It would be a mistake, however, to envision ESS as a stable or monolithic technology. In fact, the term ESS encapsulates a tremendous range of technologies, from flywheels to flow batteries, and most of these will be unfamiliar to building officials, emergency services, planners, architects and engineers. The goal of this Guide is to provide a handy reference to ESS technologies with an eye toward the key information that these groups need to safely plan, design, build and permit ESS in the built environment. This information includes consideration of how the technologies function, safety considerations and the applicability of current Codes and Standards, which are evolving quickly to address these, and other, related new technologies.

Beginning in 2010 and extending into the 2020s, lithium-ion battery-based ESS dominate the global market, representing over 90 percent of all new energy storage capacity installed; as such, much of the Guide will focus on this group of technologies. Attention will also be given to a number of other technologies that are gaining ground and seeing successful commercial or near-commercial projects in construction globally.

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About the International Building Code® (IBC®)

Building officials, design professionals and others involved in the building construction industry recognize the need for a modern, up-to-date building code addressing the design and installation of building systems through requirements emphasizing performance. The *International Building Code*® (IBC®), in the 2021 edition, is intended to meet these needs through model code regulations that safeguard public health and safety in all communities, large and small. The IBC is kept up to date through the open code development process of the International Code Council® (ICC®). The provisions of the 2018 edition, along with those code changes approved in the most recent code development cycle, make up the 2021 edition.

The International Code Council (ICC), publisher of the IBC, was established in 1994 and is a nonprofit association that provides a wide range of building safety solutions including product evaluation, accreditation, certification, codification and training. The ICC develops model codes and standards used worldwide to construct safe, sustainable, affordable and resilient structures. The ICC's mission is to provide the highest-quality codes, standards, products and services for all concerned with the safety and performance of the built environment.

The IBC is one of 15 International Codes® (I-Codes®) published by the ICC. This comprehensive building code establishes minimum regulations for building systems through prescriptive and performance-related provisions. It is founded on broad-based principles that make possible the use of new materials and new building designs. The IBC is available for adoption and use by jurisdictions internationally. Its use within a governmental jurisdiction is intended to be accomplished through adoption by reference, in accordance with proceedings established by the jurisdiction's laws.

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One in a family of International Codes published by ICC, the IFC is a model code that establishes minimum fire safety requirements for new and existing buildings, facilities, storage and processes. It addresses fire prevention, fire protection, life safety and safe storage and use of hazardous materials. The IFC provides a total approach of controlling hazards in all buildings and sites, regardless of the hazard being indoors or outdoors.

The IFC is a design document. For example, before a building is constructed, the site must be provided with an adequate water supply for fire-fighting operations and a means of building access for emergency responders in the event of a medical emergency, fire or natural or technological disaster. Depending on the building's occupancy and uses, the IFC regulates the various hazards that may be housed within the building, including refrigeration systems, application of flammable finishes, fueling of motor vehicles, high-piled combustible storage and the storage and use of hazardous materials. The IFC sets forth minimum requirements for these and other hazards and contains requirements for maintaining the life safety of building occupants, the protection of emergency responders, and to limit the damage to a building and its contents as the result of a fire, explosion or unauthorized hazardous material discharge and electrical systems. The IFC is available for adoption and use by jurisdictions internationally. Its use within a governmental jurisdiction is intended to be accomplished through adoption by reference, in accordance with proceedings establishing the jurisdiction's laws.

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The International Code Council is the leading global source of model codes and standards and building safety solutions that include product evaluation, accreditation, technology, codification, training and certification. The Code Council's codes, standards and solutions are used to ensure safe, affordable and sustainable communities and buildings worldwide. The International Code Council family of solutions includes the ICC Evaluation Service, the International Accreditation Service, General Code, S. K. Ghosh Associates, NTA Inc., Progressive Engineering Inc., ICC Community Development Solutions and the Alliance for National & Community Resilience. The Code Council is the largest international association of building safety professionals and is the trusted source of model codes and standards, establishing the baseline for building safety globally and creating a level playing field for designers, builders and manufacturers.

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1 Introduction

Energy Storage Systems (ESS) do not generate electricity in the way that solar facilities do. In fact, ESS are net consumers of electricity because they store and discharge electricity at less than 100 percent efficiency. However, ESS have a pivotal role to play in the adoption of clean and distributed energy resources, particularly resources that generate electricity based on variable sources, such as solar or wind, that are difficult for utilities to dispatch. As more variable renewable energy resources begin coming online, electricity network operators face more challenges to balance periods of high demand and periods of high generation, which may occur hours apart during any given day. It is these situations that can be helped by the application of ESS, allowing for excess generation to be stored for later use when demand increases. This time shifting of energy, called arbitrage, is one of the most common use cases for ESS. In fact, because electricity prices vary so frequently throughout the day, arbitrage can also be used to generate revenue by purchasing lower priced electricity (e.g., at night or during a period of high generation/low demand) and selling at higher prices (usually peak demand periods).

Of course, the electricity grid is much more complicated than simply balancing energy generation and demand (although that is certainly complicated enough). In addition, grid operators must provide reliable power, supplied with a tightly controlled frequency. This is another good opportunity for ESS, which can react quickly to grid operator signals and provide a high degree of control and flexibility in its operation. This capability creates opportunities for more novel value streams, and most commercial and utility-scale ESS will combine several of these revenue streams in a process called value stacking.

1.1 A Brief History of Energy Storage Technologies

Modern Energy Storage Systems bear little resemblance to battery backup systems from a few years ago, and the technology has undergone significant changes in recent years.

Energy storage, interpreted broadly to mean harnessing some form of potential energy for performing work on-demand, can be traced back to antiquity. Harnessing of water power via early water wheels was seen in Ancient Greece, China and the Near East around the fourth century BCE. While many of these water wheels utilized the mechanical energy of running water, certain types were constructed using dams or reservoirs that could be considered an early form of hydropower storage. The use of dams to create mill ponds dates to at least the seventh century, when Islamic engineers used such mill ponds with water wheels in North Africa, Asia and elsewhere (Figure 3-1). Eventually, mill ponds were so prevalent across the United Kingdom and the United States that there remain many place names, such as "Mill Pond Road," to be found to the present day. This speaks to the ubiquitous use of energy storage for controlling the application of power to align with needed work far earlier in history than most would expect.

Figure 1-1

Mill ponds and water wheels like these were used throughout the world as an early form of energy storage, with sluice gates controlling water flows in and out of the pond to provide mechanical power for a variety of applications via the water wheel. Photo credit "mill pond calm" by johnb/Derbys/UK is licensed under CC BY-NC-SA 2.0

Such devices continued to be used throughout the Roman Empire and medieval periods and have led to relatively modern hydroelectric facilities, which generally use a series of dams to store water for controlled release over electricity-generating turbines. The first commercial facility of this type was the Niagara Falls facility constructed in 1895 and still in operation (Figure 3-2). In fact, despite the majority of the news being about battery-based ESS, pumped water still (by far) represents the majority of energy storage capacity worldwide.

Figure 1-2

Niagara Falls is the first commercial hydropower facility and continues operating today, demonstrating the significant energy storage potential of dams and reservoirs. Photo credit "Niagara Falls Hydro Plant" by gobanshee1 is licensed under CC BY-SA 2.0

Batteries, aside from the controversial Baghdad Battery[1], are a more recent invention, and the term "battery" was first coined, related to storing electricity, by Benjamin Franklin in 1749 in reference to a group of capacitors used to store electrical charge. From there, the first recognizable cells using chemical potential to store charge were developed by Alessandro Volta and others, in the late eighteenth century. In 1800, Volta created the Voltaic Pile (Figure 3-3), a device consisting of copper and zinc discs with various electrolyte materials (e.g., cloth soaked in brine) that was able to produce a relatively stable voltage and maintain charge over time. However, Volta had not yet conceived of a way to prevent an electroplating action or the creation of excess hydrogen gas in his cell, so advancements in the 1830s by John Frederic Daniells, Golding Bird and John Dancer contributed to the concept of using various materials that allow the transfer of ions but maintain separation of differing electrolyte solutions, effectively introducing the idea that would later become the separator used in modern batteries. There were many variations on these liquid electrolyte batteries through the nineteenth

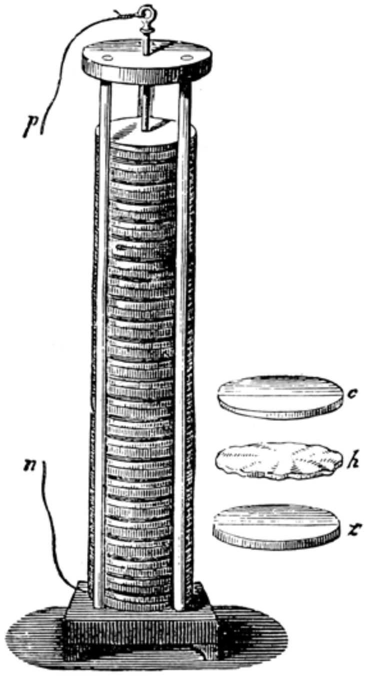

Figure 1-3

The Voltaic Pile, named for Alessandro Volta, was created in 1800 and can be considered the most direct precursor of the modern primary battery cell. Image courtesy of Getty Images.

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[1] The "Baghdad Battery" is one interpretation of the potential uses for a set of historical artifacts, consisting of a clay pot, a copper tube and an iron rod that were found in Iraq. The dating of the artifacts is believed to be sixth century or earlier. One hypothesis for the purpose of the artifacts is that they could have been combined, with a suitable electrolyte, into an early type of battery. However, there is not scientific consensus on the use of these artifacts; and their use as batteries would likely have required a means of connecting several jars together (i.e., wires in modern usage) and no such connection means were found.

century, using various combinations of electrodes, electrolyte and earthenware jars acting as a sort of separator. These early batteries were not rechargeable in the modern sense and extending the life of such batteries required replacement/replenishment of the electrodes and electrolytes. Somewhat ironically, in an era where batteries are seen as critical to supporting the electricity grid of the future, it was batteries such as these that provided much of the electrical energy used for things like train stations and telegraphs, before there was widespread electrical service.

Rechargeable[2] batteries got their start in 1859 when Gaston Planté invented the first lead acid battery that could be recharged by passing current through the electrodes in the reverse direction. This early battery (Figure 1-4) consisted of lead sheets, with rubber separators between the sheets, immersed in a sulfuric acid solution. The electrodes consisted of a lead anode and lead dioxide cathode and the battery was notable for its ability to source significant amounts of current at higher voltages than other cells available at the time, such as the Daniell Cell; however, the energy capacity was relatively low. The technology evolved for better exposing the lead to the acid solution by improving the form factor of the lead sheets into lattices and plates but, generally, the lead acid batteries used in gasoline powered cars and other vehicles today resemble the early cells created by Planté.

Figure 1-4

The Plante Battery was the first rechargeable cell and is remarkably similar to the modern lead-acid batteries used in vehicle and backup power applications. Photo courtesy of Maglab.

Another nineteenth century battery that saw use well into the early twenty-first century was the nickel-cadmium (NiCd) battery. The NiCd battery first appeared in 1899, invented by Waldemer Junger, and was used for applications like portable power tools and even early cell phones. NiCd batteries have been largely supplanted, first by nickel metal hydride (NiMh) and then by lithium-ion (li-ion) batteries for most applications. Though NiCd was suitable for some of these portable power applications, it suffered from reduced capacity over time that was highly dependent on charge and discharge behavior and the toxicity of the key materials made waste management problematic. Notably, NiCd batteries were the first to use an alkaline, rather than acidic, electrolyte.

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[2] Rechargeable batteries are often referred to as "secondary" cells or batteries; and batteries incapable of being recharged are referred to as "primary" cells or batteries.

Alkaline batteries continued to be developed through the early twentieth century (and common primary cells used today are still alkaline cells based on these early designs) and drew the attention of famous inventors such as Thomas Edison. Edison, in the early 1900s, developed a nickel-iron battery that he hoped could be mass produced at sufficiently low cost to make electric automobiles viable. While history has shown that this did not quite come to fruition, Edison's nickel-iron battery proved to be useful in other applications, such as rail transportation and backup power, and the technology continues to draw interest today as a battery option that relies on readily available materials.

Lithium-based batteries are a bit more recent, with most of their development occurring from the 1970s onwards. Initial lithium batteries were primary cells, still used in some watches or cameras today, where high energy and small form factor are critical. From there, lithium-ion and lithium polymer batteries were developed as rechargeable lithium batteries, with Sony commercializing the first li-ion battery in 1991. These initial li-ion batteries used a lithium cobalt oxide cathode and graphite anode, though (as discussed later), development of new cathode materials is an ongoing and active area of research that is key to improving li-ion cell performance and safety. In 2019, three scientists credited with foundational work in the development of li-ion batteries were awarded the Nobel Prize in Chemistry. Based on previous work by John Goodenough and Stanley Whitingham, Akiro Yoshino created the first commercially viable li-ion cell in 1985, as shown in Figure 1-5.

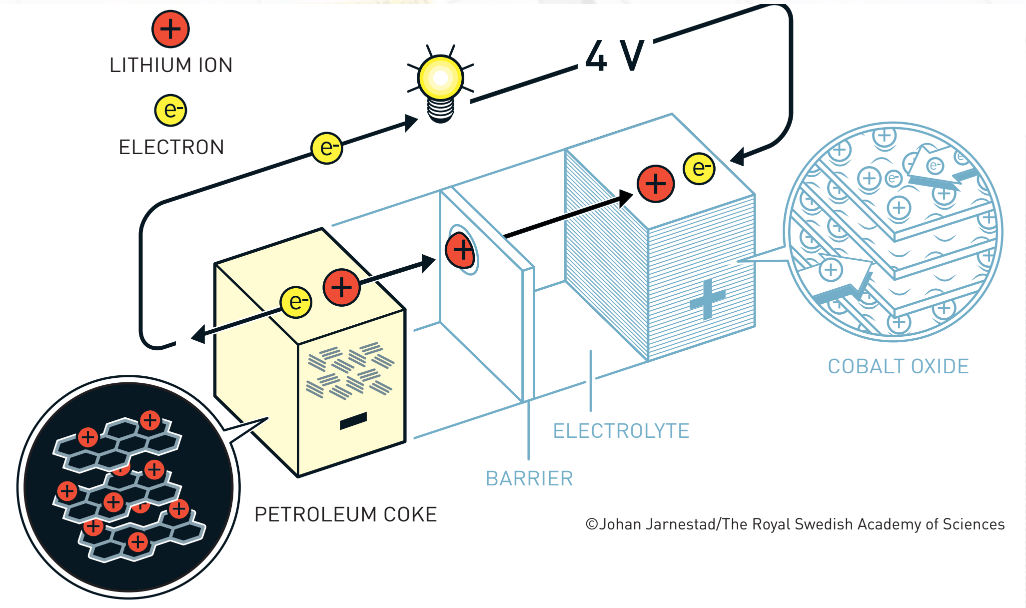

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Figure 1-5

Yoshino's Li-ion Cell used a lithium cobalt oxide cathode and petroleum coke (carbon) anode. Image courtesy of the Royal Swedish Academy of Sciences.

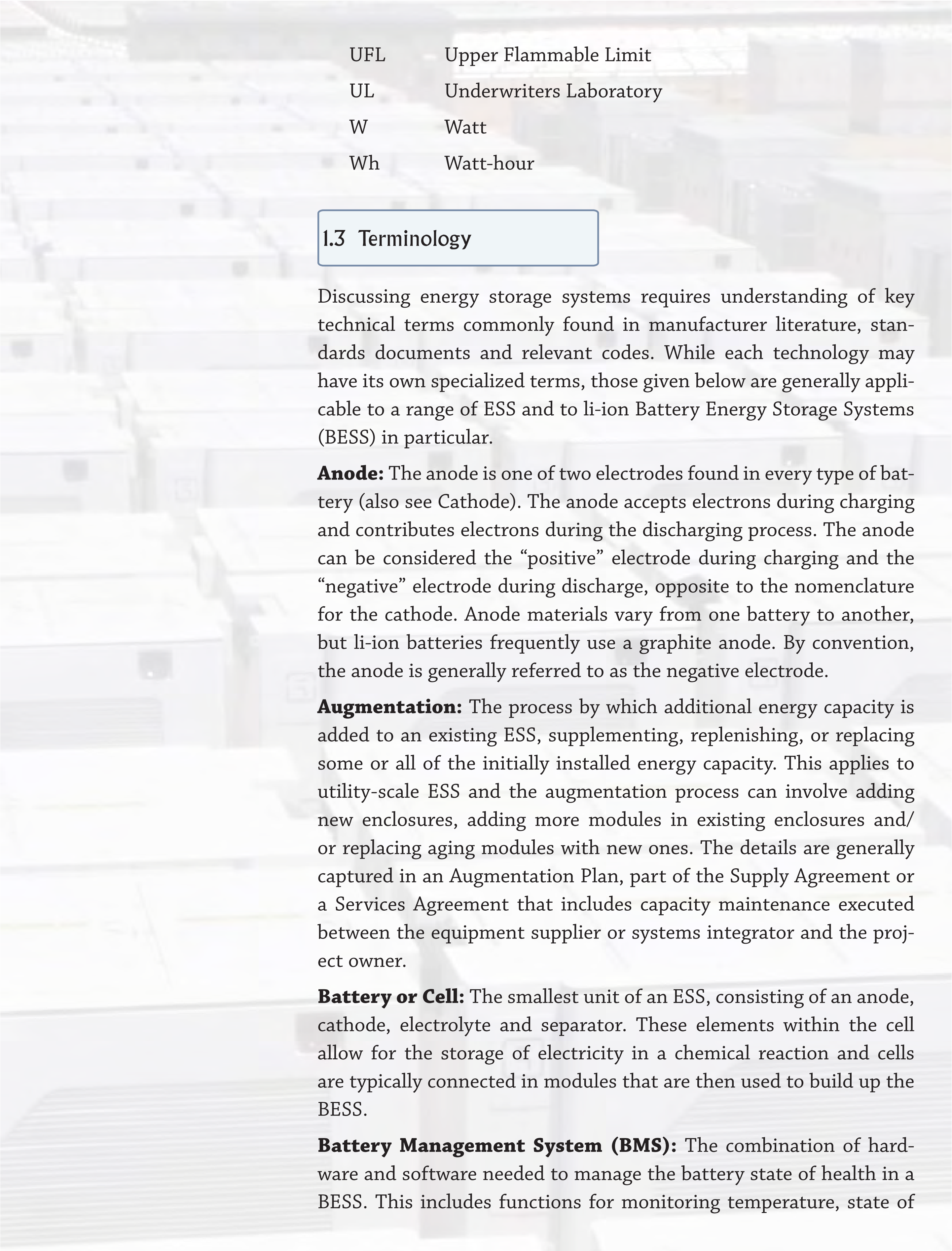
Since the 1990s, battery technology has continued to evolve, with steady improvements in cell design, chemistry, manufacturing methods, safety and applications. The li-ion cells developed by Yoshino continue to form the basis of modern ESS designs and current li-ion chemistry, as discussed throughout this publication.

1.2 Acronyms

Energy Storage System specifications, manuals and documents (including this one) employ a dizzying array of acronyms. Below is a brief list of some of the more commonly used acronyms. Further explanation of specific terms is covered in the following section.

Acronym	**Meaning**
A	Ampere (or Amp)
AC	Alternating Current
Ah	Ampere-hour (or Amp-hour)
AHJ	Authority Having Jurisdiction
BESS	Battery Energy Storage System
BMS	Battery Management System
C&I	Commercial and Industrial
CAES	Compressed Air Energy Storage
CFD	Computational Fluid Dynamics
CP	Constant Power
CV	Constant Voltage
DAS	Data Acquisition System
DC	Direct Current
EMS	Energy Management System
ESS	Energy Storage System
FAT	Factory Acceptance Test
FSS	Fire Suppression System
HMI	Human Machine Interface
HV	High Voltage
HVAC	Heating, Ventilation and Air Conditioning
IBC	International Building Code

IE	Independent Engineer
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IFC	International Fire Code
IRC	International Residential Code
kW	Kilowatt
kWh	Kilowatt-hour
LEL	Lower Explosive Limit
LFL	Lower Flammable Limit
LFP	Lithium Iron Phosphate
Li-ion	Lithium-ion
LIB	Lithium-Ion Battery
LV	Low Voltage
MV	Medium Voltage
MW	MegaWatt (1,000,000 Watts)
MWh	MegaWatt-hour
NCA	Nickel Cobalt Aluminum Oxide
NEC	National Electrical Code
NFPA	National Fire Protection Association
NiCd	Nickel Cadmium
NiMh	Nickel Metal Hydride
NMC	Nickel Manganese Cobalt
NRTL	Nationally Recognized Testing Laboratory
O&M	Operations and Maintenance
OCPD	Overcurrent Protection Device
OE	Owner's Engineer
PCS	Power Conditioning System
PV	(Solar) Photovoltaics
RTU	Remote Terminal Unit
SAT	Site Acceptance Test
SCADA	System Control and Data Acquisition



UFL	Upper Flammable Limit
UL	Underwriters Laboratory
W	Watt
Wh	Watt-hour

1.3 Terminology

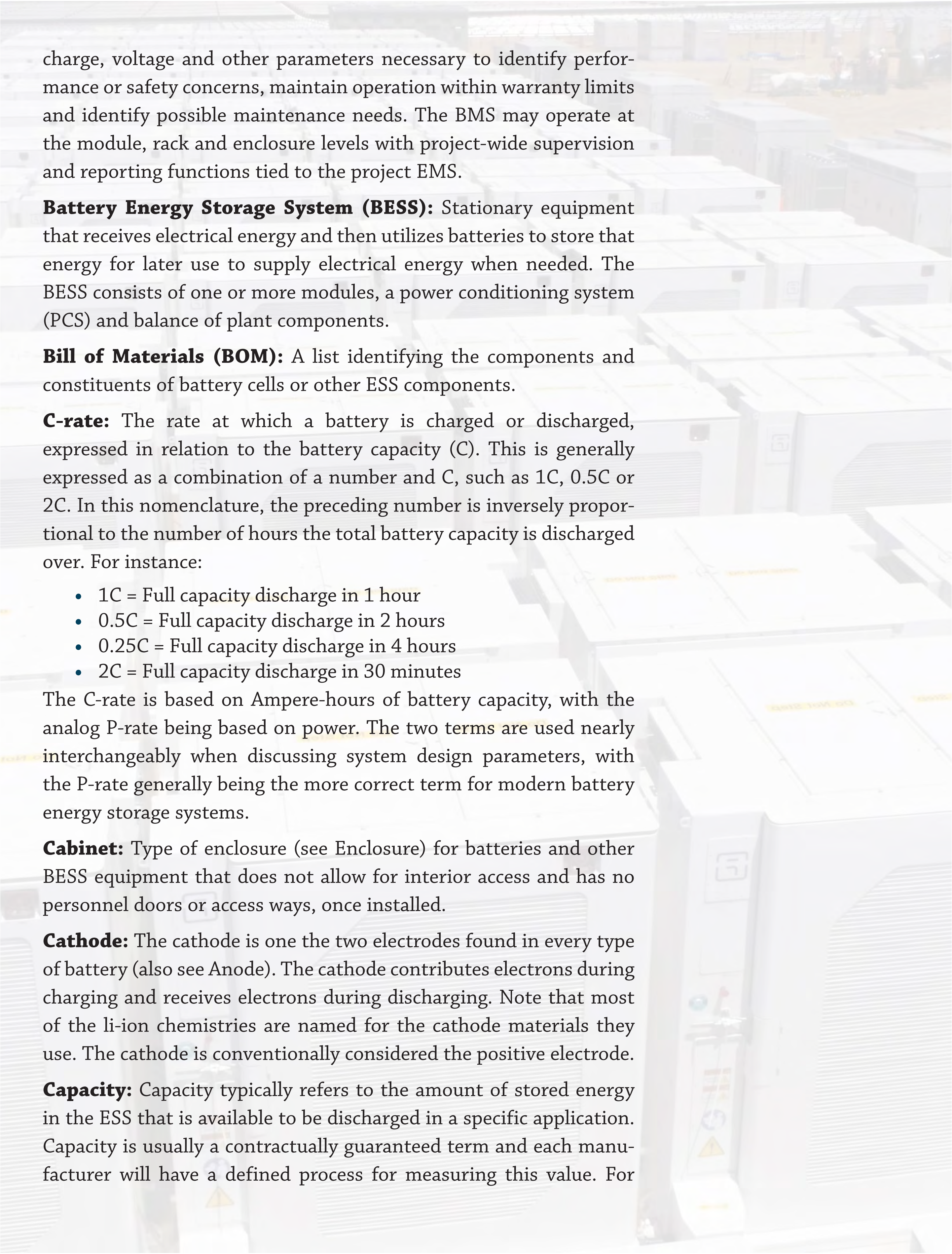
Discussing energy storage systems requires understanding of key technical terms commonly found in manufacturer literature, standards documents and relevant codes. While each technology may have its own specialized terms, those given below are generally applicable to a range of ESS and to li-ion Battery Energy Storage Systems (BESS) in particular.

Anode: The anode is one of two electrodes found in every type of battery (also see Cathode). The anode accepts electrons during charging and contributes electrons during the discharging process. The anode can be considered the “positive” electrode during charging and the “negative” electrode during discharge, opposite to the nomenclature for the cathode. Anode materials vary from one battery to another, but li-ion batteries frequently use a graphite anode. By convention, the anode is generally referred to as the negative electrode.

Augmentation: The process by which additional energy capacity is added to an existing ESS, supplementing, replenishing, or replacing some or all of the initially installed energy capacity. This applies to utility-scale ESS and the augmentation process can involve adding new enclosures, adding more modules in existing enclosures and/or replacing aging modules with new ones. The details are generally captured in an Augmentation Plan, part of the Supply Agreement or a Services Agreement that includes capacity maintenance executed between the equipment supplier or systems integrator and the project owner.

Battery or Cell: The smallest unit of an ESS, consisting of an anode, cathode, electrolyte and separator. These elements within the cell allow for the storage of electricity in a chemical reaction and cells are typically connected in modules that are then used to build up the BESS.

Battery Management System (BMS): The combination of hardware and software needed to manage the battery state of health in a BESS. This includes functions for monitoring temperature, state of



charge, voltage and other parameters necessary to identify performance or safety concerns, maintain operation within warranty limits and identify possible maintenance needs. The BMS may operate at the module, rack and enclosure levels with project-wide supervision and reporting functions tied to the project EMS.

Battery Energy Storage System (BESS): Stationary equipment that receives electrical energy and then utilizes batteries to store that energy for later use to supply electrical energy when needed. The BESS consists of one or more modules, a power conditioning system (PCS) and balance of plant components.

Bill of Materials (BOM): A list identifying the components and constituents of battery cells or other ESS components.

C-rate: The rate at which a battery is charged or discharged, expressed in relation to the battery capacity (C). This is generally expressed as a combination of a number and C, such as 1C, 0.5C or 2C. In this nomenclature, the preceding number is inversely proportional to the number of hours the total battery capacity is discharged over. For instance:

- 1C = Full capacity discharge in 1 hour
- 0.5C = Full capacity discharge in 2 hours
- 0.25C = Full capacity discharge in 4 hours
- 2C = Full capacity discharge in 30 minutes

The C-rate is based on Ampere-hours of battery capacity, with the analog P-rate being based on power. The two terms are used nearly interchangeably when discussing system design parameters, with the P-rate generally being the more correct term for modern battery energy storage systems.

Cabinet: Type of enclosure (see Enclosure) for batteries and other BESS equipment that does not allow for interior access and has no personnel doors or access ways, once installed.

Cathode: The cathode is one the two electrodes found in every type of battery (also see Anode). The cathode contributes electrons during charging and receives electrons during discharging. Note that most of the li-ion chemistries are named for the cathode materials they use. The cathode is conventionally considered the positive electrode.

Capacity: Capacity typically refers to the amount of stored energy in the ESS that is available to be discharged in a specific application. Capacity is usually a contractually guaranteed term and each manufacturer will have a defined process for measuring this value. For

modern battery systems, capacity degrades over time depending on use case and many other factors.

Capacity Fade: See Degradation.

Capacity Maintenance: See Augmentation.

Container: Also called a "walk-in unit." A BESS container is often made from readily available shipping containers or trailers, with battery racks installed inside, typically around a central walkway for personnel access. Each container will likely have independent heating, ventilation, and air conditioning (HVAC), as well as fire detection and suppression systems. Note that not all ESS use a container (also see Enclosure).

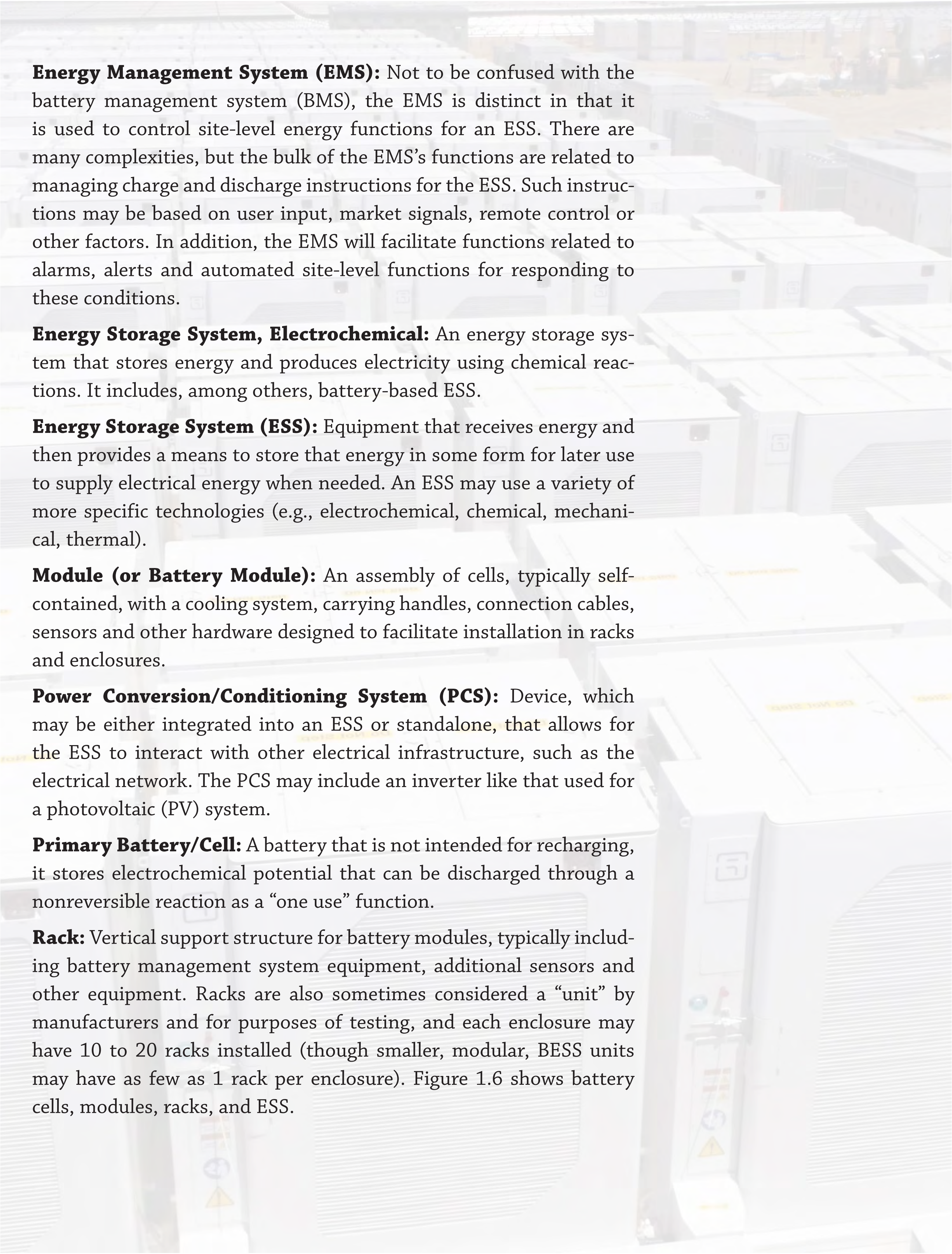
Degradation: Also called "capacity fade," degradation is the process by which batteries lose energy capacity over time. The mechanisms that cause degradation can be complex but higher degradation rates are typically correlated to depth of discharge, cell temperature and charge/discharge rate. Note that degradation can impact both energy capacity and round-trip efficiency, as both may be reduced over time.

Dendrite: Growth of lithium metal caused by deposition on the electrode in a li-ion battery. At the microscopic level, dendrite growth resembles tree branches and growth accumulates over charge and discharge cycles. Left unchecked, dendrites can pierce the separator and ultimately lead to capacity degradation and short circuits.

Duration: ESS typically have a nameplate power output (given in kW or MW) and duration is related to capacity in that it indicates the period of time the ESS is designed to discharge at its nameplate power. For instance, a "4-hour battery" is intended to be able to discharge at its full rated power for a 4-hour period. In general, increasing the duration of an ESS results in more equipment (e.g., batteries, modules, flywheels, enclosures) but this has minimal impact on the sizing of key electrical equipment, for instance, because the operating voltage and power of the ESS do not change.

Electrolyte: Batteries generally require a medium, either liquid or solid, that facilitates the transfer of ions between the cathode and anode. These electrolytes will be either alkaline or acidic, depending on the battery.

Enclosure: Prefabricated (i.e., not built onsite) equipment for providing a noncombustible and weatherproof location to install batteries and BESS equipment. More specific variants can include walk-in units, containers and cabinets.



Energy Management System (EMS): Not to be confused with the battery management system (BMS), the EMS is distinct in that it is used to control site-level energy functions for an ESS. There are many complexities, but the bulk of the EMS's functions are related to managing charge and discharge instructions for the ESS. Such instructions may be based on user input, market signals, remote control or other factors. In addition, the EMS will facilitate functions related to alarms, alerts and automated site-level functions for responding to these conditions.

Energy Storage System, Electrochemical: An energy storage system that stores energy and produces electricity using chemical reactions. It includes, among others, battery-based ESS.

Energy Storage System (ESS): Equipment that receives energy and then provides a means to store that energy in some form for later use to supply electrical energy when needed. An ESS may use a variety of more specific technologies (e.g., electrochemical, chemical, mechanical, thermal).

Module (or Battery Module): An assembly of cells, typically self-contained, with a cooling system, carrying handles, connection cables, sensors and other hardware designed to facilitate installation in racks and enclosures.

Power Conversion/Conditioning System (PCS): Device, which may be either integrated into an ESS or standalone, that allows for the ESS to interact with other electrical infrastructure, such as the electrical network. The PCS may include an inverter like that used for a photovoltaic (PV) system.

Primary Battery/Cell: A battery that is not intended for recharging, it stores electrochemical potential that can be discharged through a nonreversible reaction as a "one use" function.

Rack: Vertical support structure for battery modules, typically including battery management system equipment, additional sensors and other equipment. Racks are also sometimes considered a "unit" by manufacturers and for purposes of testing, and each enclosure may have 10 to 20 racks installed (though smaller, modular, BESS units may have as few as 1 rack per enclosure). Figure 1.6 shows battery cells, modules, racks, and ESS.

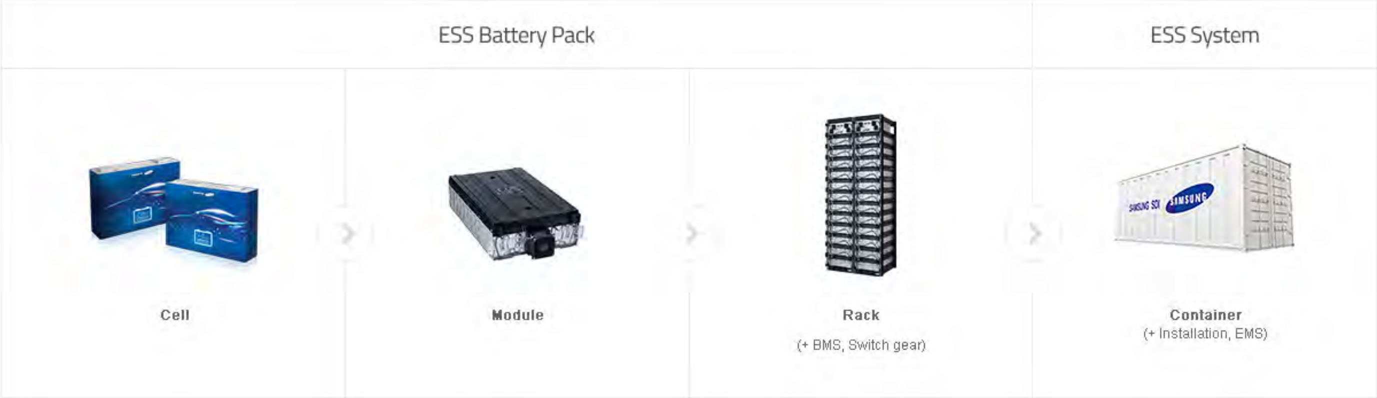


Figure 1-6

Modern BESS consist of modular units made up of cells, modules, racks and enclosures that allow a great deal of flexibility in system design. Image courtesy of Samsung SDI.

Secondary Battery/Cell: A battery that operates via a reversible chemical reaction, allowing electrical energy to be stored and discharged multiple times.

Separator: Batteries use a membrane-like material to separate the anode and cathode (preventing a short circuit), while being sufficiently porous to allow the transport of lithium-ions via the electrolyte.

Site Acceptance Testing (SAT): A process that combines commissioning and a rigorous inspection of all equipment. SAT typically includes commissioning tests for all equipment, performance testing, visual inspection, manufacturer-required measurements and similar completion activities. The SAT will typically be documented via a written test plan and, once complete, a written report summarizing the results of all SAT activities.

Supply Agreement: Agreement between the equipment supplier and buyer that stipulates key manufacturer warranties, guarantees, commercial terms, delivery dates and other details related to purchasing the ESS equipment. These agreements also frequently include substantial technical detail, such as specification sheets, manuals, test data and third-party reports, as exhibits.

Thermal Runaway: Chemical process that results in an irreversible exothermic reaction initiated by heat buildup in the cell because of external heating, overcharging, internal short circuits, mechanical damage or other forms of damage (internal or external), and continuing through consumption of cell materials and potential propagation to neighboring cells or modules in the ESS.

1.4 A Quick Overview of Common Energy Storage Technologies

Energy storage systems may call to mind images of large banks of batteries when, in fact, the term broadly applies to many ways of storing various forms of energy for use at a later time. The list of technologies that can be considered ESS is quite broad, as shown in Figure 1-7, and can be broken down into categories based on the type of energy being stored.

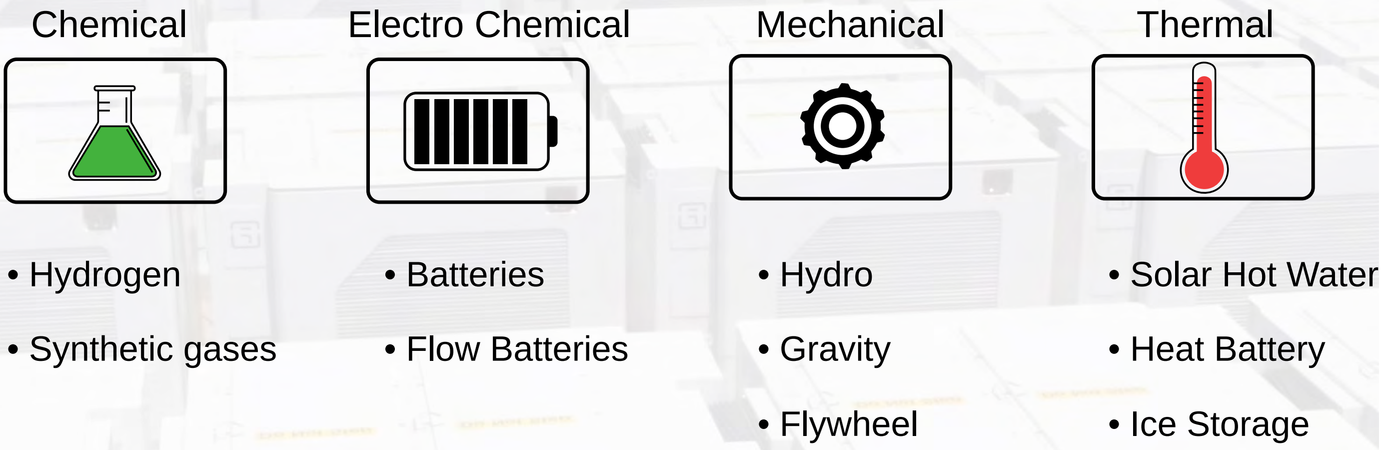


Figure 1-7

Energy storage can take a variety of forms, from batteries to flywheels. It is generally categorized as electrochemical, mechanical, chemical or thermal. Of course, new technologies are always developing so we may see even more creative solutions in the future.

Thermal energy storage

In thermal energy storage, energy is stored by heating or cooling matter, often involving a phase change such as freezing. These types of ESS do not necessarily provide direct electrical output but may be used in various ways that offset or reduce electrical use. Examples include ice-based systems that consume inexpensive electricity to produce ice, which is then used to supplement air conditioning during peak electricity demand periods. Such systems have seen use in a number of urban areas and can reduce electricity costs for expensive summer air conditioning. In some parts of the United States and in the United Kingdom, thermal batteries are used to store excess heat for later use in domestic hot water or heating applications. One notable application of this concept is solar hot water (SHW) systems (Figure 1-8). In these systems, solar collectors are used to heat water (either directly or indirectly via a closed loop water/glycol mixture and heat exchanger). This heated water is then stored in an insulated tank for later use to serve a range of hot water needs, from domestic showers to large-scale industrial applications. In this way, a SHW system is storing solar energy as heat for use later, much like a solar photovoltaic (PV) system can store electrical energy in a battery system.

Finally, in larger scale installations, thermal energy may be stored in molten salt solutions. At higher temperatures, extracting heat for useful generation of electricity becomes more feasible, and salt or fluid-based storage systems have a history of being incorporated into solar thermal plants in order to allow continued generation after the sun has set.

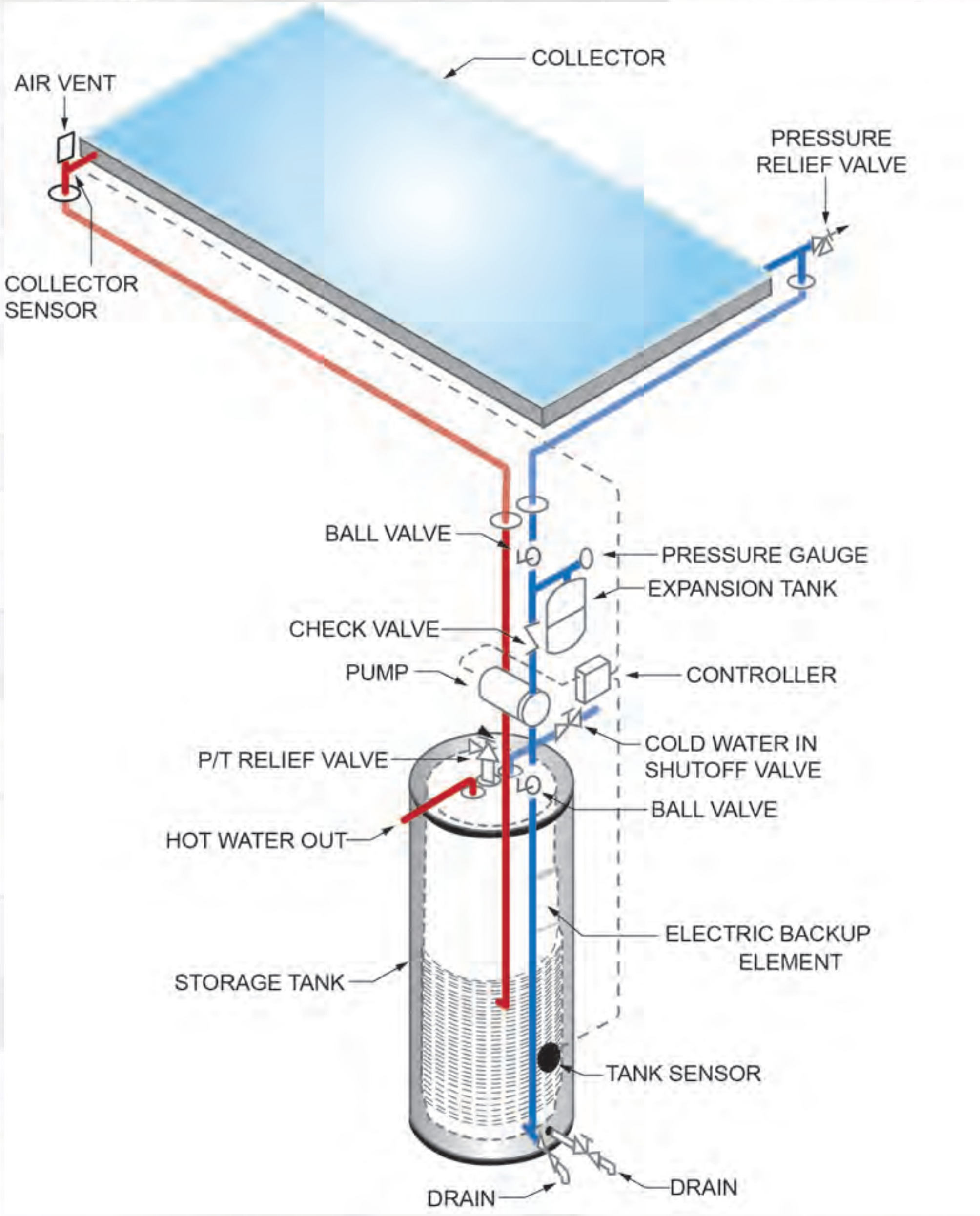


Figure 1-8

Solar hot water systems store solar energy in insulated tanks for use later in applications ranging from showers and dishwashing in a residence to process heating in large industrial facilities.

Mechanical Energy Storage

Energy can be stored mechanically, based on the controlled movement of mass and converting that stored energy into useful output.

Kinetic energy refers to the energy stored in a moving mass, such as a flywheel. Conceptually, energy (usually electricity) is used to spin up the storage device when electricity supply is high and prices are low and then released at a later time by coupling the storage device to a generator and using the stored rotational inertia to generate electricity. In these types of devices, the state of charge is reflective of the speed or momentum the device has remaining; kinetic energy storage devices will slow down as their energy is transferred to power loads or to operate a generator.

Modern flywheels, as shown in Figure 1-9, are typically modular in design and installed as assemblies wholly or partially below grade. This modular design minimizes the amount of onsite construction required and allows for flywheel assemblies to be deployed at scale and employing the same kind of modular design that has proven successful in other types of ESS projects. The placement below ground also provides an added element of safety in the unlikely event that one of the flywheels experiences a failure.

Figure 1-9

This 20MW facility, by Beacon Power, is providing frequency regulation services to PJM. The blue cylinders shown are each a discrete flywheel assembly with associated power electronics and balance of plant components located nearby. Photo courtesy of Beacon Power.

Instead of relying on a mass in motion (e.g., a flywheel), energy can be stored by lifting a mass and then releasing it later. The initial lifting energy can be provided by lower priced electricity or natural forces that allow the stored energy to accumulate over time. Pumped hydro, which remains the most prevalent energy storage technology globally, uses this principle by pumping water to the top of a tower or upper reservoir, as shown in Figure 1-10, when there is excess electricity available and then discharging by releasing the water in a controlled manner later and using well-developed hydropower technology to turn the moving water back into electricity. When geography and hydrology is favorable, these upper reservoirs can also be filled over time by diverting flowing

Figure 1-10

This 120MW pumped hydro facility in Geesthacht, Germany pumps water from the Elbe river into an upper retention pond, giving the generators sufficient water to operate at full power for 4.5 hours. Photo courtesy of Vattenfall.

water from another natural reservoir or upstream portion of the river (reducing the need for mechanical pumping).

Pumping water uphill is not the only way to use potential energy as a means of storing electricity. One of the newer methods gaining traction in some of the European markets is gravity storage, wherein large specially designed blocks are stacked, by crane, and later moved from the top of the stack to ground level. The controlled descent of these heavy blocks provides energy that can be converted into electricity. Unlike pumped hydro systems, this type of gravity system can be deployed in areas where water supplies may be more limited. This approach, as of this writing, is relatively new and not yet seen in widespread deployment, but companies like Energy Vault (Figure 1-11) have attracted significant investment in the technology. Like pumped hydro, this type of gravity-based storage solution has the potential for longer durations and scalability, but long-term reliability and ease of construction near population centers may not be fully assessed yet.

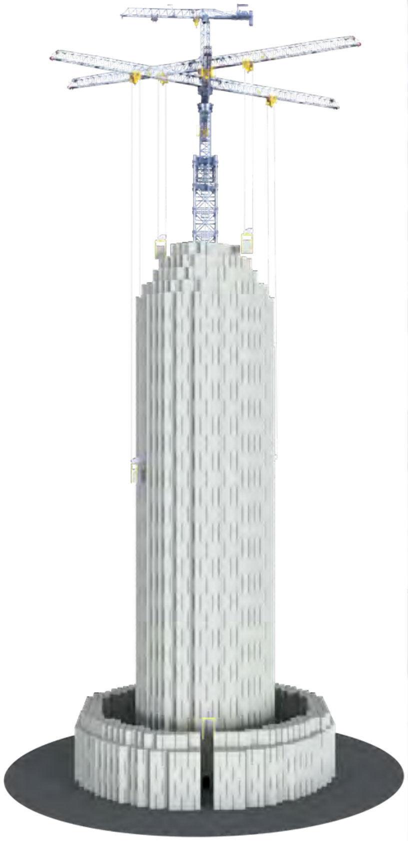


Figure 1-11

This ESS from Energy Vault uses 35-ton blocks to store and discharge energy by raising and lowering the blocks. As blocks are lifted into place, energy is stored and as they are unstacked by the upper cranes, the controlled falling action is used to generate electricity. Image courtesy of Energy Vault, Inc.

In the case of both pumped hydro and gravity storage, the majority of the equipment relies on relatively common industrial machinery and materials (e.g., steel, concrete) and, as such, may be less impacted by the supply of rare minerals and may seem more familiar because of parallels with other types of industrial equipment.

Finally, another example of mechanical energy storage is compressed air energy storage (CAES). This technology involves using electricity to compress air and store it in specially designed tanks or even repurposed underground caverns. The high-pressure air can then be extracted later to perform work or drive a generator.

Electrochemical Energy Storage

Electrochemical energy storage is the most ubiquitous form of energy storage system in our daily lives and includes batteries of all types, from AA alkaline batteries used in household electronics to the batteries found in laptops, electric vehicles and stationary energy storage systems. The specific chemical process varies based on the specific battery technology, but most batteries will consist of a cathode, anode, separator and electrolyte (as shown for the Yoshino Battery in Figure 1-5).

While most batteries include these common elements, flow batteries take the key concept of transferring material between cathode and anode as a way of charging and discharging in a slightly different direction. Where the anode and cathode in most batteries is a solid material, flow batteries operate by pumping two chemically reactive solutions

Figure 1-12

Completed installation of Invinity VS3 modular flow battery units in South Korea. Photo courtesy of Invinity.

through a central cell with an ionically permeable membrane that allows electrons to transfer and create useful current. From there, the fluids are pumped back into tanks and the process can either be reversed, to effectively recharge the flow battery, or new electrolyte solutions can be added to the tanks to facilitate a more rapid recharging rate. While such flow batteries are not really batteries, they are considered one of the popular alternatives to li-ion chemistries for stationary ESS applications. Some recent market innovations have included iron-based flow batteries with the potential for long duration applications and the implementation of modularized flow batteries, such as that shown in Figure 1-12. These innovations may provide added momentum to the more widespread adoption of flow battery technology. The key advantages of flow batteries generally include:

- Potentially very long lifetimes
- Ease and low cost of adding more energy capacity
- Safety

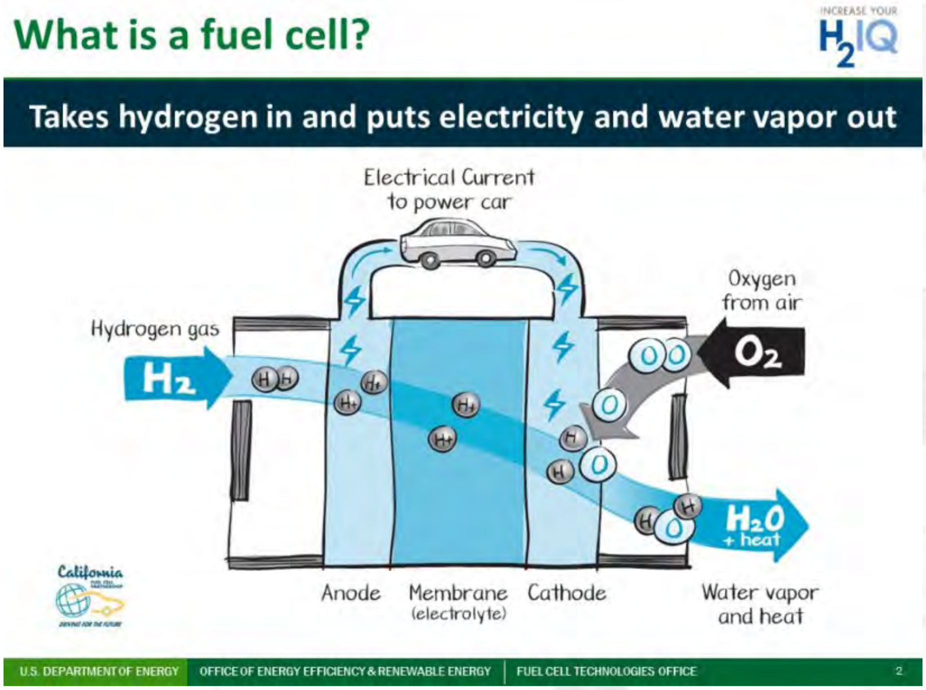
Despite these potential advantages, the increased complexity, space requirements, potentially limited electrolyte supply and current lack of scale in the technology have precluded widespread adoption beyond a small number of demonstration and early commercialization projects.

Chemical Energy Storage

The electro-chemical systems described above rely on the potential between the anode and cathode materials to create an opportunity for moving charge (i.e., charging and discharging energy). By contrast, chemical energy storage is the process of creating a material that can later be reacted (e.g., burning, reduction, oxidation) to store or release energy. This category could broadly include things like some biogases but the most commonly understood example is in the storage of hydrogen. Making hydrogen, through electrolysis or other means, results in a fuel that can be used directly (for heat), injected into chemical processes (e.g., making steel), or reacted with oxygen in a fuel cell to generate electricity. The added step of having to "store" electricity by creating an additional transport medium (i.e., hydrogen), distinguishes chemical and electrochemical energy storage modes.

With the growing interest in hydrogen as an energy storage medium, fuel cells are gaining renewed attention as a way to use hydrogen (ideally created using clean energy and electrolysis but also potentially extracted from natural gas) to generate electricity. A fuel cell operates based on supplying fuel and oxidizing agents (e.g., hydrogen and oxygen) and causing the fuel to undergo a chemical reaction wherein it is split into positive and negative ions (e.g., hydrogen atoms and electrons). While the positive ions flow to the cathode through an electrolyte, the negative ions flow through an external circuit, creating useful electricity generation. The byproducts of the fuel cell will usually be water (for a hydrogen/oxygen fuel cell), which allows fuel cells to generate essentially emission free electricity so long as they are supplied with sufficient fuel and oxygen to sustain the chemical reaction. This process is shown diagrammatically in Figure 1-13.

Individual fuel cells are typically organized into stacks and are assembled modularly into systems of the necessary size. Historically, fuel cells have seen use in a wide range of applications, from powering buildings to being integrated into vehicles. Because fuel cells do not require recharging in the same way that batteries do, many see them as a good option to provide longer duration storage, with the duration limited primarily by the availability of hydrogen, either via specialized pipelines or onsite pressurized storage vessels. As of this writing, fuel cells remain relatively uncommon in ESS applications but with significant funding being devoted to exploring options for expanding the use of green hydrogen, this is an area to keep a close eye on for the future.



What is a fuel cell?

Takes hydrogen in and puts electricity and water vapor out

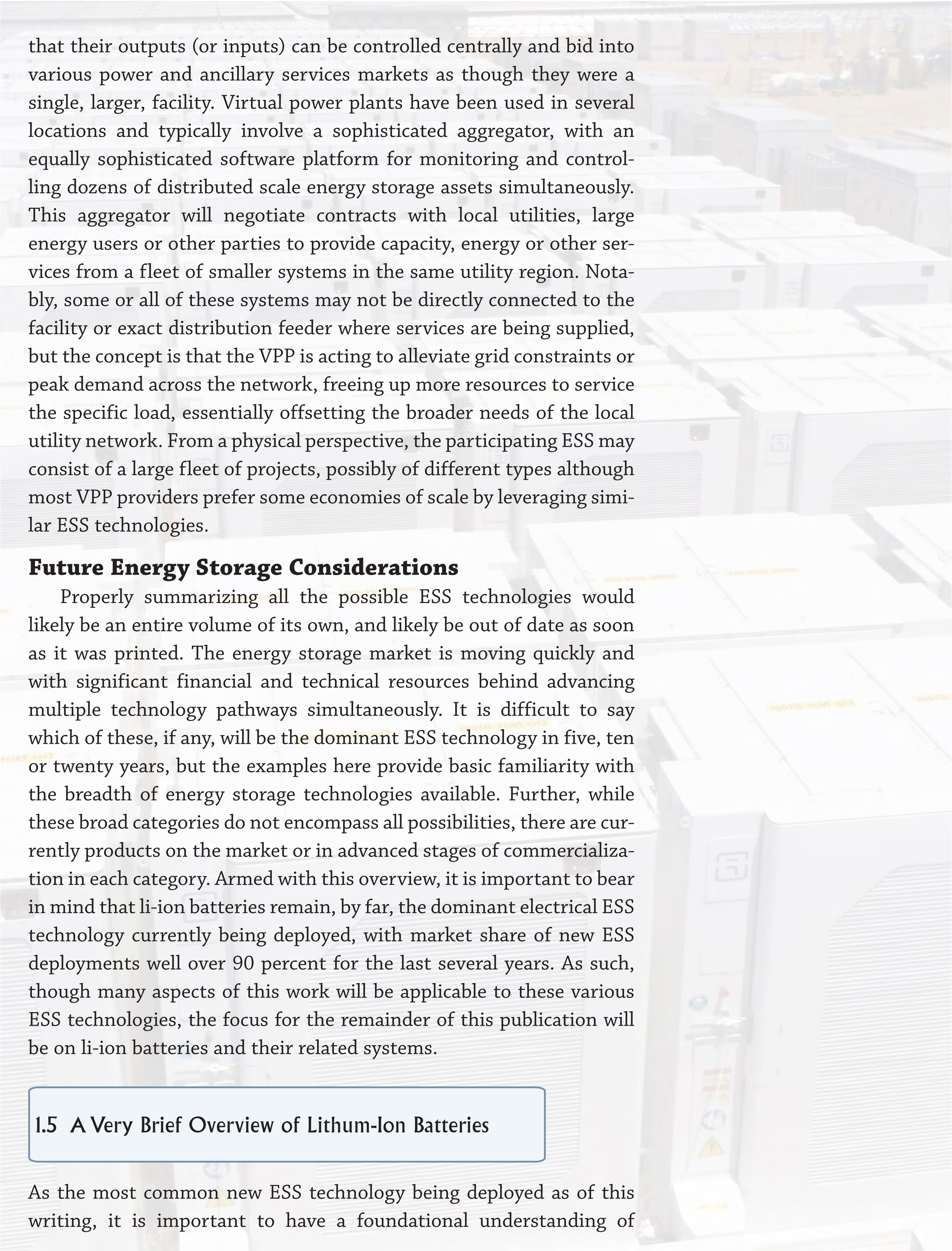
U.S. DEPARTMENT OF ENERGY | OFFICE OF ENERGY EFFICIENCY & RENEWABLE ENERGY | FUEL CELL TECHNOLOGIES OFFICE 2

Figure 1-13

This schematic shows a simplified view of how a typical hydrogen fuel cell works.
Image courtesy of the United States Department of Energy.

Virtual Power Plants

Virtual power plants (VPP) are as much a software construct as a physical one. VPPs leverage favorable market and regulatory conditions to allow for smaller (even residential) ESS to be operated in concert such



that their outputs (or inputs) can be controlled centrally and bid into various power and ancillary services markets as though they were a single, larger, facility. Virtual power plants have been used in several locations and typically involve a sophisticated aggregator, with an equally sophisticated software platform for monitoring and controlling dozens of distributed scale energy storage assets simultaneously. This aggregator will negotiate contracts with local utilities, large energy users or other parties to provide capacity, energy or other services from a fleet of smaller systems in the same utility region. Notably, some or all of these systems may not be directly connected to the facility or exact distribution feeder where services are being supplied, but the concept is that the VPP is acting to alleviate grid constraints or peak demand across the network, freeing up more resources to service the specific load, essentially offsetting the broader needs of the local utility network. From a physical perspective, the participating ESS may consist of a large fleet of projects, possibly of different types although most VPP providers prefer some economies of scale by leveraging similar ESS technologies.

Future Energy Storage Considerations

Properly summarizing all the possible ESS technologies would likely be an entire volume of its own, and likely be out of date as soon as it was printed. The energy storage market is moving quickly and with significant financial and technical resources behind advancing multiple technology pathways simultaneously. It is difficult to say which of these, if any, will be the dominant ESS technology in five, ten or twenty years, but the examples here provide basic familiarity with the breadth of energy storage technologies available. Further, while these broad categories do not encompass all possibilities, there are currently products on the market or in advanced stages of commercialization in each category. Armed with this overview, it is important to bear in mind that li-ion batteries remain, by far, the dominant electrical ESS technology currently being deployed, with market share of new ESS deployments well over 90 percent for the last several years. As such, though many aspects of this work will be applicable to these various ESS technologies, the focus for the remainder of this publication will be on li-ion batteries and their related systems.

1.5 A Very Brief Overview of Lithum-Ion Batteries

As the most common new ESS technology being deployed as of this writing, it is important to have a foundational understanding of batteries and how they work, including the more prevalent modern li-ion battery chemistries. A sample of some common li-ion chemistries is provided in Table 1-1. Note that this information is provided for general reference only and that cathode materials and manufacturers are current as of this writing but may change quickly. The reader should consult relevant manufacturer specifications for details pertaining to any project being reviewed.

Table 1-1 *Summary of Common Li-Ion Cell Chemistries*

ACRONYM	CATHODE MATERIAL	ANODE MATERIAL	CATHODE	ENERGY DENSITY WH/KG	EXPECTED CYCLE LIFE	EXAMPLE MANUFACTURERS
NMC	Lithium Nickel Manganese Cobalt Oxide	Graphite	Li Ni0.6 Co0.2 Mn0.2 O2	120–300	3,000–10,000	BYD, Samsung, LG Chem, CATL
LFP	Lithium Iron Phosphate	Graphite	Li Fe PO4	50–130	6,000–8,000	BYD, Saft, CATL
LTO	Lithium Titanate	LiTO2	Various	70–80	15,000–20,000	Toshiba, Kokam, Leclanche
LMO	Lithium Manganese Oxide	Graphite	LiMn2O4	100–150	300–700	Saft, AESC
NCA	Lithium Nickel Cobalt Aluminium Oxide	Graphite	LiNiCoAlO2	200–260	500	Tesla (Panasonic)

Background on Nickel Manganese Cobalt Chemistry

Lithium nickel manganese cobalt (NMC) batteries are a subset of lithium-ion batteries that is characterized by a relatively high energy density and favorable charge retention characteristics. In most cases, NMC batteries can be expected to have useful lifetimes in the range of 3,000 to 10,000 equivalent full charge/discharge cycles. These batteries have seen significant use in the stationary ESS market, as well as in applications like electric vehicles where the high energy density is a favorable characteristic. NMC cells are manufactured by the largest battery manufacturers, including LG Energy and Samsung, and have been used by major electric vehicle manufacturers and in some of the largest ESS projects worldwide.

One drawback of the higher energy density offered by NMC is the potential for flaming to occur under thermal runaway conditions. This has been discussed in several well-publicized cases that, while affecting only a very small fraction of NMC batteries, has caused some concerns about safety. All li-ion batteries (and most energy storing equipment of any kind, especially those with high energy density) can be driven to fail destructively, given the right abuse conditions. The risks associated with NMC batteries, as discussed later in this publication, can be managed with well-designed safety systems, suitable testing and adherence to the relevant codes and standards.

Background on Lithium Iron Phosphate Battery Chemistry

Lithium iron phosphate (LFP) batteries are a subset of lithium-ion chemistry that uses a LiFePO4 cathode material. LFP cells are offered by a variety of major cell suppliers and are seeing increased popularity in stationary energy storage applications. Most LFP cells are manufactured by large manufacturers based in China, such as BYD and CATL.

With respect to fire safety and risk of thermal runaway, LFP is considered relatively safe and stable due to the lack of cobalt in the cathode and the strongly bonded oxygen molecules. In practical terms, this means that LFP cells are less prone to exhibiting flames when they are driven into thermal runaway (more on this later). While this may seem to make sense at first glance, the presence of visible flame is only one consideration for battery safety and LFP cells have a similar (or, perhaps, more severe) risk of explosion compared to NMC cells. This lack of visible flame is borne out in the majority of large-scale fire testing results, with LFP cells exhibiting cell gas venting at similar temperatures to NMC cells [in the range of 302°F to 338°F (150°C to 170°C) but requiring a higher temperature to initiate thermal runaway, 410°F (210°C), surface temperature for NMC compared to 572°F to 662°F (300°C to 350°C) for LFP]. In addition, while thermal runaway in NMC cells has resulted in observed flames outside the cell surface, LFP cells typically do not exhibit this behavior. While the lack of flame in typical LFP large-scale fire tests is a generally positive indicator for fire safety, the presence of open flame may actually reduce the risk of explosion, as flammable gases in the vicinity are consumed by the flame, rather than being allowed to accumulate to an explosive level. It is worth noting that LFP chemistries have been largely touted as "safe" by their proponents. This is an overly simplistic view and LFP batteries, in fact, have many of the same safety hazards as other chemistries, especially with respect to gas generation and explosion risk.

The Great Chemistry Debate

For those working in the ESS industry, there is often lively debate about which "chemistry" is the best. As of this writing, the industry trend is to tout LFP batteries as the safer alternative to NMC batteries but, in reality, battery chemistry is only one element of system-level safety. Other aspects of the ESS, such as fire suppression systems, equipment layout, ventilation strategies, sensing and detection, and the training of first responders can make far more difference to the overall safety of an installation than the selection of battery chemistry.

For this reason, it is important not to automatically treat any chemistry as inherently "safe" or "dangerous" and to always perform thorough due diligence on the overall system design.

In addition to the chemical stability of the cathode, the lack of cobalt[3] also reduces the risk of constrained markets impacting key cell materials and affecting pricing and supply of potential parts. The major components used in LFP cathode construction are relatively available and obtainable, providing a degree of supply chain resilience.

The voltage profile of LFP cells tends to be flat with respect to state of charge, meaning that the cells will generally maintain a constant voltage from fully charged to nearly fully discharged. This can simplify the control scheme needed and reduce the burden on monitoring and control circuitry.

The primary disadvantage of LFP chemistries is a somewhat lower energy density than other li-ion technologies. Because most ESS projects are not heavily space constrained, this drawback has little impact and ongoing research is driving energy density for LFP cells upwards.

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[3] Lithium-ion chemistries reliant on Cobalt have significantly reduced the use of this mineral and there are even nickel-based battery chemistries under development that substitute other materials for cobalt entirely.

2 Understanding Utility-Scale and Large Commercial-Scale ESS Projects

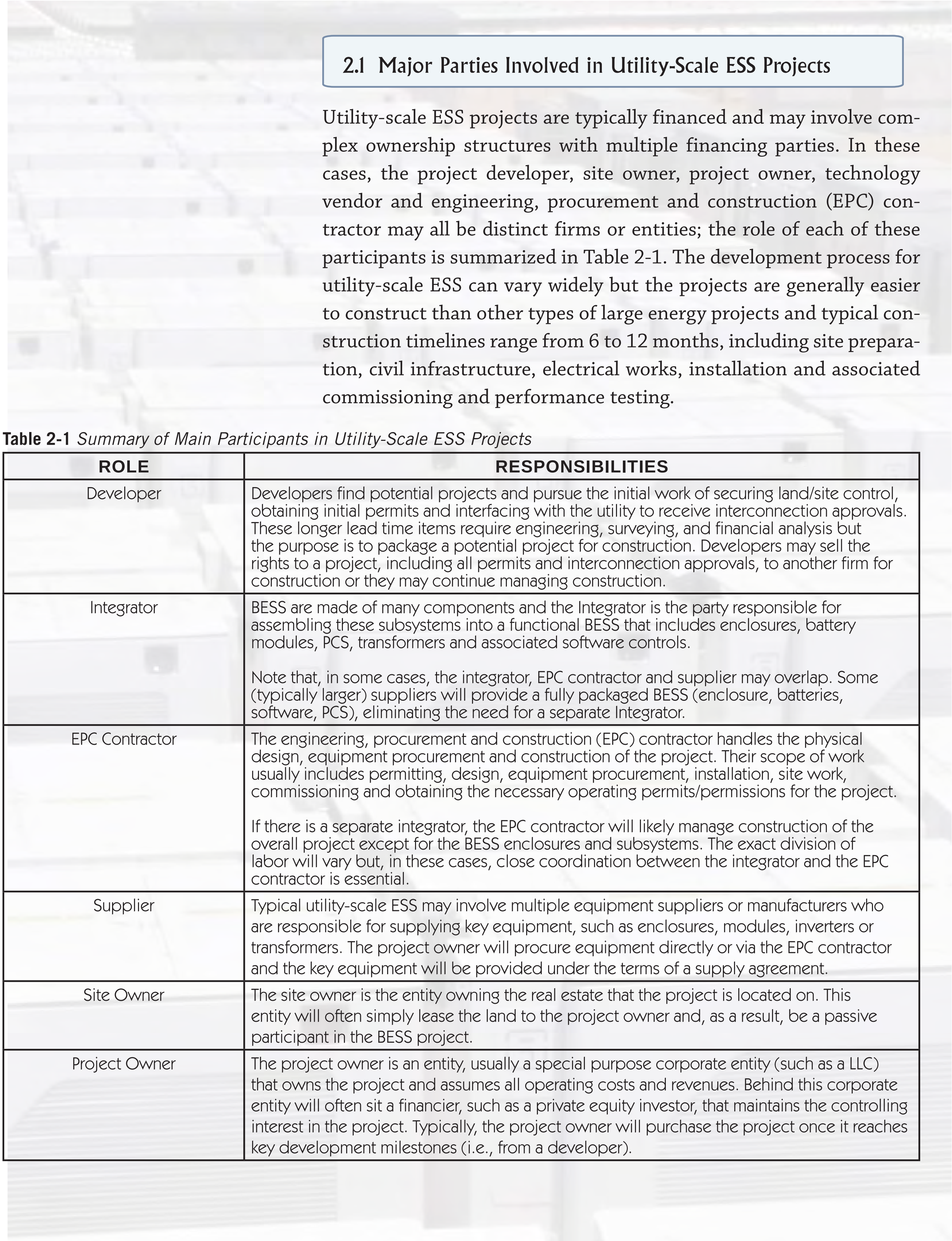
While there is no universally accepted definition for "utility-scale" energy storage, the US Department of Energy's Energy Information Administration uses a nameplate capacity of 1 MW as its threshold for "large-scale" energy storage systems. More distinctively than capacity of the system, utility-scale ESS (such as the one shown in Figure 2-1) are generally installed at a dedicated point on the distribution network or in front of the meter at a commercial facility. This allows the ESS to participate in a variety of potential markets and revenue streams, such as:

- Capacity market participation
- Frequency regulation
- Spinning reserve
- Energy arbitrage

With these revenue streams comes added financial opportunity for owners but this also creates added complexity, as discussed in this chapter.

Figure 2-1

This utility-scale ESS in Vermont is using li-ion batteries to provide peak reduction and frequency regulation services. Photo courtesy of WEG.

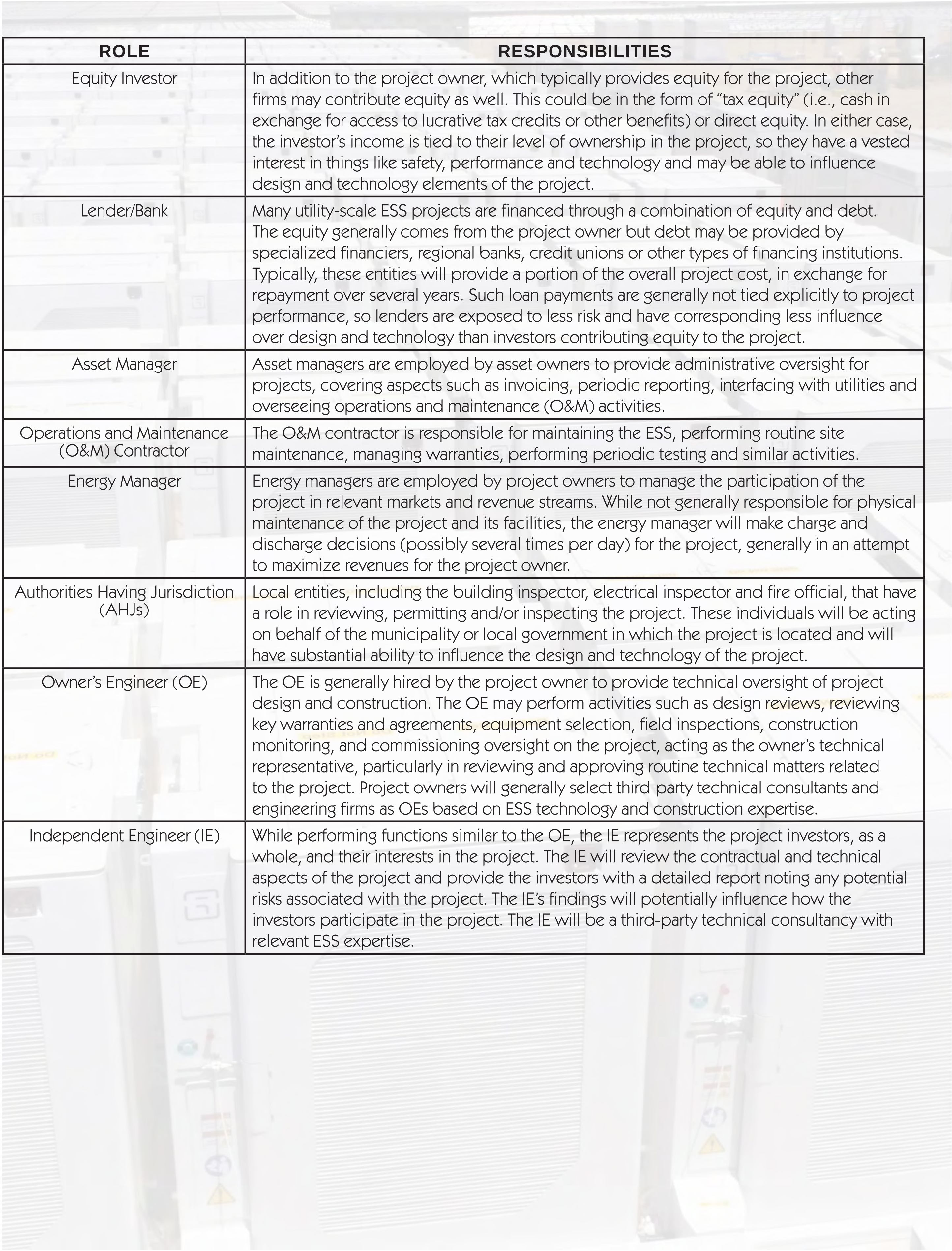


2.1 Major Parties Involved in Utility-Scale ESS Projects

Utility-scale ESS projects are typically financed and may involve complex ownership structures with multiple financing parties. In these cases, the project developer, site owner, project owner, technology vendor and engineering, procurement and construction (EPC) contractor may all be distinct firms or entities; the role of each of these participants is summarized in Table 2-1. The development process for utility-scale ESS can vary widely but the projects are generally easier to construct than other types of large energy projects and typical construction timelines range from 6 to 12 months, including site preparation, civil infrastructure, electrical works, installation and associated commissioning and performance testing.

Table 2-1 *Summary of Main Participants in Utility-Scale ESS Projects*

ROLE	RESPONSIBILITIES
Developer	Developers find potential projects and pursue the initial work of securing land/site control, obtaining initial permits and interfacing with the utility to receive interconnection approvals. These longer lead time items require engineering, surveying, and financial analysis but the purpose is to package a potential project for construction. Developers may sell the rights to a project, including all permits and interconnection approvals, to another firm for construction or they may continue managing construction.
Integrator	BESS are made of many components and the Integrator is the party responsible for assembling these subsystems into a functional BESS that includes enclosures, battery modules, PCS, transformers and associated software controls. Note that, in some cases, the integrator, EPC contractor and supplier may overlap. Some (typically larger) suppliers will provide a fully packaged BESS (enclosure, batteries, software, PCS), eliminating the need for a separate Integrator.
EPC Contractor	The engineering, procurement and construction (EPC) contractor handles the physical design, equipment procurement and construction of the project. Their scope of work usually includes permitting, design, equipment procurement, installation, site work, commissioning and obtaining the necessary operating permits/permissions for the project. If there is a separate integrator, the EPC contractor will likely manage construction of the overall project except for the BESS enclosures and subsystems. The exact division of labor will vary but, in these cases, close coordination between the integrator and the EPC contractor is essential.
Supplier	Typical utility-scale ESS may involve multiple equipment suppliers or manufacturers who are responsible for supplying key equipment, such as enclosures, modules, inverters or transformers. The project owner will procure equipment directly or via the EPC contractor and the key equipment will be provided under the terms of a supply agreement.
Site Owner	The site owner is the entity owning the real estate that the project is located on. This entity will often simply lease the land to the project owner and, as a result, be a passive participant in the BESS project.
Project Owner	The project owner is an entity, usually a special purpose corporate entity (such as a LLC) that owns the project and assumes all operating costs and revenues. Behind this corporate entity will often sit a financier, such as a private equity investor, that maintains the controlling interest in the project. Typically, the project owner will purchase the project once it reaches key development milestones (i.e., from a developer).



ROLE	RESPONSIBILITIES
Equity Investor	In addition to the project owner, which typically provides equity for the project, other firms may contribute equity as well. This could be in the form of "tax equity" (i.e., cash in exchange for access to lucrative tax credits or other benefits) or direct equity. In either case, the investor's income is tied to their level of ownership in the project, so they have a vested interest in things like safety, performance and technology and may be able to influence design and technology elements of the project.
Lender/Bank	Many utility-scale ESS projects are financed through a combination of equity and debt. The equity generally comes from the project owner but debt may be provided by specialized financiers, regional banks, credit unions or other types of financing institutions. Typically, these entities will provide a portion of the overall project cost, in exchange for repayment over several years. Such loan payments are generally not tied explicitly to project performance, so lenders are exposed to less risk and have corresponding less influence over design and technology than investors contributing equity to the project.
Asset Manager	Asset managers are employed by asset owners to provide administrative oversight for projects, covering aspects such as invoicing, periodic reporting, interfacing with utilities and overseeing operations and maintenance (O&M) activities.
Operations and Maintenance (O&M) Contractor	The O&M contractor is responsible for maintaining the ESS, performing routine site maintenance, managing warranties, performing periodic testing and similar activities.
Energy Manager	Energy managers are employed by project owners to manage the participation of the project in relevant markets and revenue streams. While not generally responsible for physical maintenance of the project and its facilities, the energy manager will make charge and discharge decisions (possibly several times per day) for the project, generally in an attempt to maximize revenues for the project owner.
Authorities Having Jurisdiction (AHJs)	Local entities, including the building inspector, electrical inspector and fire official, that have a role in reviewing, permitting and/or inspecting the project. These individuals will be acting on behalf of the municipality or local government in which the project is located and will have substantial ability to influence the design and technology of the project.
Owner's Engineer (OE)	The OE is generally hired by the project owner to provide technical oversight of project design and construction. The OE may perform activities such as design reviews, reviewing key warranties and agreements, equipment selection, field inspections, construction monitoring, and commissioning oversight on the project, acting as the owner's technical representative, particularly in reviewing and approving routine technical matters related to the project. Project owners will generally select third-party technical consultants and engineering firms as OEs based on ESS technology and construction expertise.
Independent Engineer (IE)	While performing functions similar to the OE, the IE represents the project investors, as a whole, and their interests in the project. The IE will review the contractual and technical aspects of the project and provide the investors with a detailed report noting any potential risks associated with the project. The IE's findings will potentially influence how the investors participate in the project. The IE will be a third-party technical consultancy with relevant ESS expertise.

2.2 Major Equipment on Utility-Scale ESS

The majority of utility-scale ESS consists of arrangements of battery enclosures, either large (40 foot or 53 foot) enclosures or smaller, more modular units. Each enclosure includes racks of batteries and the battery management system, HVAC systems and fire safety systems. The ESS may also include a power conversion system (PCS) or inverter, often located adjacent to the enclosure. From there, the output of the PCS (alternating current) is stepped up via a transformer to reach the relevant distribution voltage compatible with the local distribution system, as shown in Figure 2-2. Additional equipment onsite will include code-required disconnects, overcurrent protection devices, system control and data acquisition (SCADA) systems, metering equipment and similar electrical infrastructure. Major equipment found on a utility-scale ESS is discussed further in subsequent sections.

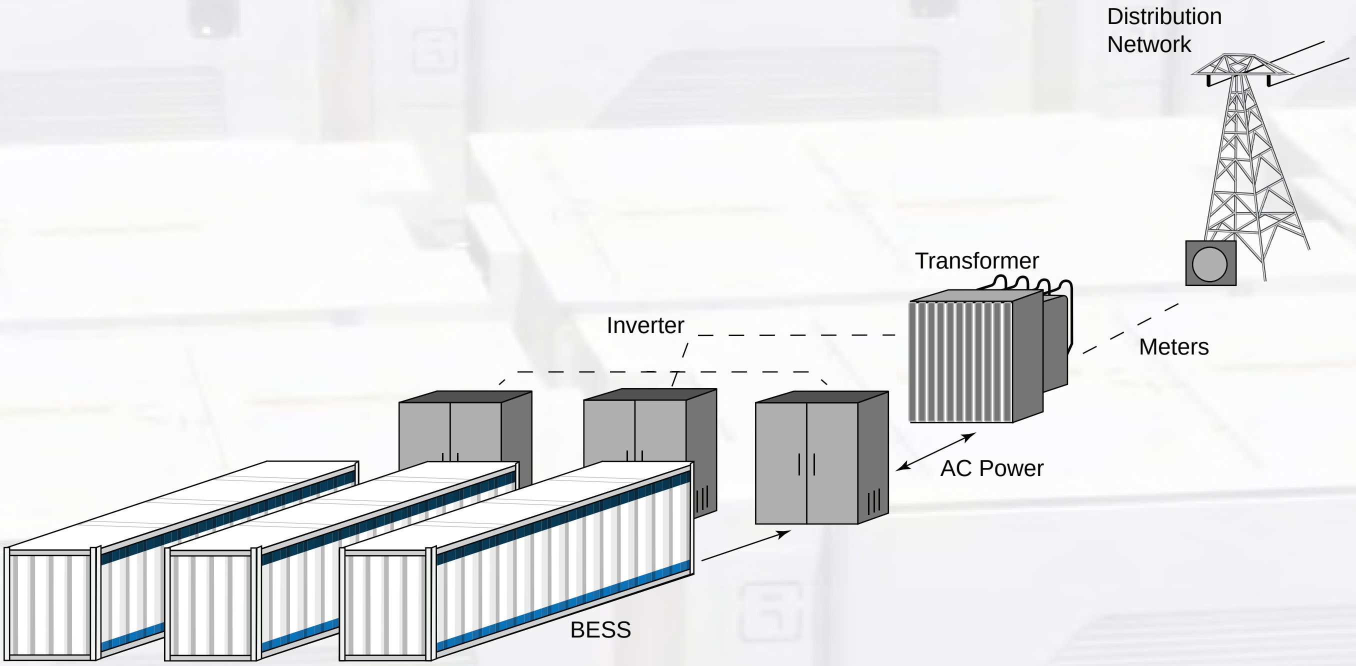


Figure 2-2

This diagram illustrates a typical utility-scale ESS layout and major components.

This section describes several of these specialized pieces of equipment that might be found on a BESS project during design review or inspection activities.

Enclosures

Battery cells are vulnerable to weather and temperature effects and are generally protected inside of some form of enclosure or container. These enclosures, broadly speaking, provide a physical structure to house and protect the sensitive electronics and batteries that allow the ESS to operate. Historically, BESS enclosures were made from ISO shipping containers, particularly for early BESS projects, as these containers were already designed to protect their contents against a variety of weather conditions and were structurally durable, with nonflammable construction. This led to the evolution of 20-foot, 40-foot, and 53-foot containers as a relatively standardized form factor. From there, containers were modified to add HVAC units to provide thermal management and various types of fire safety systems to reduce the risk from thermal runaway and fires. In a typical utility-scale BESS project, the enclosures are shipped to the site with racks installed but the added weight of the battery modules would preclude readily shipping and moving them, so the battery modules are shipped separately and installed by field crews.

Early, walk-in style enclosures required personnel to enter to service and monitor the batteries. These early enclosure interiors typically included a central walkway, computer terminals to access the battery management system and racks of batteries in all available space flanking the central corridor. This approach posed an increased safety risk as it required emergency personnel to enter enclosure interiors to assess conditions after an alarm event, as only minimal observations could be made from outside the enclosure. Today's larger enclosures provide for all equipment to be accessed via exterior doors around the perimeter of the enclosure, so technicians are not required to enter the enclosure during normal operations and maintenance activities. Figure 2-3 shows an example of an exterior access enclosure. With the door open, the battery racks and modules are accessible for inspection and servicing without entering the enclosure.

Figure 2-3

This image shows a utility-scale ESS enclosure with doors opened for easy access to key equipment. Photo courtesy of Matt Paiss, Pacific Northwest National Laboratory, and Snohomish PUD.

Figure 2-4

Cabinet-based ESS, like the Fluence 6th generation system shown here, provide site designers with a lot of flexibility and can be used from small commercial through large utility scale sites. Photo courtesy of Fluence.

Many of the major manufactures now offer enclosures that are even more modular and specialized. These cabinets may be approximately the size of a large refrigerator or freezer, with sufficient space to house one or two racks and associated hardware. A larger site may include many of these cabinets connected, with communications and controls routing to a central panelboard. In Figure 2-4, many of these sorts of modular units are shown in a typical utility-scale layout, with more modular units taking the place of the 40 foot or 53 foot larger enclosures seen on other sites and a central pathway for access and efficiently locating AC equipment such as inverters and transformers. These designs can be highly modular, giving more options for site layout and simplifying logistics. In addition, the smaller form factor allows for these enclosures to be fully assembled offsite (including the installation of battery modules) and shipped to the site as a fully integrated unit, requiring minimal field assembly. This greatly simplifies the installation process, as workers do not have to directly handle battery modules or be responsible for their installation.

Thermal Management

Battery cells typically have nuanced warranties governing their expected performance and one of the key variables in such warranties is the operating temperature of the batteries. All batteries, to some extent, experience a reduction in energy capacity based on temperatures; this effect can be seen at both high and low extremes, so keeping the batteries at approximately 68°F to 86°F (20°C to 30°C) (i.e., near room temperature) is key for maintaining warranty and overall health of the system. That said, batteries and associated equipment generate considerable heat during charging and discharging operations, with a typical rack of lithium iron phospate (LFP) batteries likely generating approximately 1kW of thermal load during operation. Batteries at standby dissipate much less heat but the trend for modern ESS is to keep batteries operating into a variety of revenue streams, so operation may be close to continuous for some use cases. A fully loaded 53-foot enclosure can easily require 5 to 10 tons[4] of cooling capacity, which is roughly equivalent to the air conditioning load of two average size homes in the United States.

Clearly, thermal management has a major impact on BESS performance and reliability, and this need is met through either air cooling (i.e.,

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[4] In this case, a "ton" refers to a unit of cooling equal to 12,000 Btu/hour of heat removal.

air conditioners) or, increasingly, liquid cooling systems. In the case of air-cooled BESS, most enclosures will include two or four exterior-mounted HVAC units on the ends of the enclosures. These units distribute cold air throughout enclosures via ducting, fans and other means. In the case of liquid cooled systems, a liquid (generally a refrigerant) is cycled through the system to extract heat from the modules and stacks before dissipating it via a heat exchanger to the ambient outdoor air. The latter system allows for better control and improved efficiency but is more feasible for integrated enclosures/battery systems, whereas air cooling HVAC systems tend to be easier for integrators who may be assembling ESS with equipment from multiple suppliers.

Battery Management System

Each BESS will have a battery management system (BMS), which is a series of hardware and software controls tasked with maintaining the safe operation of the batteries [5]. Key functions of the BMS include:

- Monitoring key cell and module-level parameters (e.g., voltage, temperature)
- Performing balancing (balancing charge/discharge currents between cells and modules)
- Generating alarms based on manufacturer or owner-specified set points

The BMS functions are generally aggregated at the rack level via a dedicated module that houses the relevant sensors, controllers, data handling and similar equipment.

Energy Management Systems

Utility-scale ESS use an energy management system (EMS) for system-wide controls and monitoring, as well as to control the ESS's interface with the local utility. At a very basic level, the EMS sits above the BMS in terms of control hierarchy, receiving and interpreting signals from the energy manager, utility or operator. The EMS then translates these external inputs into directions that are passed to the system, giving it instructions to charge, discharge or take other action. These instructions are interpreted by the BMS into instructions that are passed to enclosure, rack and module level controls that can then initiate actions at the appropriate level. This function goes both ways, however, as the BMS will also pass data and alerts upwards to the EMS, triggering effects like notifications and alarms when needed. This process is diagrammed in Figure 2-5.

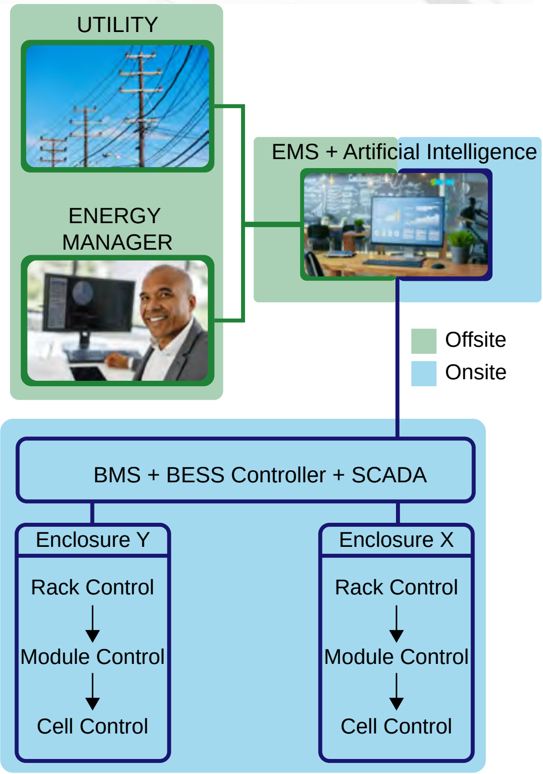

Figure 2-5

Modern ESS rely on a sophisticated controls and monitoring system wherein the system can receive signals from an energy manager or the utility and must react quickly to charge, discharge, disconnect or perform other functions without human intervention.

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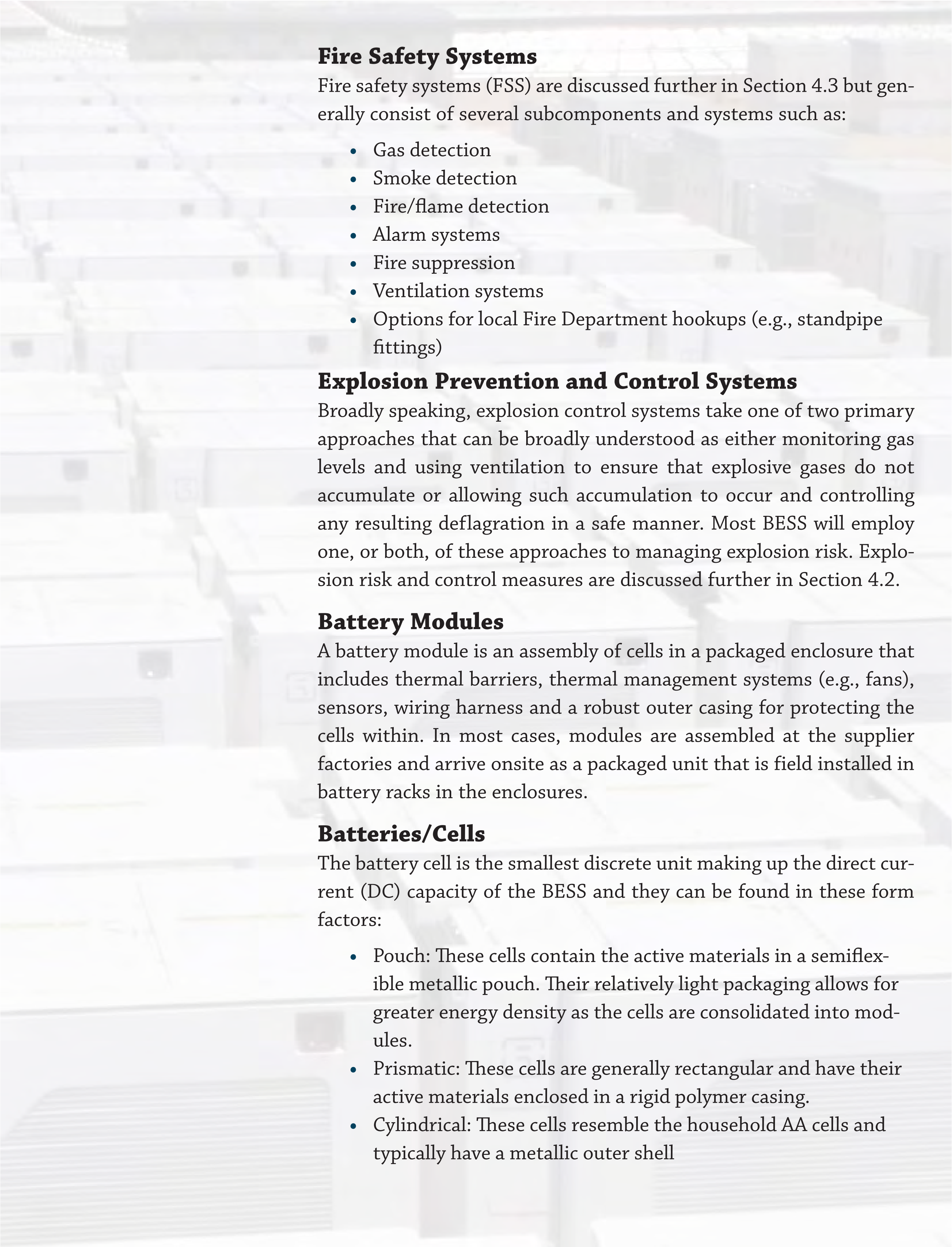
[5] The BMS can be conceptualized as a single system but each direct current (DC) bus will likely have an at least semi-independent BMS managing things like voltage independent of what is happening on other DC busses.



Fire Safety Systems

Fire safety systems (FSS) are discussed further in Section 4.3 but generally consist of several subcomponents and systems such as:

- Gas detection
- Smoke detection
- Fire/flame detection
- Alarm systems
- Fire suppression
- Ventilation systems
- Options for local Fire Department hookups (e.g., standpipe fittings)

Explosion Prevention and Control Systems

Broadly speaking, explosion control systems take one of two primary approaches that can be broadly understood as either monitoring gas levels and using ventilation to ensure that explosive gases do not accumulate or allowing such accumulation to occur and controlling any resulting deflagration in a safe manner. Most BESS will employ one, or both, of these approaches to managing explosion risk. Explosion risk and control measures are discussed further in Section 4.2.

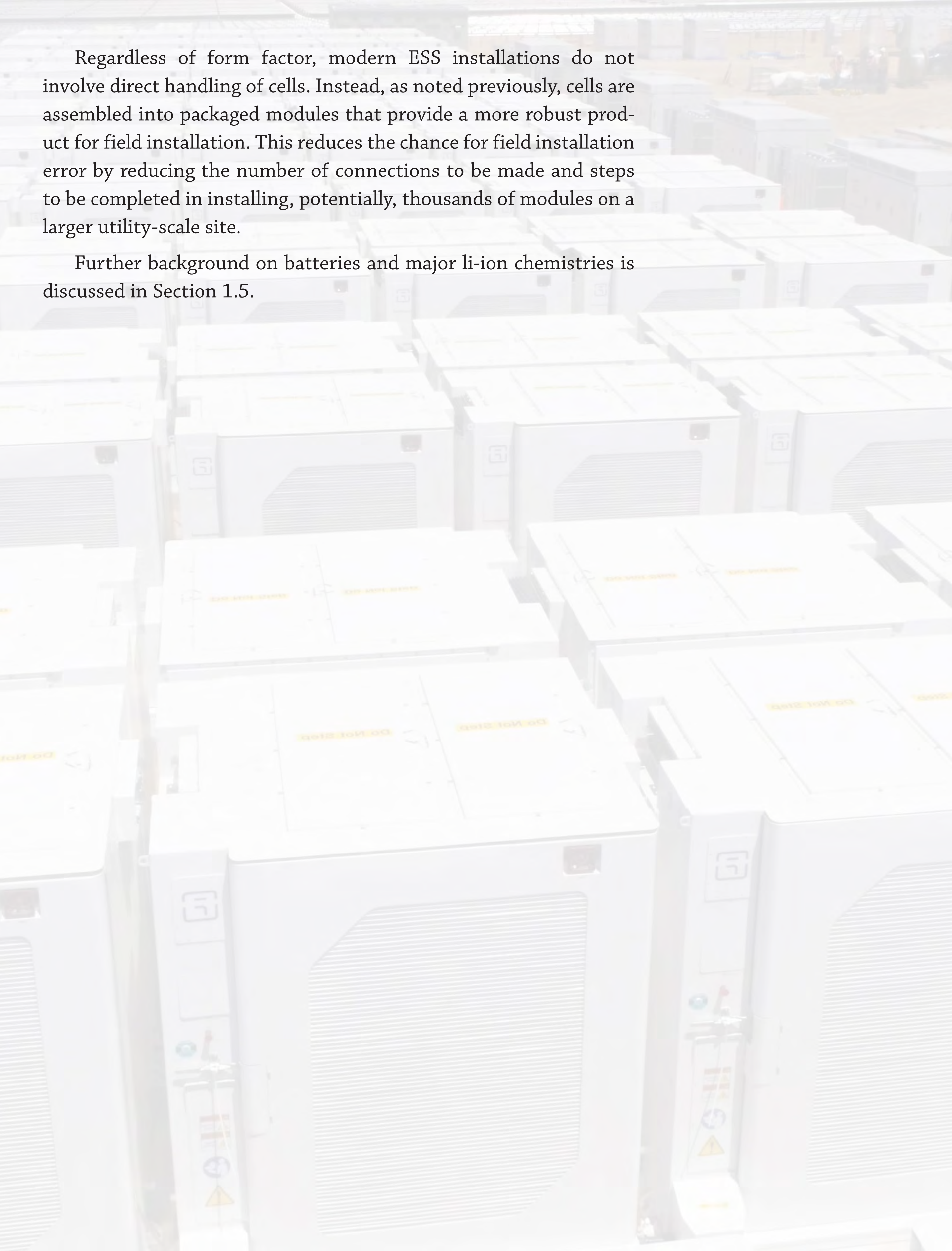
Battery Modules

A battery module is an assembly of cells in a packaged enclosure that includes thermal barriers, thermal management systems (e.g., fans), sensors, wiring harness and a robust outer casing for protecting the cells within. In most cases, modules are assembled at the supplier factories and arrive onsite as a packaged unit that is field installed in battery racks in the enclosures.

Batteries/Cells

The battery cell is the smallest discrete unit making up the direct current (DC) capacity of the BESS and they can be found in these form factors:

- Pouch: These cells contain the active materials in a semiflexible metallic pouch. Their relatively light packaging allows for greater energy density as the cells are consolidated into modules.
- Prismatic: These cells are generally rectangular and have their active materials enclosed in a rigid polymer casing.
- Cylindrical: These cells resemble the household AA cells and typically have a metallic outer shell



Regardless of form factor, modern ESS installations do not involve direct handling of cells. Instead, as noted previously, cells are assembled into packaged modules that provide a more robust product for field installation. This reduces the chance for field installation error by reducing the number of connections to be made and steps to be completed in installing, potentially, thousands of modules on a larger utility-scale site.

Further background on batteries and major li-ion chemistries is discussed in Section 1.5.

3 Residential and Small Commercial Scale Projects

Energy storage systems have a growing role in providing value to residential and small commercial customers. Sometimes referred to as "behind the meter" energy storage because of this placement on the customer side of the utility revenue meter, these ESS can be used for a range of applications, including:

- Demand charge reduction
- Resilience or backup power
- Virtual power plants
- Energy arbitrage

Residential and small scale-commercial ESS are more likely to be found in areas prone to power outages, offering lucrative incentive programs, and/or where variable electricity rates present possible opportunities for time-shifting or energy arbitrage. Residential ESS, as shown in Figure 3-1, can also pay a role in supporting electric vehicle charging, by offsetting peak demand charges when vehicles must be charged during high energy price periods and also providing a local storage option for night-time charging with electricity generated by onsite PV during the day. The development, installation and ownership structures for these smaller ESS tend to be simpler than those for utility-scale ESS. While some of these applications are like those available to utility-scale ESS, these systems are more likely to be directly owned by the property owner, though leasing or other commercial arrangements are not unknown. Many of these behind the meter ESS are sold and installed by entities also engaged in selling and installing solar photovoltaic (PV) systems. In other cases, behind the meter ESS are directly marketed, sold and installed by vertically integrated providers.

Figure 3-1

This Tesla PowerWall 2 installation provides energy storage for household use and facilitates charging of electric vehicles. Photo courtesy of Tesla.

Specific to the demand charge reduction use case, some ESS providers have paired relatively standard hardware solutions with innovative artificial intelligence (AI) algorithms that monitor building peak demand and attempt to predictively operate the ESS in a way to identify, and reduce, the largest peaks in electricity demand. These features are often paired with real-time energy monitoring and reporting and have the potential for significant utility bill savings. These systems, such as the example shown in Figure 3-2, can be deployed on a standalone basis or paired with onsite solar photovoltaics, although they tend to provide the best economic return in markets where energy and demand costs are volatile, allowing them to charge during low cost periods and discharge during expensive periods to avoid costly energy and demand charges.

Figure 3-2

Some systems, such as the Stem system shown here, use a combination of BESS hardware (as previously discussed) and sophisticated artificial intelligence algorithms to help commercial customers reduce costly peak demand and energy charges. Photo courtesy of Stem, Inc.

4 Fire and Explosion Risk in Lithium-Ion Battery Energy Storage Systems

As with any new technology, there are understandable questions regarding the safety of lithium-ion battery energy storage systems (li-ion BESS). Given their modular nature, the technology lends itself to everything from residential to utility-scale applications. This chapter provides a brief introduction to the main li-ion chemistries and addresses the greatest concerns related to li-ion BESS fires and explosions.

4.1 Battery Fire and Explosion Risk Background

There are numerous news reports and sensational videos showing eye-catching failures of lithium-ion batteries and some jurisdictions have used these as the basis for prescribing overly burdensome or nonsensical safety requirements for ESS. As a stored energy medium, batteries must always be treated with care and respect, but it would be overly simplistic to equate the types of failures seen in poorly regulated consumer products with the behavior of a properly designed, installed and listed ESS. Nevertheless, there are several credible reports of thermal events associated with ESS that are important to be familiar with. It is likewise important to bear in mind that the industry's understanding of failure mechanisms, mitigation measures, codes and standards is evolving and improving at a rapid pace. Modern ESS are, for example, markedly safer than those installed even two or three years ago, and it is expected that those installed two or three years in the future will be safer than those installed today.

Figure 4-1

This image shows the dramatic aftermath of the 2019 BESS fire at the APS McMicken facility. The left image was taken directly after the incident, the right image shows the enclosure with debris removed. Photos accessed at IEEE Spectrum and attributed to Arizona Public Service.

There are two major areas of concern for ESS: fire and explosion. These two risks are distinct and have a complex relationship that may not be obvious at first glance.

Fire is a chemical reaction requiring fuel and oxygen to react and produce a flame. Explosions occur through the ignition of a flammable combination of gases that results in a rapid reaction and release of energy. The following sections provide more context on these phenomena, as well as provide a brief overview of the thermal runaway process, a key factor in designing safety systems for li-ion BESS.

Thermal Runaway

Thermal runaway is an exothermic chemical reaction occurring when one, or more, cells reach a state in which there is an ongoing internal reaction that results in the cell(s) generating more heat than can be explained by any external factors (such as a nearby heat source). This reaction breaks down internal cell resistance, thereby accelerating the buildup of heat further (hence the "runaway" term). Thermal runaway is a chemical process that occurs within the cell and should not be confused with "propagation," which refers to the spread of thermal runaway to other nearby cells, driven by the heat generated in the initiating cell's reaction. In this way, a single cell going into thermal runaway can create sufficient heat to drive other nearby cells into the same condition.

The following summarizes the key steps for thermal runaway caused by an internal short circuit, such as might be caused by a cell manufacturing defect:

1. A parallel connection forms between the anode and the cathode.
2. This parallel path causes a drop in cell voltage (on the order of 0.2 to 0.4V on a cell voltage of 3 to 4V).
3. The parallel path has low resistance and begins pulling a significant amount of current which generates heat (as a reminder, heat generated by resistance is related to the square of the current, so doubling current leads to four times the heat and so forth).
4. The heat generated begins to burn the separator (an observer may begin to see vapor starting to escape the cell at this stage).
5. As the separator burns, it lowers the electrical resistance between the anode and cathode further, increasing the short circuit current and accelerating heat buildup (note that most modern separators begin to deteriorate at approximately 176°F (80°C).

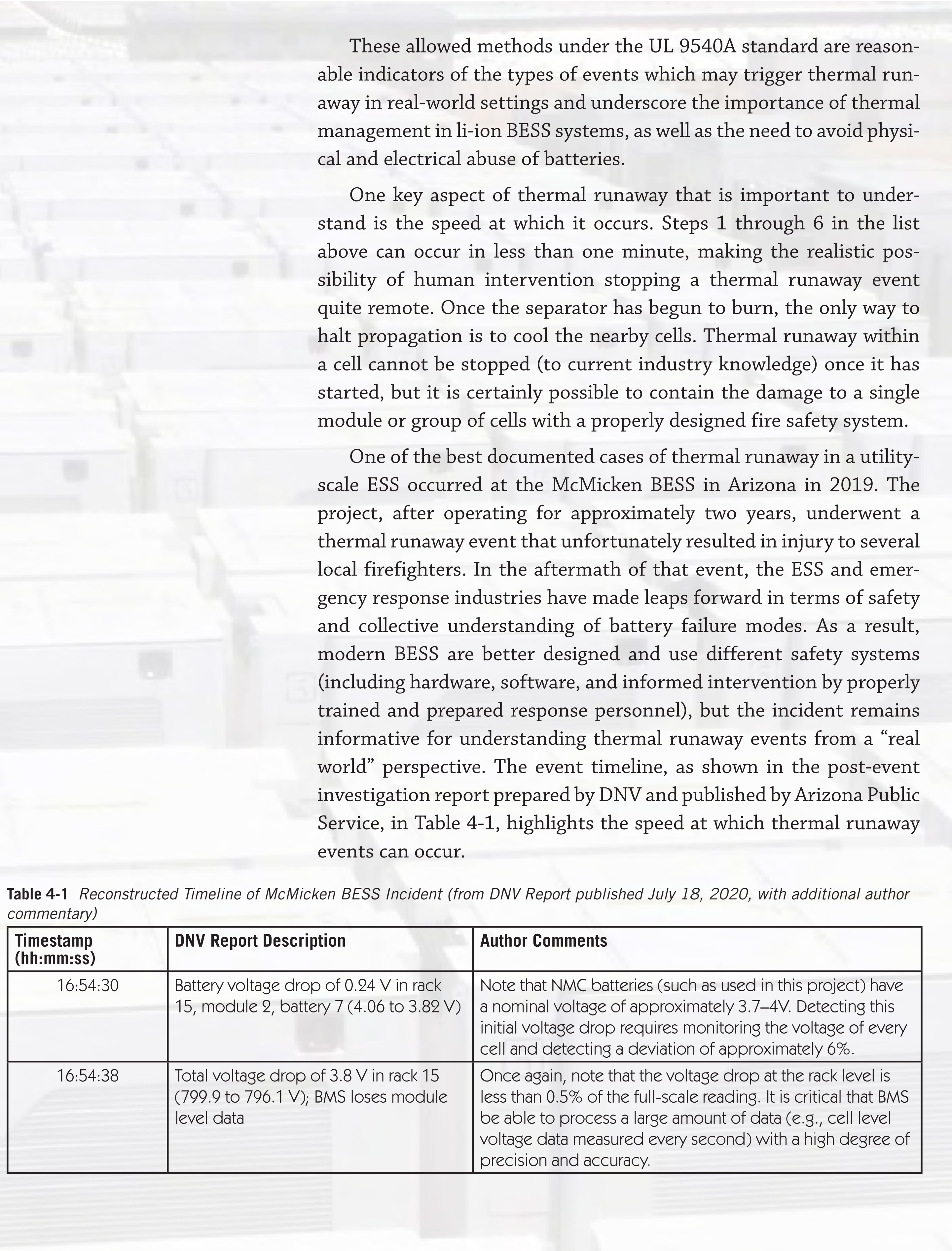
6. The liquid electrolyte begins to burn (an observer would now see a significant amount of off-gassing from the cell).
7. Depending on the chemistry, the cell may begin flaming and/or generating significant heat, which may result in neighboring cells or other equipment catching fire. (Return to step 3.)

Figure 4-2

During UL 9540A testing, cells like this one are forced into thermal runaway and may exhibit smoking, flaming or explosive behaviors as part of the testing. Photos courtesy of Energy Safety Response Group.

It is worth noting that thermal runaway can be initiated by any mechanism that sufficiently raises the temperature of the cell. In the above list, it can be assumed that the initial event is a short circuit within the cell but it is equally possible, for example, to initiate thermal runaway by exposing a cell to an external heat source or by mechanically damaging the cell (e.g., dropping or penetrating with a sharp metal object). Newsworthy battery fires of the past couple of years have been initiated by internal cell defects and failures of control systems to adequately monitor and control battery conditions. When performing testing under UL 9540A, in which the test laboratory is deliberately attempting to initiate thermal runaway, the allowed methods include:

- Direct application of heat (e.g., with a strip heater affixed to the cell exterior)
- Indirect application of heat (e.g., in an oven or similar means of raising ambient temperature)
- Mechanical penetration
- Overcharging
- Over-discharging



These allowed methods under the UL 9540A standard are reasonable indicators of the types of events which may trigger thermal runaway in real-world settings and underscore the importance of thermal management in li-ion BESS systems, as well as the need to avoid physical and electrical abuse of batteries.

One key aspect of thermal runaway that is important to understand is the speed at which it occurs. Steps 1 through 6 in the list above can occur in less than one minute, making the realistic possibility of human intervention stopping a thermal runaway event quite remote. Once the separator has begun to burn, the only way to halt propagation is to cool the nearby cells. Thermal runaway within a cell cannot be stopped (to current industry knowledge) once it has started, but it is certainly possible to contain the damage to a single module or group of cells with a properly designed fire safety system.

One of the best documented cases of thermal runaway in a utility-scale ESS occurred at the McMicken BESS in Arizona in 2019. The project, after operating for approximately two years, underwent a thermal runaway event that unfortunately resulted in injury to several local firefighters. In the aftermath of that event, the ESS and emergency response industries have made leaps forward in terms of safety and collective understanding of battery failure modes. As a result, modern BESS are better designed and use different safety systems (including hardware, software, and informed intervention by properly trained and prepared response personnel), but the incident remains informative for understanding thermal runaway events from a “real world” perspective. The event timeline, as shown in the post-event investigation report prepared by DNV and published by Arizona Public Service, in Table 4-1, highlights the speed at which thermal runaway events can occur.

Table 4-1 *Reconstructed Timeline of McMicken BESS Incident (from DNV Report published July 18, 2020, with additional author commentary)*

Timestamp (hh:mm:ss)	**DNV Report Description**	**Author Comments**
16:54:30	Battery voltage drop of 0.24 V in rack 15, module 2, battery 7 (4.06 to 3.82 V)	Note that NMC batteries (such as used in this project) have a nominal voltage of approximately 3.7–4V. Detecting this initial voltage drop requires monitoring the voltage of every cell and detecting a deviation of approximately 6%.
16:54:38	Total voltage drop of 3.8 V in rack 15 (799.9 to 796.1 V); BMS loses module level data	Once again, note that the voltage drop at the rack level is less than 0.5% of the full-scale reading. It is critical that BMS be able to process a large amount of data (e.g., cell level voltage data measured every second) with a high degree of precision and accuracy.

Timestamp (hh:mm:ss)	**DNV Report Description**	**Author Comments**
16:54:40	Temperature readings begin to increase in the rear of rack 15	Within 10 seconds of the initial voltage drop in a single cell, there is beginning to be heat buildup at the rear of the rack. The heat in the initiating cell is becoming noticeable outside of the module.
16:55:20	BESS smoke alarms 1 and 2 activate and the fire protection system triggers several circuit breakers to open (BMS DC breakers, inverter AC contactors, main AC breaker)	Less than one minute after a single cell experienced a small voltage drop, there was enough smoke to activate both smoke alarms in the enclosure. Even if the BMS had immediately alerted an onsite technician, it is unlikely that they could have taken any action in the allotted time to materially change the outcome.
16:55:45	Ground fault detected	
16:55:50	Fire suppression system discharges Novec 1230 suppression agent (30 second delay from alarm time, as per its design)	See discussion of clean agent fire suppression systems in Section 4.2.
16:57	APS contacts Fluence to verify the fire suppression system discharged	Contact made with Fluence approximately 2 minutes after the FSS discharged, demonstrating a quick response by monitoring personnel.
17:07	Fluence advises APS that its Field Service Engineer is en route to the site for visual confirmation of potential fire	Manual interventions were happening quickly and within the bounds required in most O&M agreements. Overall, relevant parties were notified within the first few minutes and an assessment was made to notify local authorities within a half hour of personnel being dispatched to the site.
17:12	APS dispatches a Troubleman to the site	
17:40	Fluence field service engineer calls 911 to report suspected fire	
17:44	APS notifies 911 End of data collection and cessation of remote communications (end of battery backup power for main servers and communications equipment)	Note that this is approximately 50 minutes after discharge of the NOVEC 1230 and onsite personnel lost any sort of internal monitoring data. Even given a fast response by relevant personnel, it can take hours or even days to safely extinguish and secure a scene after a li-ion battery fire. It is important to ensure a means of maintaining visibility to sensors inside enclosures for a sustained period of time, even if the main power connections to the enclosure must be disconnected. This was not fully understood at the time and, in some cases, remains a topic of discussion on modern projects.
17:48	Fire department arrival time	The Fire Department arrived after the facility had reported losing internal sensor data. From the fire department's perspective, there was no good way to tell what is happening inside the enclosure at this point and there are many unknowns in how to address the situation safely and effectively.
20:02	Front door of container opened by emergency responders	
20:04	Explosion occurs	Note that it took 2 minutes for the explosion to occur. This is because the explosive gases had stratified in the container and the door opening caused those gases to mix and come into contact with some of the hot surfaces remaining from the fire, which appear to have been sufficient to cause ignition.

4.2 Fire and Explosion Risk and Mitigation Measures

A BESS project, like any utility infrastructure or energy system, is prone to some level of fire risk. Electrical equipment, in rare cases, can experience failures or problems that result in a fire and addressing the causes of fires in transformers, switchgear, HVAC and other subsystems is beyond the scope of this publication. In addition to these typical pieces of electrical equipment, BESS have the added fire risk related to the use of batteries.

The risk of fire and associated thermal runaway is influenced by several factors:

- Cell chemistry
- Cell design
- BMS sensing and controls
- Thermal management
- Use case
- Maintenance activities

Understanding the impact of these factors on BESS safety and design can provide some insights but requires a deep knowledge of BESS and subsystem technologies. However, such understanding may not be of immediate use in an emergency response situation and local authorities should be cautious about attempting to infer system behavior based on any, one or more, of these factors taken in isolation. Put simply, the author does not recommend that specific design requirements be imposed on projects based on the background information provided in this document (e.g., specifying only cells with a specific separator material be used or banning the use of certain battery chemistries), above and beyond what is required in the relevant codes.

With that in mind, cell chemistry plays an important role in fire risk, with some chemistries proving more difficult to ignite than others. The ease of causing a cell to ignite can be directly related to its energy density, with the relatively energy dense NMC cells, for example, generally proving easier to cause ignition during UL 9540A testing. That being the case, it is important to consider that the UL 9540A testing is specifically intended to cause fires and most of these tests are conducted by directly applying heat to the cell (called the "Initiating Unit") via a lab-installed heating element. As such, an inability to cause flaming in a cell under the UL 9540A testing should not be construed to mean that a certain cell chemistry will never exhibit such behavior under other types of abuse cases. Claims by manufacturers that their battery is "impossible to catch on fire" should be viewed with a reasonable level of skepticism. Also, it bears emphasizing the "System" in Battery Energy Storage System. It can be easy to focus on dramatic cell-level testing results showing flaming behavior, but a well-designed and code-compliant BESS will manage cell-level risk of fire through a variety of potential means. As a result, a more fire-prone chemistry with a well-designed BMS and fire safety system could be considered more safe than a "safer" chemistry that is installed in a less well-considered system.

The manufacturing process behind an installed BESS involves an impressive level of sophistication and a large supply chain. First, cell manufacturing facilities will produce cells via a heavily automated process that includes assembly of cell container, electrolyte, separator, anode and cathode. As cells are produced, they undergo various automated tests to check for voltage, internal resistance, dimensions and other factors before being prepared for shipping. Most factories producing batteries for one of the major manufacturers will measure their annual production in Gigawatt-hours of capacity, corresponding with 1 to 1.5 million cells per GWh of line capacity, depending on the type of cell being produced.

Quality Assurance

Like any manufacturing process, ensuring the quality of components at the factory is important to overall quality of the assembled BESS. As such, quality assurance can help provide comfort that BESS components are produced to the relevant standards and a high degree of quality. This is especially important for catching possible issues that are not visible in the fully installed BESS. Typical QA activities, as might be provided by a third-party engineering or advisory firm, might include factory audits (as shown in Figure 4-3), inline production monitoring, preshipment inspections on a sample of completed units and overseeing factory acceptance testing of enclosures and major subsystems.

Figure 4-3

Third-party factory inspections are frequently required on larger orders to ensure the quality of BESS components meets relevant standards and requirements. Here, such a third-party inspector oversees a portion of the electrode manufacturing process. Photo courtesy of Clean Energy Associates.

In most cases, BESS are assembled from modules or packs, as discussed previously, and the cells are delivered to another production facility (sometimes located entirely separate from the cell factory) for assembly into modules.

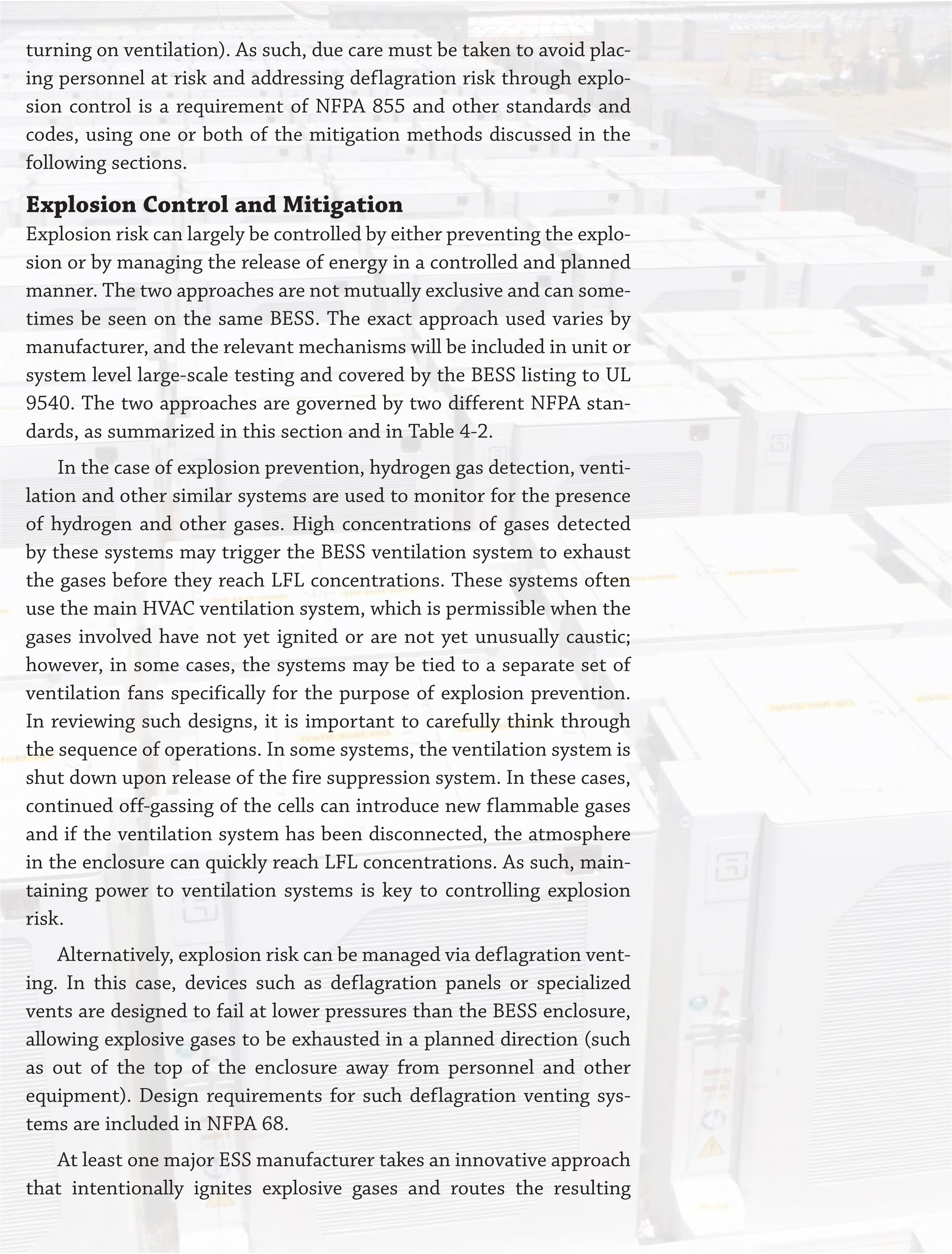
Enclosure manufacturing will also be happening at the same time as cell and module production, though generally at a different facility. In general, most major manufacturers can produce cells and modules significantly faster than they can produce enclosures and integrated systems, so timely delivery of BESS equipment will be carefully coordinated by the relevant suppliers.

Once enclosures and modules are produced, racks and subsystems will be added to the enclosures. For larger enclosures (20 feet and larger, typically), the enclosure will be shipped to the project site with racks, panelboards, wireways, thermal management, and safety systems installed. However, the weight of shipping larger enclosures with battery modules installed can be prohibitive. A 40-foot enclosure, without battery modules, can be expected to weigh approximately 40 tons, with the battery modules adding another 50 to 60 tons. In these cases, the enclosure and battery modules are shipped to the site separately and the modules are field-installed. For smaller enclosures containing only 1 to 6 racks, the entire assembly can happen at the factory and the unit will be shipped to the project site fully assembled and ready for installation. This reduces field installation time and complexity considerably.

Explosion Risk

The risk of a deflagration event in BESS is generally driven by the ignition of flammable gases in an enclosed space, like a BESS cabinet or enclosure. Perhaps counterintuitively, the risk of explosion can sometimes be indirectly correlated to the presence of fire, as open flame will often consume the explosive gases. In fact, this is one of the nuances that makes the use of clean agent suppression methods more problematic for BESS fires and why extinguishing the visible flame is only part of the solution in these situations. Concentrations of flammable gases exceeding the lower flammable limit (LFL) indicate a risk of explosion when those gases come into contact with an ignition source including hot surfaces, flame, sparks or electrical arcs.

The presence of flammable gases and ignition sources in the same place at the same time without explosion does not indicate that there is no further risk. As with the McMicken incident, flammable gases tend to stratify and any action that causes the air within an enclosed space to mix may trigger an explosion (e.g., opening an enclosure door,



turning on ventilation). As such, due care must be taken to avoid placing personnel at risk and addressing deflagration risk through explosion control is a requirement of NFPA 855 and other standards and codes, using one or both of the mitigation methods discussed in the following sections.

Explosion Control and Mitigation

Explosion risk can largely be controlled by either preventing the explosion or by managing the release of energy in a controlled and planned manner. The two approaches are not mutually exclusive and can sometimes be seen on the same BESS. The exact approach used varies by manufacturer, and the relevant mechanisms will be included in unit or system level large-scale testing and covered by the BESS listing to UL 9540. The two approaches are governed by two different NFPA standards, as summarized in this section and in Table 4-2.

In the case of explosion prevention, hydrogen gas detection, ventilation and other similar systems are used to monitor for the presence of hydrogen and other gases. High concentrations of gases detected by these systems may trigger the BESS ventilation system to exhaust the gases before they reach LFL concentrations. These systems often use the main HVAC ventilation system, which is permissible when the gases involved have not yet ignited or are not yet unusually caustic; however, in some cases, the systems may be tied to a separate set of ventilation fans specifically for the purpose of explosion prevention. In reviewing such designs, it is important to carefully think through the sequence of operations. In some systems, the ventilation system is shut down upon release of the fire suppression system. In these cases, continued off-gassing of the cells can introduce new flammable gases and if the ventilation system has been disconnected, the atmosphere in the enclosure can quickly reach LFL concentrations. As such, maintaining power to ventilation systems is key to controlling explosion risk.

Alternatively, explosion risk can be managed via deflagration venting. In this case, devices such as deflagration panels or specialized vents are designed to fail at lower pressures than the BESS enclosure, allowing explosive gases to be exhausted in a planned direction (such as out of the top of the enclosure away from personnel and other equipment). Design requirements for such deflagration venting systems are included in NFPA 68.

At least one major ESS manufacturer takes an innovative approach that intentionally ignites explosive gases and routes the resulting products of combustion safely away from the battery module location. This is just one example of an alternative means of addressing explosion risk and we can expect to see other novel approaches develop as the ESS industry continues to tackle explosion-related risks.

Table 4-2 *Explosion management strategies*

STRATEGY	PREVENTION	CONTROL
Relevant UL Standard	NFPA 69	NFPA 68
Description of Methods	Explosion prevention involves the detection and removal of explosive gases before they can reach the LFL. Key components are gas detection, ventilation and alarms.	Explosion control addresses the safe management of explosive expansion of gases to minimize hazard to personnel and property. Strategies include deflagration panels, vents and other devices designed to fail at lower pressures than the mechanical strength of the enclosure, thereby giving release to rapidly expanding gases before pressures reach explosive levels and cause greater damage.

4.3 Key BESS Safety Systems

The fire safety system on a utility-scale BESS consists of a variety of subsystems designed to detect, prevent and extinguish fires (most notably caused by thermal runaway). In completing inspections and plan reviews, it is important to note that an ESS's product listing (to UL 9540) will include all relevant safety systems.

While it is important that local authorities understand how these systems work, it is critical for ESS to be installed according to their listing. In some cases, well-meaning authorities may require modification of an ESS's fire safety system in order to obtain a permit, but this will likely violate the UL 9540 listing. Adjusting the fire safety systems on packaged ESS that are UL 9540 listed should be undertaken in a careful and considered manner, understanding that well-intentioned modifications may result in voiding the manufacturer's UL 9540 listing (and, as a result, requiring field listing be undertaken).

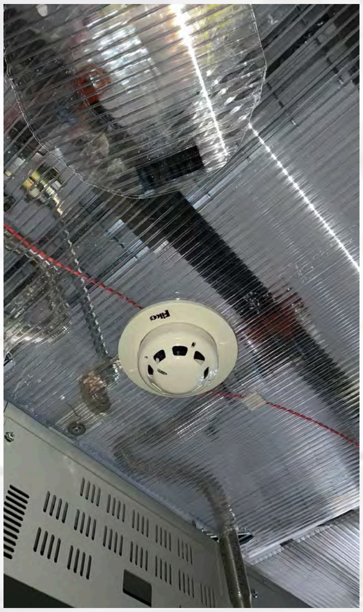


Figure 4-4

There will likely be several smoke detectors, like this one, mounted at ceiling level in larger enclosures.

Smoke detectors

Smoke detectors are typically mounted in enclosures near the ceiling, as shown in Figure 4-4, and, in most cases, there will be two to four smoke detectors per large enclosure. Smoke detectors can be of either the "ionization" or "photoelectric" type (combination units are also available). Ionization type detectors use a small amount of radioactive material (Americium-241) that creates an electrical charge on the detector circuit. When smoke enters the chamber, this ionization is interrupted resulting in a loss of voltage and triggering the alarm. In a photoelectric detector, a small beam of light passes through the sensor chamber during normal operation. When smoke enters the chamber, this light is refracted and strikes a light sensor, triggering the alarm. Major fire protection agencies typically recommend the use of both sensor types within homes, as they are each slightly more effective at different types of fires. This approach is equally valid in a BESS fire safety system and the use of both sensor types (or a combination unit) is recommended.

Flame Detectors:

In addition to smoke detectors, some BESS enclosures will feature a means of detecting heat generation and open flame. This is generally accomplished via an infrared or ultraviolet (UV) sensor that may be triggered based on:

- Absolute temperature
- Rate of change in temperature over time

Generally, the detector is sampling radiation within a specified wavelength range and applying an internal algorithm to compare readings to known emissions patterns associated with combustion; UV detectors are particularly fast-responding.

Because flame is usually only seen at the late stages of thermal runaway, flame detectors are not always used or required in BESS, as the systems already have extensive temperature monitoring capability, as well as gas and smoke detection. With respect to battery fires, flame is generally detected after considerable volumes of gas and smoke have been generated and the temperature elevated. As such, flame detectors may not provide meaningful added protection to a well-designed system that does not include such detectors as part of its UL 9540 listing.

Figure 4-5

Gas detection systems can be used to detect the early stages of thermal runaway and can be deployed at the rack or enclosure level. Deployment at rack level provides the fastest detection of a possible developing thermal runaway event but will have an increased cost compared with deploying a smaller number of enclosure-level sensors. Photo courtesy of Matt Paiss, Pacific Northwest National Laboratory, and Snohomish PUD.

Gas Detectors:

Gas detectors can be purchased to measure concentrations of various gases. Hydrogen detection is particularly important for BESS, as hydrogen gas is one of the first gases released from a cell undergoing early stages of thermal runaway. Gas detectors may be connected to enclosure ventilation systems, with the aim of detecting and ventilating flammable gases before they can reach explosive concentrations. Typically, such detectors are triggered at approximately a 1-percent gas concentration and should be triggered at no more than 25 percent of the LFL, which is approximately 4 percent by volume for pure hydrogen. During thermal runaway, the gas resulting from the reaction will contain more than hydrogen; the UL 9540A test report will include key information on the gas composition and volume released during the test. Additionally, the test report will include values for both the upper flammable limit (UFL) and the LFL that can be confirmed against the proposed gas detection system specifications.

Fire Control Panel:

The fire control panel provides a quickly understandable summary of the status of associated alarm and suppression systems, allowing emergency personnel to quickly determine the status of these systems. The fire control panel is colored a distinctive red and is to be found inside the BESS enclosure (on larger enclosures) or located near control systems for groups of smaller enclosures.

Figure 4-6

Fire control panel (red) shown with panelboard for AC loads and elements of the controls and communications system for the enclosure (installation work in progress).

Fire Suppression System (Clean Agent):

Clean agent fire suppression systems rely on the use of specialized chemical spray, foam or pellets to deprive a fire of access to oxygen, thereby starving the fire and extinguishing it. The agent is generally dispersed from nozzles mounted in the ceiling of the enclosure and is intended to cover a wide area. In order to function, clean agents must be applied to meet or exceed the manufacturer-specified concentration (expressed as a fraction of total air volume) and allowing the concentration of clean agent to fall below this threshold will significantly diminish its effectiveness. For this reason, clean agent suppression systems are usually used in conjunction with ventilation controls that shut down active ventilation, attempting to maintain the clean agent concentration within the enclosure for as long as possible. Natural air leakage, opening enclosure doors and chemical reaction will all diminish the concentration of the clean agents over time. It is notable that clean agents are not effective at halting thermal runaway, as they provide insufficient cooling effect and do not reach the deep-seated smoldering type fires that may consume a battery module, nor do they reach cells undergoing thermal runaway inside modules. In fact, as discussed in Section 4.1, thermal runaway can propagate through a rack of battery modules with no visible exterior flame whatsoever and is instead purely based on chemical reactions in the cells, convection and radiant heat transmission. Though demonstrably ineffective at halting thermal runaway, there may be applications for clean agent suppression in cases where such systems are supplementing a water-based suppression system or are intended to address fires in the non-battery portion of the BESS.

Fire Suppression System (Water):

As of this writing, water-based fire suppression is the generally recommended means of fire suppression for li-ion BESS. Unlike clean agents, water can more effectively remove heat from cells and modules undergoing thermal runaway, while simultaneously cooling nearby cells and modules to prevent thermal runaway from progressing through larger portions of the system. Water-based suppression generally involves dispersion of water via ceiling mounted sprinkler systems. Some BESS manufacturers have introduced rack-level water systems that dispense water directly into modules that are experiencing thermal runaway, delivering a significant quantity of water directly to the most affected cells rather than spraying or flooding an entire enclosure at once. In general, it can require a significant volume of water to extinguish a BESS fire. Therefore, it is important that the fire suppression system be properly engineered and if the site does not have access to municipal water, that sufficient onsite storage is provided based on the results of large-scale fire testing (i.e., UL 9540A) and in consultation with fire protection experts and equipment manufacturers.

Figure 4-7

In cases where a high volume (e.g., municipal) water source is not available, BESS designers may have to include onsite tanks to provide the necessary volume, as shown here

Water-based suppression methods are not without drawbacks. While much of the conversation around BESS safety is related to thermal runaway, for which water is a generally suitable response, modern BESS can be built to operate at 1,000V, or higher, and mixing water and electricity should always be done with caution, especially if batteries are located in proximity to high voltage (HV) electrical infrastructure.

Note that there are also several BESS on the market without fire suppression systems. These BESS are designed, in general, around the concept that potential fires can be contained fully within the enclosure. UL 9540A system-level testing is required to demonstrate that there is minimal heat radiation and no flame spread or explosion risk outside of the enclosure. Under these conditions, it may be permissible to use alternatives to water-based fire suppression, including potentially foregoing fire suppression altogether.

Cell Safety Features

Modern BESS safety features begin at the cell level. Just as the chemistries described previously are subsets of li-ion batteries as a group, it is important to understand that not all NMC or LFP cells are manufactured in the same way. Each manufacturer will have proprietary manufacturing methods and materials used in their cells, with tradeoffs in cost, safety, efficiency and performance. These materials and methods may not be evident from a perusal of product specifications, but battery cells can include a variety of added, proprietary safety features, including:

- Ventilation caps or burst discs in cylindrical cells that are designed to fail, facilitating controlled gas venting as an early sign of cell distress and allowing heat to be directed away from adjacent cells.

- Use of flame retardant materials in cell separator materials to improve heat resistance
- Addition of ceramic coating to separators to improve strength and resistance to dendrite penetration
- Use of solid-state electrolyte materials, which are less flammable and resist dendrite growth
- Thermal fusing to disconnect cells under high heat/current

These examples, along with other cell safety features, are commonly found in commercially available Li-ion batteries and more advances are being made every year to identify and implement further safety measures.

4.4 Emergency Planning and Response

Though BESS are generally safe and operate for years without incident, proper planning for an emergency event, such as a fire, is critical to ensure the safety of nearby personnel and property, as well as emergency responders. Additionally, some elements of preparedness are required in relevant codes and standards, such as the *International Fire Code* and National Fire Protection Association Standard 855 (NFPA 855).

Hazard Mitigation Analysis

Some ESS will require a Hazard Mitigation Analysis. These analyses are only called for under unusual circumstances where the other documentation provided for the ESS are insufficient to address potentially complex hazards. NFPA 855 Section 4.1.4 indicates that a Hazard Mitigation Analysis should be performed when:

- Technologies not otherwise listed in the standard are used (i.e., new or novel technologies for which safety requirements are not fully defined)
- More than one ESS technology is present in the same space (i.e., the analysis must cover possible interactions that neither supplier, alone, would necessarily have documented)
- When allowed as a basis for increasing ESS capacity beyond specified thresholds (see discussion of Maximum Energy Capacity in Chapter 6)

NFPA 855 does not specify the exact method or format for the analysis but frameworks, such as the Bow-Tie Model, used in other industrial applications can be applied to ESS Hazard Mitigation Analyses. The key consideration for such analyses, regardless of framework, is to methodically step through each identified risk, its associated hazards, mitigating factors and remedial actions so that local authorities can clearly understand the potential hazards and how they can be avoided or remediated.

Emergency Operations Plan

ESS meeting the minimum size thresholds established in the relevant codes (see Chapter 6) must typically have an Emergency Operations Plan. The intent of this document is to provide local authorities, nearby building occupants and first responders with a concise summary of the ESS and clear instructions on how to safely perform the initial steps required in responding to a fire or other emergency event. NFPA 855 provides an outline of elements that must be included in the emergency operations plan, but key items generally include:

- Procedure for safely shutting down ESS and key subsystems
- Procedure for inspecting alarms and controls
- Procedures for responding to alarms and alerts generated by the EMS or BMS
- Emergency procedures to follow in case of fire or explosion
- Safety data sheets or equivalent information regarding possible hazards to responders
- Procedure for safely removing and handling damaged ESS equipment
- Procedures for performing drills or reviews of the emergency operations plan

The Emergency Operations Plans should be clearly written, with concise summary information in the first few pages, and saved in an obvious (and well-labeled) location onsite. Storage of the plan onsite is a requirement of NFPA 855 when the site is occupied; identifying a suitable location onsite to store an extra copy, regardless of site occupancy, is best practice.

Emergency Response

The methods for safely responding to ESS fires or other emergencies are evolving quickly and prescribing methods for such response is both unfeasible and outside the scope of this work, if for no other reason than any advice given would likely be out of date by the time the work is published.

Nevertheless, it can be helpful to review some of the key considerations that are relatively universal to modern BESS, with the understanding that it is important to review the most up-to-date fire safety methods and recommendations, as there is significant work underway to address the risks noted below:

- Stranded Energy: After a BESS fire event, the remaining batteries may not be fully discharged and there can still be high-voltage DC electrical hazards present in the system. In addition, the elevated state of charge of the batteries represents a continuing risk of reignition. As of this writing, there is not yet industry consensus on the best means of addressing stranded energy and a variety of methods, from placing damaged batteries in tanks of water (or salt water) to using customized resistive circuits to discharge have been proposed or attempted.
- Explosion: As discussed for the 2019 McMicken incident, batteries undergoing thermal runaway can exhaust significant amounts of flammable gases in enclosed spaces. If power is cut as part of the emergency response process, ventilation systems that normally would exhaust such gases may not be operable and there may be explosive environments in any enclosed cabinet, enclosure or walk-in unit.
- Fire: Even if the initial fire is extinguished, responders should be aware of the risk of reignition, especially in batteries at a high state of charge that are exposed to heat sources.
- Toxic Gases: Modern batteries release a range of gases when undergoing a thermal runaway event and such gases will be toxic, particularly in enclosed spaces without adequate ventilation. Test reports compliant with UL 9540A will include gas analyses showing the makeup of such off-gassing and should be consulted to determine the appropriate filtration and breathing apparatus to be used.

Major organizations are working to clarify these and other risks for first responders. New methods and technologies are emerging rapidly to safely combat these challenges, as has been the case in the past when the advent of new technologies drove innovation in firefighting methods and technologies (e.g., when semiconductor technologies became ubiquitous in homes and businesses). So, while battery fires in the news have proven to be dramatic events and first responders should exercise all due care in combatting such events, the advancement of fire protection science in response to a new technology is hardly unique to BESS.

Solutions for Existing Systems

With the rapidly changing technology options and best practices for BESS design and installation, a well-designed system installed even one to two years ago can be behind the current best thinking in terms of safety. In these cases, there are some options for improving the safety of existing systems through continuous evaluation and retrofit solutions.

Firstly, it is important to periodically (at minimum, annually) review existing installations to confirm that they continue to operate safely and consistently with new thinking in BESS safety. This process should be undertaken by the asset owner and O&M team and the options for improving safety considered and evaluated. Implementing some types of new measures may be possible at a low cost but the costs and benefits of each retrofit measure must be weighed carefully on a case by case basis.

Secondly, based on the results of the periodic evaluation process, the implementation of operating changes or retrofit solutions may be undertaken. These will continue to develop and, as of this writing, there are several retrofit solutions available, such as the Intellivent system pioneered by the Pacific Northwest National Laboratory. In essence, the Intellivent system involves installing door controls on the existing BESS enclosure that allow for exterior doors to be remotely opened by operators and emergency personnel from a safe distance away during a possible fire event. Remote door operation provides several advantages:

- Ventilation of harmful or explosive gases without the need for operating a mechanical ventilation system
- Visibility of batteries within the enclosure without needing to approach and place personnel at risk
- Ability to focus hose spray (one of the most effective

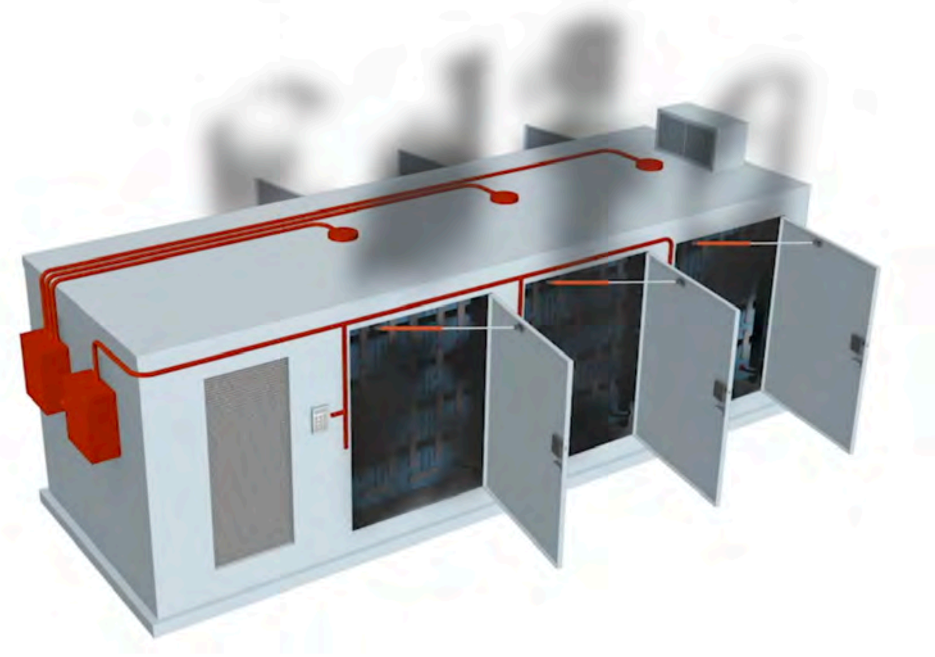


Figure 4-8

Schematic of Intellivent system operating enclosure doors to provide access for emergency personnel and ventilate potentially explosive gases. Image courtesy of Matt Paiss and Pacific Northwest National Laboratory.

firefighting techniques available at present) directly on affected modules from a safe distance.

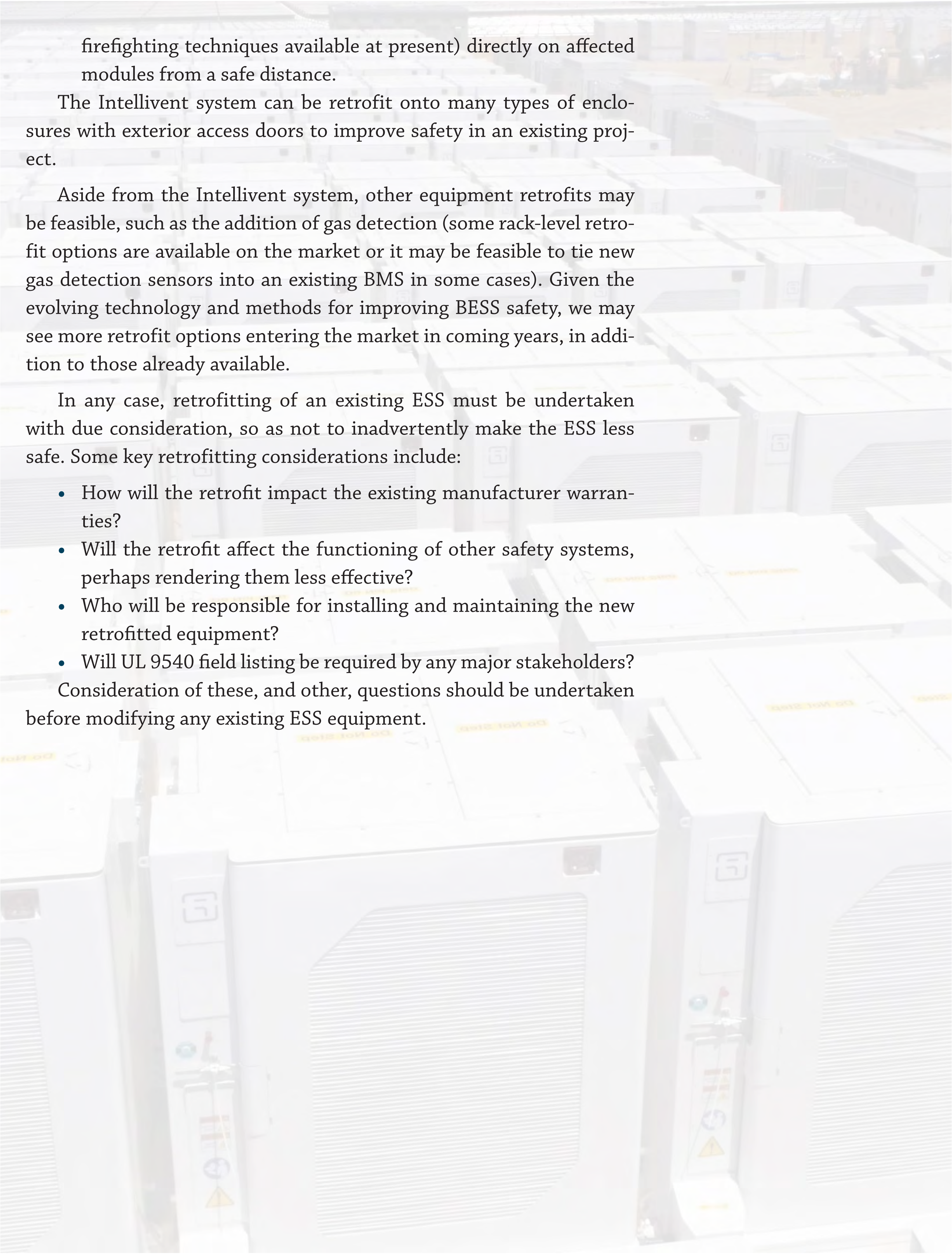
The Intellivent system can be retrofit onto many types of enclosures with exterior access doors to improve safety in an existing project.

Aside from the Intellivent system, other equipment retrofits may be feasible, such as the addition of gas detection (some rack-level retrofit options are available on the market or it may be feasible to tie new gas detection sensors into an existing BMS in some cases). Given the evolving technology and methods for improving BESS safety, we may see more retrofit options entering the market in coming years, in addition to those already available.

In any case, retrofitting of an existing ESS must be undertaken with due consideration, so as not to inadvertently make the ESS less safe. Some key retrofitting considerations include:

- How will the retrofit impact the existing manufacturer warranties?
- Will the retrofit affect the functioning of other safety systems, perhaps rendering them less effective?
- Who will be responsible for installing and maintaining the new retrofitted equipment?
- Will UL 9540 field listing be required by any major stakeholders?

Consideration of these, and other, questions should be undertaken before modifying any existing ESS equipment.



5 Key Standards for ESS Equipment and Installations

As with many pieces of electrical equipment, ESS and their subsystems are subject to a variety of safety standards, some of which may appear to overlap and provide conflicting guidance. While it would be challenging to summarize every standard that applies on a utility-scale ESS project, there are a small handful of key standards that are particularly helpful to understand for those seeking to review, inspect, permit or build ESS of all sorts.

5.1 Brief Review of Applicable Standards

Table 5-1 summarizes many of the current relevant standards that are likely to be seen in documentation from ESS suppliers or that should be referenced in the review of such systems. Note that this summary is not intended to be exhaustive for all potential pieces of equipment that might be found on an ESS installation and excludes important equipment (e.g., transformers, circuit breakers, switches) that are outside the scope of this work. Also excluded are standards with narrow focus or emphasis on ESS technologies that are infrequently seen in modern grid-interactive stationary ESS applications (e.g., lead acid batteries, nickel metal hydride batteries, off-grid applications). It is also important to realize that while these standards are informative and useful, the use of the standard can in no way supersede the legal authority granted by the jurisdiction and its adopted codes.

Table 5-1 *Summary of Relevant ESS-Related Standards*

STANDARD	TITLE	RELEVANCE
NFPA 855 (2020)	Standard for the Installation of Stationary Energy Storage Systems	One of the primary standards to reference for general installation requirements. NFPA 855 discusses a variety of ESS technologies with general and technology-specific guidance on documentation, design and installation requirements for ESS.
NFPA 68 (2018)	Standard on Explosion Protection by Deflagration Venting	Addresses explosion protection by means of directly covering deflagration and includes such devices as deflagration panels and specialized vents.
NFPA 69 (2019)	Explosion Prevention Systems	Addresses explosion control via gas detection and ventilation strategies that prevent buildup of explosive gases.
UL 1741 (2010)	Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use with Distributed Energy Resources	Not specific to ESS but as most ESS include a power conversion system/inverter, this standard is frequently referenced in ESS literature. It broadly governs the listing of inverters, including labeling, documentation and testing requirements.

STANDARD	TITLE	RELEVANCE
UL 1973 (2018)	Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications	More focused on specific applications than the more general UL 1642 and is typically the standard that batteries used in ESS will be listed to.
UL 9540 (2020)	Energy Storage Systems and Equipment	Primary standard used for listing of ESS, as required by most of the major codes (see Chapter 6) and it covers a range of topics, from construction materials to electrical wiring, with a focus on the ESS as a listed product.
UL 9540A (2019)	Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems	One of the most referenced standards for BESS and it outlines the process for testing a cell, module, rack or system to determine its behavior under a thermal runaway condition. Currently in its 4th edition, there is no "pass" or "fail" result for this method, but a properly conducted test to this standard will provide vital information on off-gassing, flame spread, propagation and other design topics.
IEC 62933-1:2018	Electrical Energy Storage (EES) Systems – Part 1: Vocabulary	Provides key terms and nomenclature for ESS/EES, as used in the subsequent International Electrotechnical Commission (IEC) Standards.
IEC 62933-2-1:2017	Electrical Energy Storage (EES) Systems – Part 2-1: Unit Parameters and Testing Methods – General Specifications	Covers a variety of performance tests, such as capacity testing and round-trip efficiency testing procedures and requirements.
IEC 62933-3-1:2018	Electrical Energy Storage (EES) Systems – Part 3-1: Planning and Performance Assessment of Electrical Energy Storage Systems – General Specifications	Addresses many of the important planning aspects of an ESS project, such as system sizing and discussion of use cases. It also addresses requirements for Factory Acceptance Testing and Site Acceptance Testing, which are key steps in the project supply chain and commissioning processes.
IEC 62933-4-1:2017	Electrical Energy Storage (EES) Systems – Part 4-1: Guidance on environmental issues - General specification	Outlines requirements for assessing the environmental impacts, during both normal operation and abnormal conditions, of an ESS. It also includes impacts of the environment on the ESS and evaluation of potential human health impacts.
IEC 62933-5-1:2017	Electrical Energy Storage (EES) Systems – Part 5-1: Safety considerations for grid-integrated EES systems – General specification	Covers broad safety topics applicable to all ESS, including risk analysis, risk reduction, worker training and protection and system testing.
IEC 62933-5-2:2020	Electrical Energy Storage (EES) Systems – Part 5-2: Safety requirements for grid-integrated EES systems –Electrochemical-based systems	Similar to the IEC 62933-5-1 standard, but more specific to batteries and electrochemical-based systems. This standard has overlap with UL 9540, UL 9540A and NFPA 855.
IEC 61427-2:2015	Secondary cells and batteries for renewable energy storage – General requirements and methods of test – Part 2: On-grid applications	Primarily focuses on the performance of secondary batteries under a range of use scenarios, including frequency regulation, load following, peak shaving and PV time shifting applications. It also includes measurement of energy capacity, efficiency, heat generation and an appendix on battery hazards.

STANDARD	TITLE	RELEVANCE
UL 1642 (2020)	Lithium Batteries	Applies to lithium batteries (including li-ion) used in products and includes a variety of tests to confirm that the cell can withstand short circuits, impacts, overcharging, high temperatures and other conditions without fire or explosion. It has some parallels with UL 1973 but is a more general standard that is not specific to stationary/light rail/auxiliary power applications. Note that, unlike UL 1973, listing of an ESS to UL 1642 is not implicit in a system level listing to UL 9540.
IEC 62932-2-1:2020	Flow battery energy systems for stationary applications – Part 1: Terminology and general aspects	Provides general terminology and definitions related to flow batteries, as well as several informative annexes about flow batteries and how they work.
IEC 62932-2-2:2020	Flow battery energy systems for stationary applications – Part 2-2 Safety requirements	Covers a range of safety related topics for flow batteries, including risk assessment methods and electrical, gaseous, liquid and operational hazards. It also includes various testing requirements and recommendations for user manual contents.
IEEE 1679 (2020)	IEEE Recommended Practice for the Characterization and Evaluation of Energy Storage Technologies in Stationary Applications	Provides a recommended framework for evaluating emerging ESS technologies rather than covering a specific product or installation. This may be most useful for consideration of precommercial or demonstration technologies and would likely be less applicable to evaluating already-commercialized ESS.
NFPA 13 (2019)	Standard for the Installation of Sprinkler Systems	A useful reference for evaluating sprinkler system designs for battery rooms or other indoor spaces and this standard should be seen as a supplement to suppression systems included in a listed ESS. This standard is referenced in NFPA 855.
NFPA 15 (2017)	Standard for Water Spray Fixed Systems for Fire Protection	NFPA 855 references this standard for battery storage areas and as an alternative to sprinkler-based suppression systems. NFPA 15 covers design, installation and maintenance requirements of water spray and associated systems.
NFPA 70E (2021)	Standard for Electrical Safety in the Workplace	Covers workplace electrical hazard identification and mitigation measures such as working spaces, exposure distances, arc flash boundary calculations and personal protective equipment requirements.
NFPA 72 (2019)	National Fire Alarm and Signaling Code	Covers the design and installation of fire alarm and signaling (e.g., strobes, horns, klaxons, alerts) systems. This standard is referenced throughout NFPA 855.
NFPA 2001 (2018)	Clean Agent Fire Extinguishing Systems	Governs the design and installation of clean agent suppression systems in many ESS. As discussed previously, these systems are generally not well-suited to address thermal runaway.
UN 38.3	Lithium Metal and Lithium-ion Batteries	Addresses international packaging and shipping requirements. The required tests are similar to those included in UL 1642, with pass criteria indicating no fire, gas venting or explosive behavior as a result of testing.

5.2 Making Sense of ESS Standards

Table 5-1 is not the first, nor likely the last, lengthy list of standards compiled with reference to ESS. The challenge with such summaries is that there are very few people who work outside the day to day world of codes and standards that can effectively use such lists when evaluating ESS projects. Even purchasing copies of all these standards would be an investment of many thousands of dollars (though subscription services to the standards bodies can reduce this cost significantly). The following sections provide some guidance on navigating standards as they relate to ESS.

Hierarchy

One of the things to notice in Table 5-1 is that some standards apply to systems and others apply to components, such as batteries. For example, UL 9540 is a system certification standard that incorporates the requirements of UL 1973, which only applies to batteries. When reviewing ESS equipment for compliance with relevant standards, it may be simpler and easier to verify compliance with the system-level standards. In this example, if you were an ESS manufacturer looking to select a cell to use in your product, then verifying UL 1973 compliance from the cell manufacturer would be important and something to be done before seeking UL 9540 listing for your overall ESS. If, however, your role is to design or approve an ESS project, verifying compliance with subordinate component standards may be less important.

This concept also applies to fire suppression systems in listed ESS. Some authorities or reviewers will seek to review integrated fire suppression systems in listed ESS against more general requirements in, for instance, NFPA 13. This can lead to a situation where a local authority is asking an ESS integrator to modify a listed product to comply with a more general standard. In most cases, this should be avoided, and the more specific standard or code should take precedence over the more general one. In particular, compliance with equipment listings and installation requirements are a key code-compliance item in most of the major building and electrical codes and therefore listed products should not be modified to meet less applicable standards.

Standards for ESS equipment are evolving at a record pace and there may appear to be overlapping standards that could apply to any given ESS project. Typically, it is best to focus on the more recent applicable standards rather than requiring compliance with an older and more general standard. Exceptions can be made if, for example, there are tests or requirements specified in an older standard that do not exist in a more modern standard. In most cases, however, ESS-related standards have become more nuanced and applicable over time, so it is recommended to consider required compliance with older standards carefully and to focus on the most current standards applicable to the project, where possible.

5.3 Most Relevant Standards

With all the preceding information in mind, it is possible to suggest a small handful of standards that are considered most applicable and relevant for the majority of modern ESS applications. This is not to say the other standards are unnecessary, but having a better understanding of the following standards will provide a solid foundation for designing and reviewing most ESS projects.

NFPA 855

This is the most recent (as of this writing) standard focused purely on installation of ESS and it covers a broad range of technologies and key applications such as documentation, ventilation, explosion control, fire suppression, site layout and other design requirements. It incorporates other standards, such as UL 9540, NFPA 68, NFPA 69 and UL 9540A by direct or indirect reference and is generally the first point of reference in evaluating an ESS project.

Note that some financiers, insurers, or other private parties may stipulate NFPA 855 compliance as a condition for receiving financing, insurance coverage, or other commercial consideration. NFPA 855 is not a code in its own right and would need to be incorporated into relevant local codes or regulations to be enforceable.

UL 9540

As with NFPA 855, UL 9540 is an overall system-level standard that includes batteries, racks, modules, BMS, enclosure and subsystems. In this sense, it may cover other, more specific, standards and listing to UL 9540 is a requirement of NFPA 855 and many of the codes discussed in Chapter 6. Manufacturers should be able to demonstrate listing of any proposed ESS to this standard and it is key to confirm that the equipment to be installed matches the equipment to which the listing applies.

UL 9540A

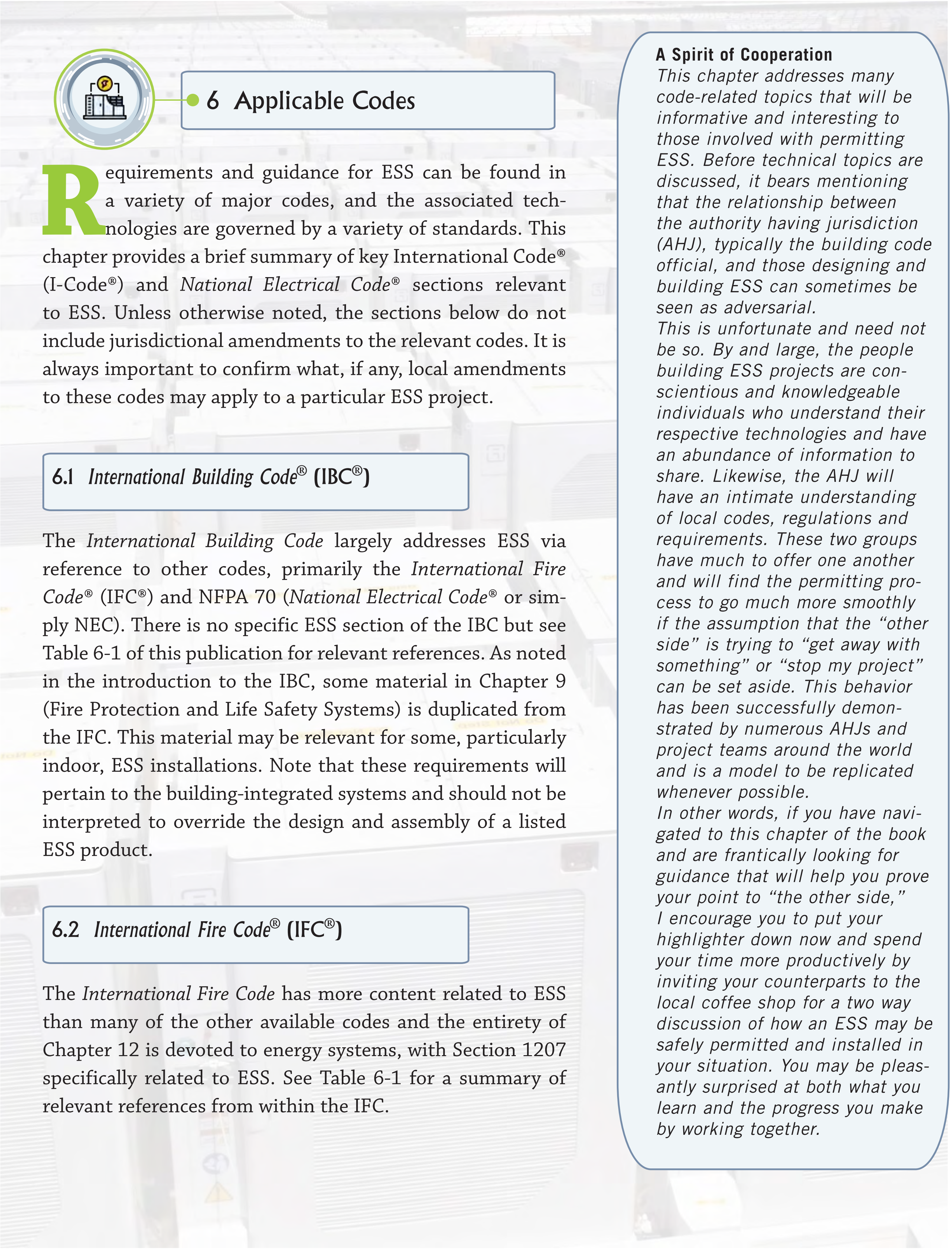
Unlike most of the other standards discussed in this section, UL 9540A is a test standard and specifies a method for large-scale fire testing. As such, it does not have a “pass” or “fail” criteria, except in the sense that certain tests within the standard may have a “fail” result if the testing laboratory, for example, was unable to complete the test. Since large-scale fire testing is a requirement of NFPA 855 (at least in most cases), this is a key standard to pay attention to. It is also one of the more actively revised and frequently updated standards. (UL 9540A is in its 4th edition as of this writing.)

NFPA 68/69

This pair of standards is key to addressing explosion risk in ESS. These standards are referenced in NFPA 855 as design requirements for explosion control (either by prevention or direct control methods) but the specific requirements are not covered in NFPA 855 or UL 9540. A working understanding of these standards is helpful in evaluating the proposed explosion control methods in context with the UL 9540A test report(s) and overall project design.

IEC 62933

For markets outside of the United States, IEC 62933 is likely one of the most relevant standards and it is broken into several major pieces that, together, cover many key aspects of ESS projects. Notably, unlike the UL and NFPA standards previously discussed, IEC 62933 has a significant focus on performance and testing, with specific guidance for round-trip efficiency tests, capacity tests and other means of validating ESS performance. These may not be applicable when reviewing the project from a design and code compliance perspective but are important for the industry overall, as standardizing these types of tests in commercial agreements is a developing process and adherence to IEC 62933 is one possibility for driving such standardization. The published IEC 62933 parts are shown in Table 5.1 and there are additional parts under development by IEC’s technical committees



6 Applicable Codes

Requirements and guidance for ESS can be found in a variety of major codes, and the associated technologies are governed by a variety of standards. This chapter provides a brief summary of key International Code® (I-Code®) and *National Electrical Code*® sections relevant to ESS. Unless otherwise noted, the sections below do not include jurisdictional amendments to the relevant codes. It is always important to confirm what, if any, local amendments to these codes may apply to a particular ESS project.

6.1 *International Building Code*® (IBC®)

The *International Building Code* largely addresses ESS via reference to other codes, primarily the *International Fire Code*® (IFC®) and NFPA 70 (*National Electrical Code*® or simply NEC). There is no specific ESS section of the IBC but see Table 6-1 of this publication for relevant references. As noted in the introduction to the IBC, some material in Chapter 9 (Fire Protection and Life Safety Systems) is duplicated from the IFC. This material may be relevant for some, particularly indoor, ESS installations. Note that these requirements will pertain to the building-integrated systems and should not be interpreted to override the design and assembly of a listed ESS product.

6.2 *International Fire Code*® (IFC®)

The *International Fire Code* has more content related to ESS than many of the other available codes and the entirety of Chapter 12 is devoted to energy systems, with Section 1207 specifically related to ESS. See Table 6-1 for a summary of relevant references from within the IFC.

A Spirit of Cooperation

This chapter addresses many code-related topics that will be informative and interesting to those involved with permitting ESS. Before technical topics are discussed, it bears mentioning that the relationship between the authority having jurisdiction (AHJ), typically the building code official, and those designing and building ESS can sometimes be seen as adversarial.

This is unfortunate and need not be so. By and large, the people building ESS projects are conscientious and knowledgeable individuals who understand their respective technologies and have an abundance of information to share. Likewise, the AHJ will have an intimate understanding of local codes, regulations and requirements. These two groups have much to offer one another and will find the permitting process to go much more smoothly if the assumption that the "other side" is trying to "get away with something" or "stop my project" can be set aside. This behavior has been successfully demonstrated by numerous AHJs and project teams around the world and is a model to be replicated whenever possible.

In other words, if you have navigated to this chapter of the book and are frantically looking for guidance that will help you prove your point to "the other side," I encourage you to put your highlighter down now and spend your time more productively by inviting your counterparts to the local coffee shop for a two way discussion of how an ESS may be safely permitted and installed in your situation. You may be pleasantly surprised at both what you learn and the progress you make by working together.

6.3 *International Residential Code®* (IRC®)

The *International Residential Code* provides requirements for ESS installation in Section R328 and includes references to the NEC and IFC Section 1207 and has significant commonality with Chapter 15 of the NFPA 855 Standard. Section R328 excludes ESS listed to UL 9540, marked for "use in residential dwelling units" and installed in accordance with the NEC. However, Section R328.2 also requires that ESS be "listed and labeled in accordance with UL 9540" and Section R328.6 further requires that "ESS shall be installed in accordance with NFPA 70." This leaves a relatively narrow gap between ESS excluded from this section and those that comply with its requirements, largely down to whether the properly listed and installed ESS is specifically marked for use in residential dwelling units.

This set of definitions enforces the general approach taken among code making authorities that ESS are required to be listed as a system. This approach generally precludes field-assembled ESS, even those constructed using individually listed components (e.g., charge controllers, inverters). Should such a system's owner seek permitting, Section R328 would require field listing to UL 9540, which is generally considered to be cost-prohibitive for small residential applications.

Note that Section R328 of the IRC includes requirements for a variety of installation locations but specifically precludes installation of ESS in sleeping rooms or closets and spaces that open directly into sleeping rooms.

6.4 *National Electrical Code®* (NEC®)

The NEC (also known as NFPA 70) governs electrical installations and is widely adopted, sometimes within local amendments, in most states and jurisdictions. Though the NEC has many applicable principles and may inform the design of ESS, the NEC may not translate directly into understandable requirements for installations outside of the United States.

Within the NEC, energy storage is specifically covered in Article 706, with key requirements and section references of the 2020 NEC noted in Table 6-1 of this publication. Where ESS is co-located with solar photovoltaics (PV), there are subsections pertaining to ESS under Articles 690 and 691 that must be referenced. Key articles relevant to evaluating ESS installations include:

- Article 110: Requirements for Electrical Installations
- Article 230: Services
- Article 240: Overcurrent Protection
- Article 250: Grounding and Bonding
- Article 300: General Requirements for Wiring Methods and Materials
- Article 310: Conductors for General Wiring
- Article 690: Solar Photovoltaic (PV) Systems
- Article 691 : Large-Scale Photovoltaic (PV) Electric Supply Stations
- Article 705: Interconnected Electric Power Production Sources
- Article 706: Energy Storage Systems

This list is not exhaustive and the entirety of the NEC should be followed. In particular, outdoor wiring methods, signage materials and compliance with product listings are of special importance and are sometimes overlooked due to the novelty of BESS installations. The NEC also has special sections on microgrids (Article 712) and Critical Operations Power Systems (Article 708) but these only apply to ESS under special circumstances and have been omitted from the above list to avoid confusion.

One other lingering point of confusion relates to the (apparent) relationship between Article 706 (Energy Storage Systems) and Article 480 (Storage Batteries). At first glance, these two articles might appear to overlap or conflict with one another but the key distinction is that Article 706 is related to energy storage systems, which is to say a system that is listed to UL 9540. That system may or may not include batteries as a component but the purpose of Article 706 is to address those listed systems (just as other articles might address a PV inverter as a listed product but not address the components inside the listed inverter separately). As such, Article 480 should not be interpreted as applying to an ESS installation, even if that installation uses batteries as part of the ESS. In general, Article 480 is applied to facilities like remote telecommunications facilities that may have lead-acid batteries for backup power, not to grid-interactive ESS as discussed in this work and in Article 706 of the NEC.

Table 6-1 *Summary of Relevant Code Sections/Articles by Design Requirement for Li-ion BESS*

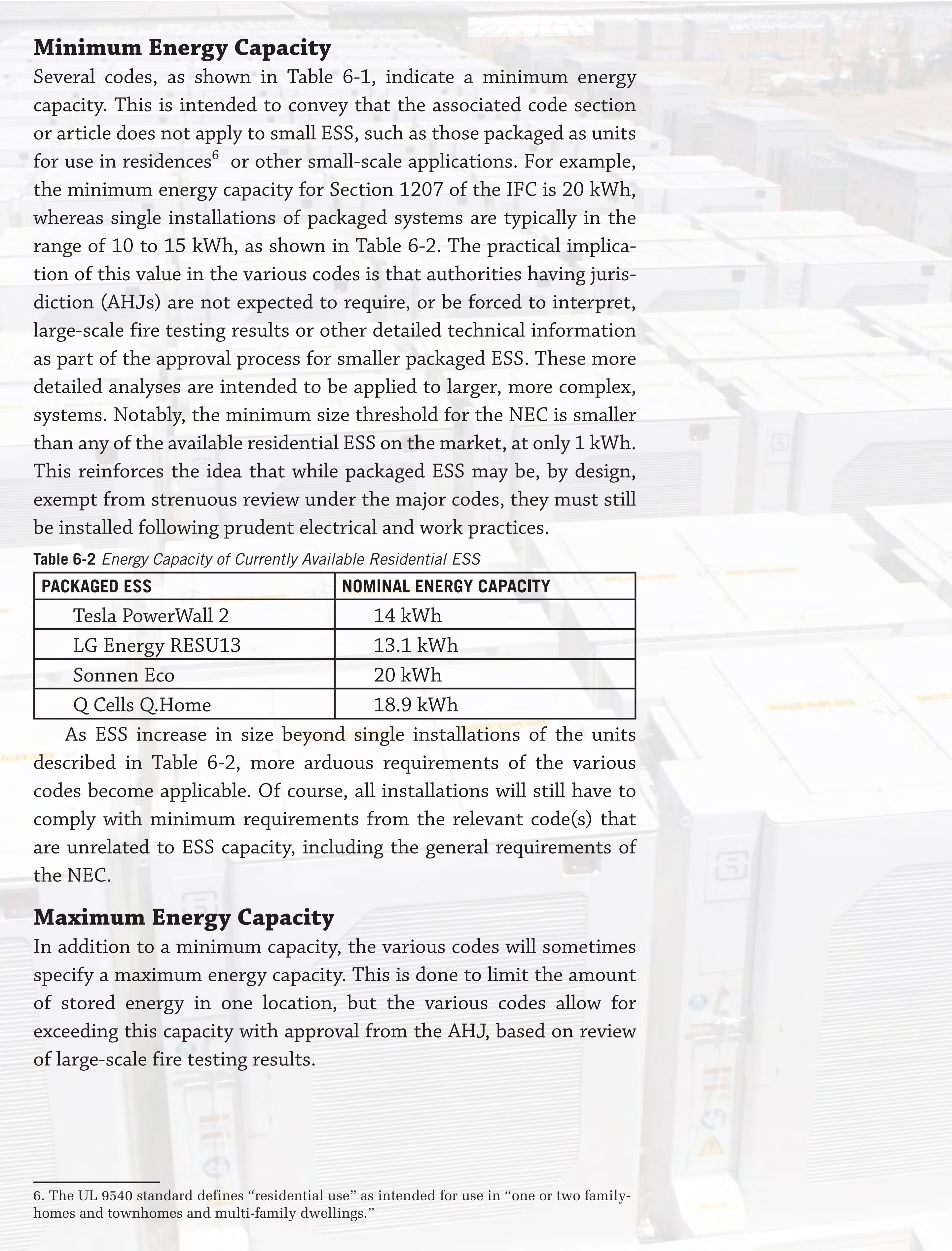
Design Requirement	International Fire Code (IFC)	International Residential Code (IRC)	International Building Code (IBC)	National Electrical Code (NEC)
Minimum Capacity	20 kWh	1 kWh	—	1 kWh
Maximum Capacity (nonresidential)	600 kWh	—	—	—
Maximum Capacity (residential)	40 kWh within utility closest, basements, and storage or utility spaces 80 kWh in garages, accessory structures, on exterior walls, or outdoors on the ground		—	—
Key Code Sections				
Product Listing and Testing	1207.1.5 1207.3.1	R328.2	—	706.5
Labeling, Signage and Marking	1207.4.8	R328.11	—	705.10 705.12 706.4 706.15(C) 706.21
Explosion Control	1207.6.1 1207.6.3	R328.9	Reference to IFC 1207	706.20
Fire Detection	1207.5.4	R328.7 R314	907.2.23	—
Fire Suppression	1207.5.5	—	—	—
Spacing and Installation Requirements	1207.4 1205.1–5.3 1207.5.6–5.8 1207.7 1207.8 1207.9 1207.11	R328.3.1 R328.4 R328.6	1010.2.9.2	706.20(C)
Documentation Required	1207.1.3 1207.1.4 1207.2.1.2	R328.11	—	—
Disconnects	1207.4.1	—	—	705.20 706.15 706.16

Note: Please reference the full editions of the I-Codes and NEC for relevant specific language and requirements.

6.5 Common Principles in Energy Storage Related Codes

The various codes include a number of cross-cutting concepts that are important to understand and will be described more fully in this section. Four of the most prominent are:

- Minimum Energy Capacity
- Maximum Energy Capacity
- Product Listing
- Large-scale Fire Testing



Minimum Energy Capacity

Several codes, as shown in Table 6-1, indicate a minimum energy capacity. This is intended to convey that the associated code section or article does not apply to small ESS, such as those packaged as units for use in residences[6] or other small-scale applications. For example, the minimum energy capacity for Section 1207 of the IFC is 20 kWh, whereas single installations of packaged systems are typically in the range of 10 to 15 kWh, as shown in Table 6-2. The practical implication of this value in the various codes is that authorities having jurisdiction (AHJs) are not expected to require, or be forced to interpret, large-scale fire testing results or other detailed technical information as part of the approval process for smaller packaged ESS. These more detailed analyses are intended to be applied to larger, more complex, systems. Notably, the minimum size threshold for the NEC is smaller than any of the available residential ESS on the market, at only 1 kWh. This reinforces the idea that while packaged ESS may be, by design, exempt from strenuous review under the major codes, they must still be installed following prudent electrical and work practices.

Table 6-2 *Energy Capacity of Currently Available Residential ESS*

PACKAGED ESS	NOMINAL ENERGY CAPACITY
Tesla PowerWall 2	14 kWh
LG Energy RESU13	13.1 kWh
Sonnen Eco	20 kWh
Q Cells Q.Home	18.9 kWh

As ESS increase in size beyond single installations of the units described in Table 6-2, more arduous requirements of the various codes become applicable. Of course, all installations will still have to comply with minimum requirements from the relevant code(s) that are unrelated to ESS capacity, including the general requirements of the NEC.

Maximum Energy Capacity

In addition to a minimum capacity, the various codes will sometimes specify a maximum energy capacity. This is done to limit the amount of stored energy in one location, but the various codes allow for exceeding this capacity with approval from the AHJ, based on review of large-scale fire testing results.

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[6] The UL 9540 standard defines “residential use” as intended for use in “one or two family-homes and townhomes and multi-family dwellings.”

Large-Scale Fire Testing

Many of the codes include a requirement for large-scale fire testing. Depending on the code, this may be required as a condition for determining equipment spacing, fire suppression requirements or approval of other system design characteristics.

In general, large-scale fire testing can be considered synonymous with testing to the UL 9540A standard. As a reminder, there is currently no “pass” criteria for the UL 9540A testing standard, which requires that designers, permitting agencies, and others must interpret the results in order to evaluate code compliance.

Labeling, Signage and Marking

One of the most confusing elements of designing an ESS installation can be finding and aligning the various code requirements related to labeling and signage. This issue has plagued the PV industry for many years. At various times, well-meaning attempts to comply with poorly conceived labeling requirements have led to numerous (sometimes conflicting or confusing) labels being applied to all the components of a PV system. Luckily, much work has been done in the relevant codes and standards to simplify and avoid this confusion and the labeling requirements now in place for ESS have benefited indirectly from these efforts.

7 Reviewing and Inspecting Energy Storage Systems

Performing plan reviews and field inspections of ESS will require knowledge of many of the topics discussed previously, as well as a good understanding of "what to look for." In addition to the topics discussed in the following sections, there are a variety of printable checklists included in Chapter 8 to facilitate a thorough and consistent review of ESS projects.

The majority of this chapter is intended to apply to larger commercial or utility-scale BESS projects. Nonbattery ESS are difficult to generalize, as hazards can range from hazardous fluids to large machinery in motion, depending on the technology. In all cases, a thorough safety briefing is strongly recommended before going onsite for any type of inspection. Residential packaged ESS are excluded from most discussions because their inspections are easier to generalize. Residential packaged ESS are designed (and listed) for residential environments and likely have few field-installation connections to be made. As such, their inspection can be straightforward and akin to inspecting many other common residential electrical installations.

Preparing for an Inspection

Inspecting ESS is similar to performing a visual inspection of other utility infrastructure and the level of detail can vary considerably from one inspection to another. Fortunately, most ESS have sophisticated onboard sensors and interfaces that largely obviate the need for handheld test equipment for many inspection functions. Nevertheless, an inspector will want to consider being well-prepared before going onsite, especially if less familiar with the type of ESS being reviewed. The inspector should follow these best practices before going onsite:

- Be familiar with potential hazards relevant to the type of ESS being inspected
- Procure and be prepared to use the appropriate personal protection equipment
- Review and print out/download relevant technical documents
- Understand what aspects of the ESS need to be reviewed
- Prepare an inspection checklist (such as the one provided in Chapter 8 of this Guide)

These topics are discussed in the following sections.

Hazards and Safety Considerations

As with any inspection, there are a variety of safety considerations for the inspector. Utility-scale ESS should be viewed as utility infrastructure and be treated with all due caution and respect. Even fairly small utility-scale or commercial installations will have lethal voltage levels present on some equipment, as well as potential hazards related more specifically to the type of ESS (e.g., rotating machinery for flywheels, high heat for thermal storage or certain types of fuel cells, moving parts for gravity-based storage systems).

With respect to modern BESS employing lithium-ion batteries, which are the most common type likely to be encountered in the current market, the inspector should have a working understanding of the relevant alarms and their meaning before entering any walk-in enclosures or other areas with restricted access. The likelihood of a significant safety event (e.g., thermal runaway) occurring during an inspection is exceedingly remote but understanding how the major safety systems function should be covered during a pre-inspection safety briefing with the project owner.

In the case of residential or packaged ESS, there may be very little that can be directly observed during an inspection. The inspector should not generally be inspecting factory-installed components internal to the ESS, so visual access is likely only needed to wiring panels and field-installed components and enclosures, such as disconnects, junction boxes, raceways or similar devices. In these cases, hazards will be similar to those seen when inspecting these same components on any other electrical system in a residential setting and awareness of general residential electrical safety is required.

Personal Protection Equipment (PPE): It is possible to perform a visual inspection of a typical ESS with only general worksite PPE, such as:

- High visibility vest or clothing
- Safety glasses/eye protection
- Hard hat
- Safety shoes
- Weather appropriate clothing

In all cases, relevant codes, standards and worksite practices must be followed and it is always prudent to speak with the relevant project owner and construction personnel before going onsite to confirm any specific requirements.

Key Documents: There are many documents generated as part of a typical utility-scale ESS project and several are particularly relevant for making the most of an onsite inspection. Before going onsite, the inspector should be generally familiar with the project and the technology being employed. In addition, the following documents are likely to be particularly useful or relevant and should be reviewed and brought onsite for reference:

- Emergency Operations Plan (these are typically designed to provide a quick overview of the system and can be used to get a quick idea of what equipment is onsite and where key elements may be found)
- Single Line Diagram
- Site Plan
- Operations Manual (primarily for reference, as this will contain more detailed information needed to operate parts of the ESS)
- Site Acceptance Test results, if completed

A checklist of key documents that should be submitted as part of an ESS project is included in Chapter 8, for reference.

Tools and Equipment: When inspecting an ESS, the tools required will be minimal as the contractor and BMS should be able to provide the majority of measurements needed. For a visual inspection, the inspector should consider bringing these items:

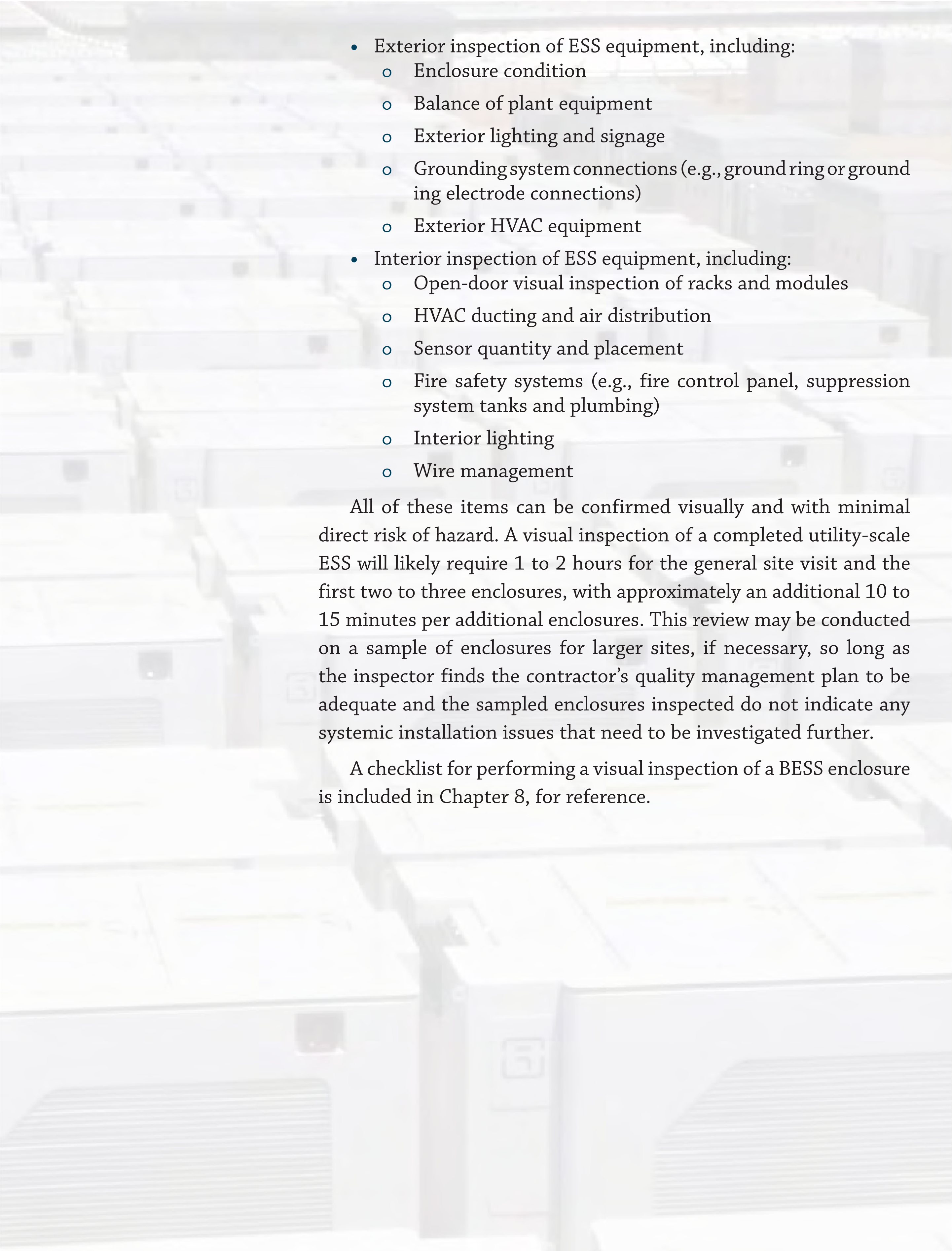
- Digital camera or smart phone for taking photos
- Measuring tape for checking the spacing of equipment
- Flashlight to illuminate poorly lit areas of an enclosure

Depending on what equipment is being inspected, the inspector may wish to request that the owner or their representative remove panelboard covers or make other equipment accessible for visual inspection. However, it is not recommended to require opening of factory-assembled components unless there is a compelling reason to do so.

What to Inspect in Utility-Scale ESS

Inspection of a utility-scale ESS will generally involve the following activities:

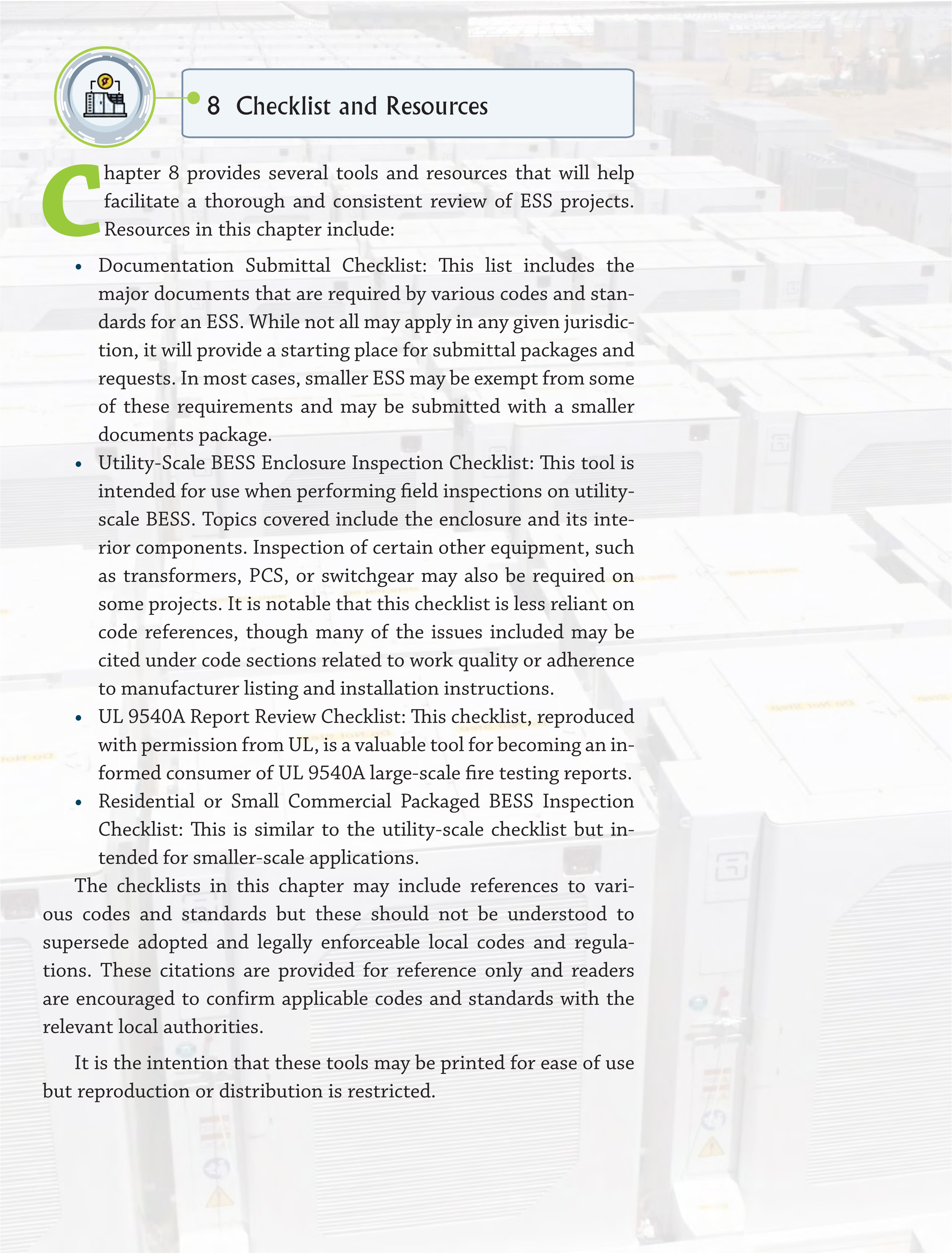
- “Tailgate” safety meeting prior to entering site to review relevant hazards and safety practices
- Review of onsite documentation, such as Quality Assurance and Safety Logs
- General walk down of the site, reviewing aspects such as:
    - Overall site layout
    - Equipment spacing and clearances
    - Condition of civil works (e.g., roads, grading, ground finishing)
    - Fencing and security systems



- Exterior inspection of ESS equipment, including:
    - Enclosure condition
    - Balance of plant equipment
    - Exterior lighting and signage
    - Grounding system connections (e.g., ground ring or grounding electrode connections)
    - Exterior HVAC equipment
- Interior inspection of ESS equipment, including:
    - Open-door visual inspection of racks and modules
    - HVAC ducting and air distribution
    - Sensor quantity and placement
    - Fire safety systems (e.g., fire control panel, suppression system tanks and plumbing)
    - Interior lighting
    - Wire management

All of these items can be confirmed visually and with minimal direct risk of hazard. A visual inspection of a completed utility-scale ESS will likely require 1 to 2 hours for the general site visit and the first two to three enclosures, with approximately an additional 10 to 15 minutes per additional enclosures. This review may be conducted on a sample of enclosures for larger sites, if necessary, so long as the inspector finds the contractor's quality management plan to be adequate and the sampled enclosures inspected do not indicate any systemic installation issues that need to be investigated further.

A checklist for performing a visual inspection of a BESS enclosure is included in Chapter 8, for reference.



8 Checklist and Resources

Chapter 8 provides several tools and resources that will help facilitate a thorough and consistent review of ESS projects. Resources in this chapter include:

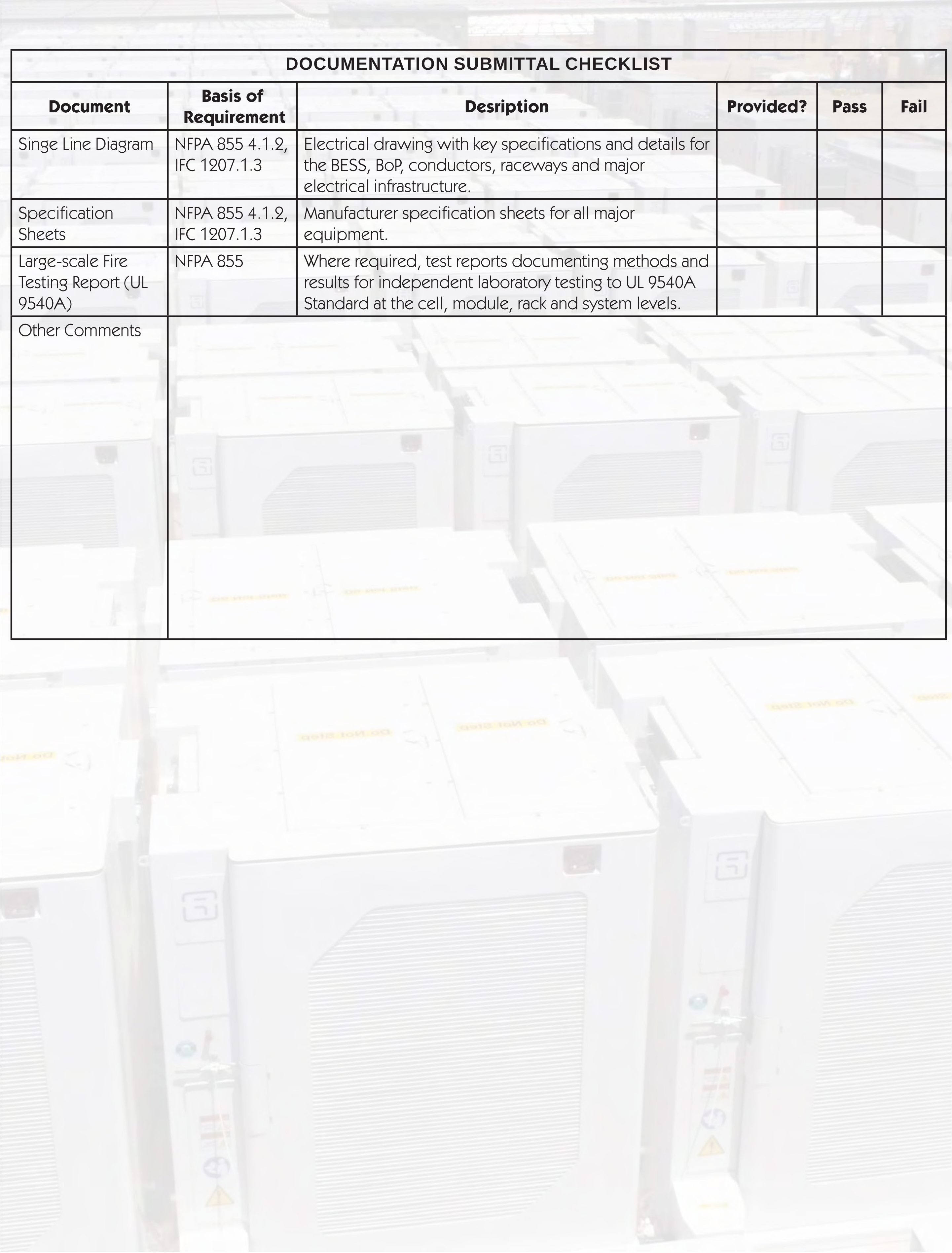
- Documentation Submittal Checklist: This list includes the major documents that are required by various codes and standards for an ESS. While not all may apply in any given jurisdiction, it will provide a starting place for submittal packages and requests. In most cases, smaller ESS may be exempt from some of these requirements and may be submitted with a smaller documents package.
- Utility-Scale BESS Enclosure Inspection Checklist: This tool is intended for use when performing field inspections on utility-scale BESS. Topics covered include the enclosure and its interior components. Inspection of certain other equipment, such as transformers, PCS, or switchgear may also be required on some projects. It is notable that this checklist is less reliant on code references, though many of the issues included may be cited under code sections related to work quality or adherence to manufacturer listing and installation instructions.
- UL 9540A Report Review Checklist: This checklist, reproduced with permission from UL, is a valuable tool for becoming an informed consumer of UL 9540A large-scale fire testing reports.
- Residential or Small Commercial Packaged BESS Inspection Checklist: This is similar to the utility-scale checklist but intended for smaller-scale applications.

The checklists in this chapter may include references to various codes and standards but these should not be understood to supersede adopted and legally enforceable local codes and regulations. These citations are provided for reference only and readers are encouraged to confirm applicable codes and standards with the relevant local authorities.

It is the intention that these tools may be printed for ease of use but reproduction or distribution is restricted.

DOCUMENTATION SUBMITTAL CHECKLIST

Document	Basis of Requirement	Desription	Provided?	Pass	Fail
Commissioning Plan	IFC 1207.1.3	Document detailing planned commissioning process, including narrative description, equipment to be tested, training for relevant personnel, and other details noted in IFC 1207.2.1.			
Commissioning Report	IFC 1207.2.1.2	Report detailing the results of testing per the commissioning plan.			
Decommissioning Instructions/Plan	IRC R328.11, NFPA 855 8.1, IFC 1207.1.3	Completed at permitting stage, document outlining decommissioning process, special equipment, hazards, disposal/recycling plans, and similar information regarding the planned decommissioning process.			
Decommissioning Report	NFPA 855 8.3	Post-decommissioning report provided by the owner documenting the completion of decommissioning process.			
Emergency Operations Plan	NFPA 855 4.1.3.2.1	Plan providing key ESS information and procedures for understanding and responding to emergency scenarios. Plan should be reviewed and approved by relevant local authorities and emergency responders.			
Energy Management System (EMS) Summary	NFPA 855 4.1.2, IFC 1207.1.3	Description of EMS hardware and software functions, including major communication modes, alarms, operating strategy, use case and other details.			
Fire and Explosion Control Summary	NFPA 855 4.1.2, IFC 1207.1.3	Documentation of fire safety and explosion control systems, including relevant manufacturer specifications, design calculations, ventilation information, thermal management information and other relevant details.			
Hazard Mitigation Analysis	NFPA 855 4.1.4, IFC 1207.1.4	Optional document addressing ESS response to potential hazard conditions (e.g., thermal runaway, failure of BMS, failure of EMS) and required in order to exceed system sizing limits.			
Installation Manual	IRC R328.11	Manufacturer installation instructions for ESS and major Balance of Plant (BoP) equipment.			
Large-scale Fire Testing Report	NFPA 855 4.1.2.1.3	Test report compliant with UL 9540A requirements for cell, module, rack and system level (where required).			
Layout Drawing	NFPA 855 4.1.2, IFC 1207.1.3	Location of BESS and associated BoP equipment, including relevant distances, clearances, working spaces, roadways, access areas and similar items of interest.			
Operations Manual	NFPA 855 4.1.2.3, IRC R328.11, IFC 1207.2.2	ESS specifications, equipment details, contact information, operating narrative and manufacturer documentation.			
Operations Record	NFPA 855 7.1.3	Written record of onsite O&M activities, generally in the form of a log (can be electronic).			
Safety Data Sheets	NFPA 855 7.1.3	Safety data sheets for any hazardous materials must be supplied and stored onsite in a readily accessible place.			
Signage Summary	NFPA 855 4.1.2, IFC 1207.1.3	List or mockup of required labels, indicating values to be displayed, signage materials and signage locations.			

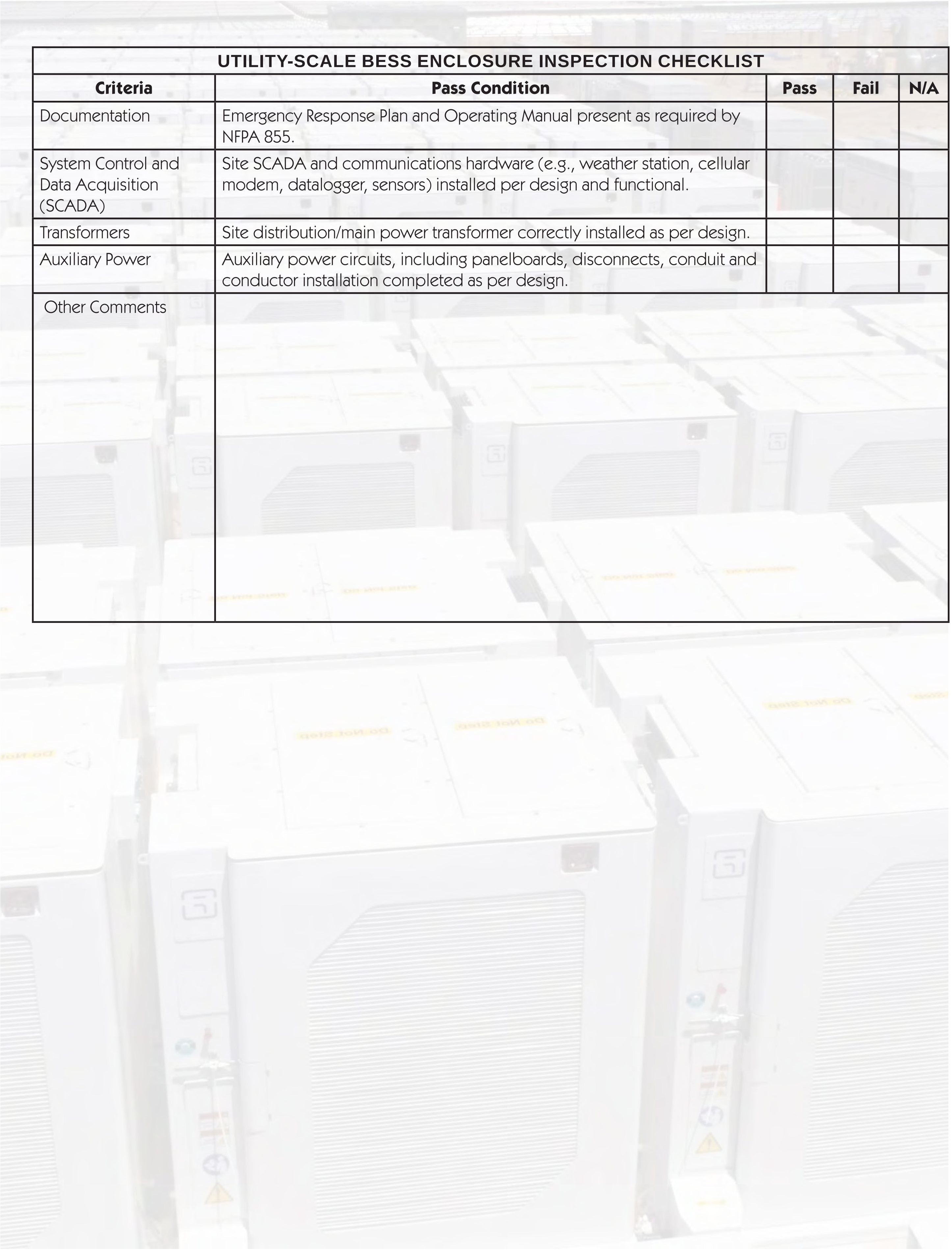


DOCUMENTATION SUBMITTAL CHECKLIST

Document	Basis of Requirement	Desription	Provided?	Pass	Fail
Singe Line Diagram	NFPA 855 4.1.2, IFC 1207.1.3	Electrical drawing with key specifications and details for the BESS, BoP, conductors, raceways and major electrical infrastructure.			
Specification Sheets	NFPA 855 4.1.2, IFC 1207.1.3	Manufacturer specification sheets for all major equipment.			
Large-scale Fire Testing Report (UL 9540A)	NFPA 855	Where required, test reports documenting methods and results for independent laboratory testing to UL 9540A Standard at the cell, module, rack and system levels.			
Other Comments					

UTILITY-SCALE BESS ENCLOSURE INSPECTION CHECKLIST

Criteria	Pass Condition	Pass	Fail	N/A
Site Fencing	Exterior fence installed, in good condition, and bearing relevant signage.			
Exterior Condition	Good visible condition, no nicks, dents, rust or other damage.			
Footings	Enclosure footings properly secured, installed and match design.			
Doors	All doors and hardware operate and are in good condition.			
Clearances	Space between enclosures and other equipment is per design and allows sufficient room for service and emergency access.			
Exterior Lights	Exterior lighting operable based on manual switch and/or motion sensor as per design.			
Exterior Alarms	Exterior horns and strobes functional as per design and can be manually activated/deactivated.			
E-Stop Installation	Emergency stop button correctly located/labeled and readily accessible.			
E-Stop Function	Confirm that E-Stop disconnects enclosure(s) from AC circuits as per design and Emergency Response Plan.			
Exterior HVAC	HVAC units correctly installed and make/model information match design.			
Interior Lights	Interior lighting operable and controlled correctly by relevant switches or other controls, as per design.			
Interior Alarms	Interior strobes and horns functional as per design and can be manually activated/deactivated.			
Interior HVAC	Interior grills, ducts, fans and other equipment correctly installed and match design.			
Rack Installation	Battery racks installed with correct spacing, secured in place and in good condition as per design.			
Module Installation	Battery modules correctly installed and match make/model information in design.			
DC Wiring	DC busbar and connections completed as per design and manufacturer requirements.			
DC Disconnect	DC disconnect present and properly rated as per design and manufacturer requirements.			
AC Wiring	AC panelboards and busbars correctly installed, and all terminations are per design and manufacturer requirements.			
BMS	Battery controllers/management systems correctly installed per design.			
HMI	HMI interfaces accessible and functional, as per design and manufacturer requirements.			
Fire Panel	Fire control panel correctly marked on enclosure exterior and installed per design and relevant local requirements.			
Gas Detectors	Gas detection system installed as per design			
Smoke Detectors	Smoke detection system installed as per design			
Fire Detectors	Fire detection system installed as per design.			
Fire Suppression	Fire suppression system, including all tanks, piping, pumps and other hardware installed as per design and UL 9540 listing.			
Explosion Control	Explosion control system (e.g., deflagration panels, vents, sparker systems) present and installed per design (where required) and NFPA 68.			
Explosion Prevention	Explosion prevention system (e.g., gas detection and ventilation) present and installed as per design (where required) and NFPA 69.			



UTILITY-SCALE BESS ENCLOSURE INSPECTION CHECKLIST

Criteria	Pass Condition	Pass	Fail	N/A
Documentation	Emergency Response Plan and Operating Manual present as required by NFPA 855.			
System Control and Data Acquisition (SCADA)	Site SCADA and communications hardware (e.g., weather station, cellular modem, datalogger, sensors) installed per design and functional.			
Transformers	Site distribution/main power transformer correctly installed as per design.			
Auxiliary Power	Auxiliary power circuits, including panelboards, disconnects, conduit and conductor installation completed as per design.			
Other Comments				

UL 9540A 4TH EDITION UNIT LEVEL REPORT CHECKLIST

Laboratory Checks:		**Yes**	**No**
1.	The lab is ISO 17025 accredited. This should include accreditation for both battery testing (e.g. UL 1973, Batteries for use in stationary, vehicle auxiliary power and light electric rail (LER) applications) and fire protection testing (e.g. ASTM E1354, Standard test method for heat and visible smoke release rates for materials and products using an oxygen consumption calorimeter; ASTM E662, Standard test method for specific optical density of smoke generated by solid materials)		
2.	The unit construction details and specifications were provided.		
3.	The number of cells and location of cells failed at the unit level was the same as what was used at the module level.		
4..	The thermal runaway method used to initiate propagation was the same as the method used at the cell level and module level tests.		
5.	Mitigation devices that are not part of the module/system construction were not introduced during the test to impact the outcome (Example: external barriers introduced around the external heater on the cell)		
6.	Critical information on any fire mitigation means employed in the system was provided and is consistant with the intended installation.		
7.	Testing was done at an indoor facility unless the ESS was intended for outdoor installations only.		

Test Setup:		**Yes**	**No**
1.	A summary of the critical data from the cell test is provided (vent temperature, thermal runaway temperature, and gas data is available as noted under gas measurements below.)		
2.	A summary of the critical data from the module test is provided (thermal runaway temperature, propagation occurance, peak heat release rate, convective heat release rate, peak smoke release rate, gas data)		
3.	Test walls and test rooms were built using 5/8 inch drywall and painted flat black expect for outdoor ground mounted residential applications or outdoor wall mounted residential applications which need to be tested with 3/4 inch plywood.		
4.	The test layout matched the intended installation layout with regard to separation distances from walls and other units.		
5.	The system was at maximum operating state of charge, which was checked prior to initiation of the test.		

Test Method:		**Yes**	**No**
1.	Test outcome did not rely upon operation of integral electrical devices such as the BMS, fans, or coolant pumps.		
2.	The test did not rely upon devices introduced into the module that are not part of the module design, to limit the effects of the heaters during the test.		
3.	Temperatures were measured on walls and did not exceed 97°C of temperature rise above ambient		
4.	Heat flux was measured in the center of the planned egress path and did not exceed 1.3 kW/m^2		
5.	Temperatures measured on target units did not exceed the onset of cell venting temperature measured during the cell test.		
6.	Heat flux measured on walls and target units were measured and recorded.		
7.	The report indicated whether there was evidence of explosions or flying debris during the test or reignitions after the test.		

8.	For residential systems, except for the outdoor ground mounted installations, the report noted whether the cheesecloth indicator was charred as a result of flame during testing.		
9.	The report indicated whether or not the performance critieria of the unit level test were met.		

Gas Measurements:		**Yes**	**No**
1.	The total hydrocarbon (THC) gas volume was measured and recorded for both the pre-flaming period and after the startof flaming during the test using flame ionization detection (FID).		
2.	The total volume of carbon monoxide (CO) and carbon dioxide (CO2) gases were measured using non-dispersive infrared spectroscopy (NDIR) and recorded for both the pre-flaming and after the initiation of flaming during the test.		
3.	The volume of hydrogen (H2) was measured using a solid state hydrogen sensor during the pre-flaming period and after initiation of flaming during the test.		
4.	The critical properties from the cell level test was provided on the cell vent gas: lower flammability limit (LFL), burning velocity (Su) and maximum deflagration pressure (Pmax). This data is necessary for evaluating the suitability of explosion mitigation means.		
5.	Smoke release rate measured with a white light source and photo detector for the duration of the test was provided.		

Supporting Documentation:		**Yes**	**No**
1.	Profiles showing the temperatures of initiating cells and nearby cells within the initiating module, modules in the initiating unit are provided.		
2.	Profiles showing that temperatures on target units do not exceed the cell vent temperature are provided.		
3.	Profiles showing the heat flux measurements are provided showing that they do not exceed 1.3 kW/m^2 at the egress path for non-residential applications and outdoor ground mounted residential applications.		
4.	Profile showing the heat release rate (Chemical & Convective heat release rate) versus time data for non-residential applications was provided.		
5.	The report provided photos taken during the test to show the progress of the initiating thermal runaway as well as diagrams and photos to show the test layout.		

UL Resources:

Access additional information online at the below links:
- UL 9540A test method: https://www.ul.com/offerings/ul-9540a-test-method
- Energy Storage testing and certification: https://ul.com/offerings/energy-storage-system-testing-and-certification
- UL Field Evaluations (FE): https://www.ul.com/offerings/field-evaluations
- Code authority resources: https://code-authorities.ul.com/about/technical-resources/application-guides

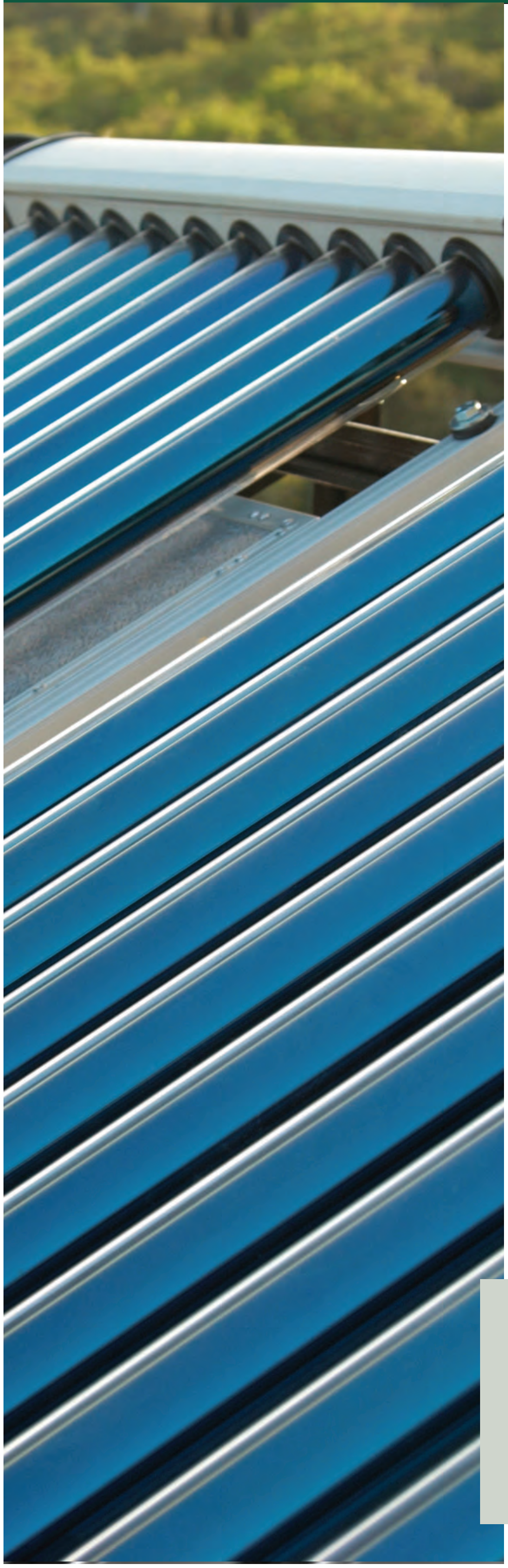
Empowering Trust®

RESIDENTIAL OR SMALL COMMERCIAL PACKAGED BESS INSPECTION CHECKLIST

Criteria	Pass Condition	Pass	Fail	N/A
Thermal Management	ESS unit has unobstructed airflow to fans, cooling vents or similar components as required by manufacturer instructions.			
Conductor Ratings	All exterior conductors, including those in conduit, raceway or enclosures, are sufficiently rated for application and use in wet environments.			
Overcurrent Protection	Backfeed breakers (load side connections) or fused disconnect (supply side connection) are properly rated for ESS output current.			
Clearances	Area around the ESS is clear and complies with relevant working spaces requirements. See NEC 110.26 in pass condition box.			
Disconnects	Disconnects present and installed as required in NEC 706.15, NEC 706.16, NEC 705.20 and IFC 1207.4.1.			
Labeling	Labeling on ESS is present, sufficient for local environment, and complies with NEC 110.16, 110.21, 110.22, 110.24, 705.10, IRC R328.11, IFC 1207.4.8 and other relevant requirements.			
Operating Status	ESS unit is capable of normal operation and has no visible faults, alarms or error notifications.			
Capacity	ESS units are individually less than 20 kWh and in total are less than 40 kWh (utility spaces/basements/storage areas) or 80 kWh (other residential areas).			
Location	ESS is not installed in a sleeping area or an area that directly opens into a sleeping area. Mechanical protection included where needed.			
Listing	ESS is listed to UL 9540, as required by IRC R328.2.			
Fire Detection	Area housing ESS, if required, has smoke detection equipment in compliance with IRC R328.7.			
General Installation	Installation spacing and other requirements comply with IRC R328.3.1, IRC R328.4 and IRC R328.6.			
Work Quality	Installation completed in a professional manner, in compliance with NEC 110.12.			
Documentation	Owner has been furnished with relevant Operations Manual and Emergency Operations Plan.			
Other Observations				

SOLAR RATING
& CERTIFICATION
CORPORATION™

Solar Rating & Certification Corporation (ICC-SRCC)™



ICC-SRCC, a program of the ICC Evaluation Service, is an accredited certification body with programs for the certification and performance rating of solar heating and cooling products. ICC-SRCC certifications and ratings are specified by many incentive programs that promote the use of solar heating and cooling technologies. Consumers benefit from objective, third-party performance data that allows them to compare products and find the best options for their project.

ICC-SRCC's certifications and listings assist code enforcement professionals, allowing them to quickly confirm the code compliance of solar heating and cooling products ICC-SRCC's consensus standards for solar thermal collectors and solar water heating systems are referenced in model codes throughout North America.

ICC-SRCC CERTIFIES:

- Solar thermal collectors for air and water
- Domestic solar water heating systems
- Pump stations
- Solar pool heating systems

ICC-SRCC BENEFITS INCLUDE:

- Evaluations of compliance to ICC-SRCC Standards 100, 300 and 400 that are referenced in codes throughout North America
- Objective performance ratings and energy savings estimates for solar water heaters
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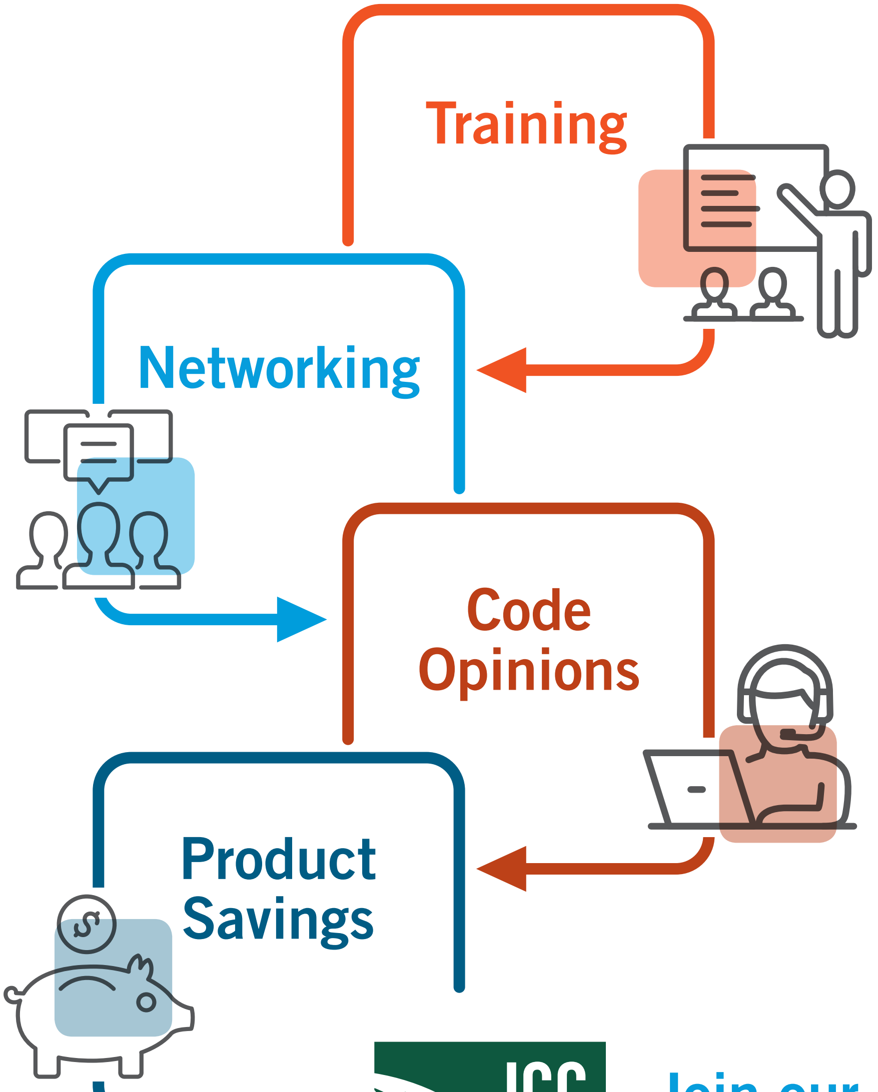

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