



Global / Energy

Hazards of utility scale **Battery Energy Storage Systems (BESS)**

BESS, or Battery Energy Storage Systems, are a technology that stores electrical energy in batteries for later use. This technology enables better integration of renewable energy sources (e.g. wind and solar) into the power grid by balancing supply and demand, providing backup power, and supporting grid stability.

Other uses of batteries can be to power a single object or location, for example, electric vehicles or smart homes. Overall, BESS can improve energy efficiency, reduce costs, and enhance reliability for utilities and consumers.

Due to their prevalence in the market and our understanding of the risks, this document focuses specifically on outdoor, utility-scale BESS involving lithium-ion technology (Lithium Iron Phosphate, LFP, and Nickel Manganese Cobalt Oxide, NMC). As BESS technology is evolving, for other types of batteries or usage please contact your local AXA XL Risk Consulting Office for additional information.

XL Risk Consulting



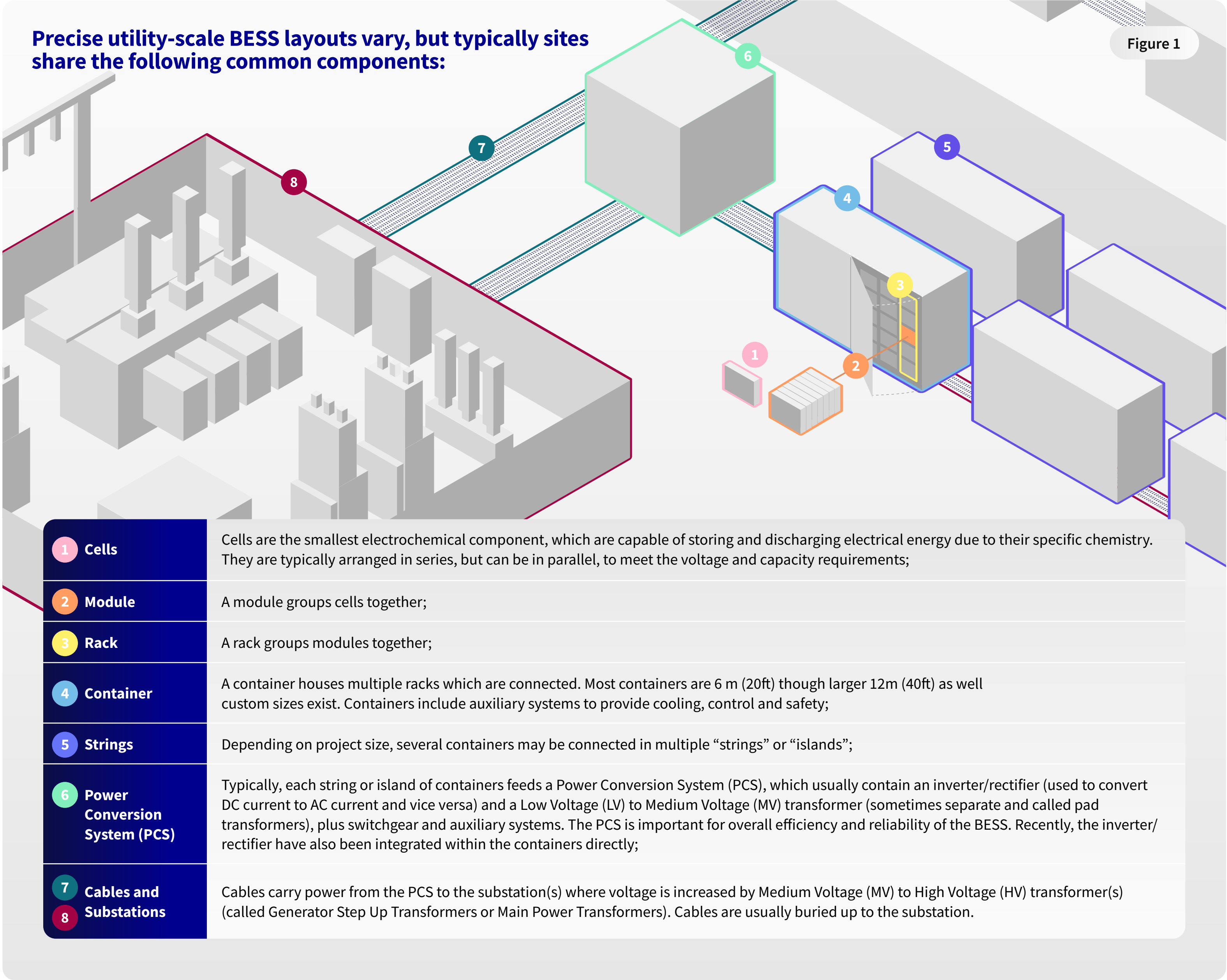
Understanding the risks of Battery Energy Storage Systems

Lithium-ion batteries present both fire and explosion hazard, because they contain high energy density cells and flammable organic electrolytes. However, this allows large amounts of stored energy to be released rapidly if the battery is damaged (due to overheating, moisture ingress, or mechanical or electrical damage). If not managed properly, these could trigger short circuits and potentially thermal runaway, leading to fire, explosion, and the release of flammable or toxic gases.

Once ignited, BESS fires are notoriously difficult to extinguish and require specialized firefighting techniques. Notably, the poor design of safety systems, can lead to both property damage, and worker injuries and fatalities, and should be considered at the design stage of BESS.

The recommendations in this document are supplementary to, and do not replace, the requirements of local and international authorities or manufacturers. They must not be interpreted as reducing the required level of prevention and/or protection.

AXA XL Risk Consulting can review future projects and the associated technical documentation pre and post construction.



Market-leading lithium-ion BESS require robust safety systems to manage critical risks.



Battery chemistries or types

Different battery chemistries exist, and the industry is rapidly evolving with ongoing advancements and new technologies entering the market. Today, lithium-ion batteries dominate the global utility-scale BESS market, led by Lithium Iron Phosphate (LFP) and then Lithium Nickel Manganese Cobalt Oxide (NMC). Thanks to its higher energy density, NMC technology used to dominate the market, but LFP has since demonstrated improved safety and cycle life and is currently the most deployed lithium-ion chemistry in projects under construction or in development. Lithium Nickel Cobalt Aluminium Oxide (NCA) has also been used in some utility-scale projects due to very high energy density, but is generally regarded as the least safe among the lithium-ion options.

While this document focuses on lithium-ion technology, other technologies are gaining traction, such as sodium-ion (still progressing toward full commercial viability) and redox flow batteries (such as vanadium redox flow battery – VRFB). VRFB technology differs significantly from lithium-ion, using two separate electrolyte tanks and pump systems, and is typically employed for longer duration storage applications with large number of cycles life, but with lower energy density requirements. Please contact your local AXA XL Risk Consulting Office for additional information.

Key risks related to Lithium-Ion BESS

When looking at lithium-ion BESS (utility scale), **thermal runaway** is the most critical risk. Thermal runaway occurs when internally generated heat drives further exothermic reactions, causing a rapid temperature rise, which may result in a fire and propagate to other cells, modules or containers. The main failures resulting in thermal runaway are summarized in the table on the right.

Electrical failure	Due to a failure of the Battery Management System, for example, leading to over-charging, over-discharging, over-voltage or under-voltage of the battery. This can lead to short circuits, lithium plating & dendrites, components breakdown/melting, etc.
Mechanical failure	Due to defective materials being used, or the impact to the BESS during transport, installation or operation leading to short circuits and/or release of gas, etc.)
Thermal failure	Due to cooling system failure, extreme environment, humidity, etc.

As discussed in the following section, many of these failures can be mitigated by effective Battery Management Systems and robust safety systems (e.g. off-gas detection, ventilation, ...) and procedures.

The goal is to prevent a fire or explosion from occurring and limit the extent of the damage if an incident does occur.

Another common risk for BESS sites is the **failure of the MV to HV transformer (GSU Transformer/Main Power Transformer)**, which can lead to a lengthy business interruption. This is particularly critical when there are supply chain constraints for replacing transformers, and in the absence of contingency planning, when the transformer configuration does not incorporate redundancy or fault tolerance.

Key recommendations to mitigate risks:

General recommendations

- Only outdoor BESS (utility scale) installations are recommended.
- All manufacturers, installers, contractors and Operations & Maintenance (O&M) providers should be reputable and have an extensive track-record in BESS installations.
- Use certified/qualified contractors/installers in countries where certification schemes exist. In areas where such schemes do not exist obtain references that should be related to BESS installations.

Applicable standards

- Components and systems should comply with relevant internationally recognized standards for electrical performance and safety (e.g. UL 9540, UL 1642, UL 1973, IEC 62933, IEC 60364, ...) and should be approved / listed by an independent testing laboratory (e.g. UL, CSA) at the cell, module, rack and container levels.
- As per NFPA 855:2026, BESS layout / spacing should be validated on the basis of UL9540A (Thermal Runaway Fire Propagation) and Large-Scale Fire Testing (e.g., CSA TS800, UL9540A) and by an engineering deflagration analysis, to ensure there is no propagation from one container to another.
- Active (continuous) and passive ventilation and protection systems should comply with recognized standards and certifications (e.g., NFPA 68, NFPA 69).
- A more complete list of applicable standards can be found at the end of this document.

Note: Depending on specific circumstances, the recommended distances outlined in the following sections may need to be increased or could be reduced. For any design adjustments, non-standard configurations, and/or for more information, please contact your local AXA XL Risk Consulting Office prior to finalizing layout.

Layout and separation distances

- Physical spacing is the preferred way to limit thermal runaway. The minimum separation distance to avoid spread between containers should be assessed according to UL9540A (including Large Scale Fire Testing) as mentioned in NFPA 855:2026 and by an engineering deflagration analysis.
- All critical equipment and buildings should be adequately distanced from the BESS containers and from each other, with appropriate protection in accordance with NFPA 850 and NFPA 855:2026.
- AXA XL Risk Consulting provides below some guidance regarding layout and separation distances for utility-scale BESS sites (see Figure 2 on the next page). These distances are a recommendation only, and are not a substitute for local code requirements, site-specific testing, manufacturer guidelines or authority approvals.

Distance between BESS containers:

- On sides containing openings (doors, panels, explosion vents, etc.), the distance between BESS containers should be a minimum of 3m/10ft.
- This distance can be reduced on the sides without openings, based on the results of Large-Scale Fire Testing and deflagration analysis results.



Distance between BESS containers and Power Conversion Systems (PCS):

- PCS can include or exclude LV to MV transformers. Most LV to MV transformers being used are dry-based transformers but some oil-based LV to MV transformers might be used in some sites.
- If there is an oil-based LV to MV transformer, the distance to BESS containers should comply with Table 6.1.4.3 from NFPA 850. This distance can also depend on active and passive fire protections, please contact your local AXA XL Risk Consulting Office for additional information.
- If the PCS only contains an inverter and dry-based LV to MV transformer then the distance between BESS containers and PCS should be 1.8m/6ft minimum. Depending on specific circumstances, this distance might need to be increased or could be reduced (please contact your local AXA XL Risk Consulting Office for additional information).

Distance between BESS containers and MV to HV oil-based main grid transformers (substation):

- The separation distance between BESS containers and oil-based transformers should comply with Table 6.1.4.3 from NFPA 850. This distance can also depend on active and passive fire protections, please contact your local AXA XL Risk Consulting Office for additional information.

Distance between BESS containers and any other buildings:

- Default separation between BESS containers and any other buildings not directly related to the utility-scale BESS site should be 20m/67ft.

General best practice:

- To reduce the risk of a low probability, high consequence thermal runaway event, AXA XL recommends that the BESS installation be divided into separate fire areas with a spacing of 20 meters/67ft between them.

Fire detection and protection

- BESS container enclosures should be non-combustible construction, with non-combustible insulation materials achieving a two-hour fire-resistance rating or greater.
- If PCS is inside the battery container, there should be a fire barrier around the PCS.
- AXA XL relies on space separation and deflagration management to prevent container-to-container fire spread. Therefore, we typically will not ask for water based or gaseous suppression systems. When such systems are desired for other reasons, or where space separation cannot be maintained, contact AXA XL for the most up-to-date information on the most appropriate suppression system arrangement.
- Although automatic fire protection systems are generally not required for BESS containers, fire protection may be required for other critical equipment or building (e.g. substations, transformers and control building) within the facility, particularly in cases where space separation does not meet the specified separation distance requirements. This ensures adequate fire mitigation and compliance with applicable standards.
- Adequate off-gassing and fire detection systems should be included in the BESS container.

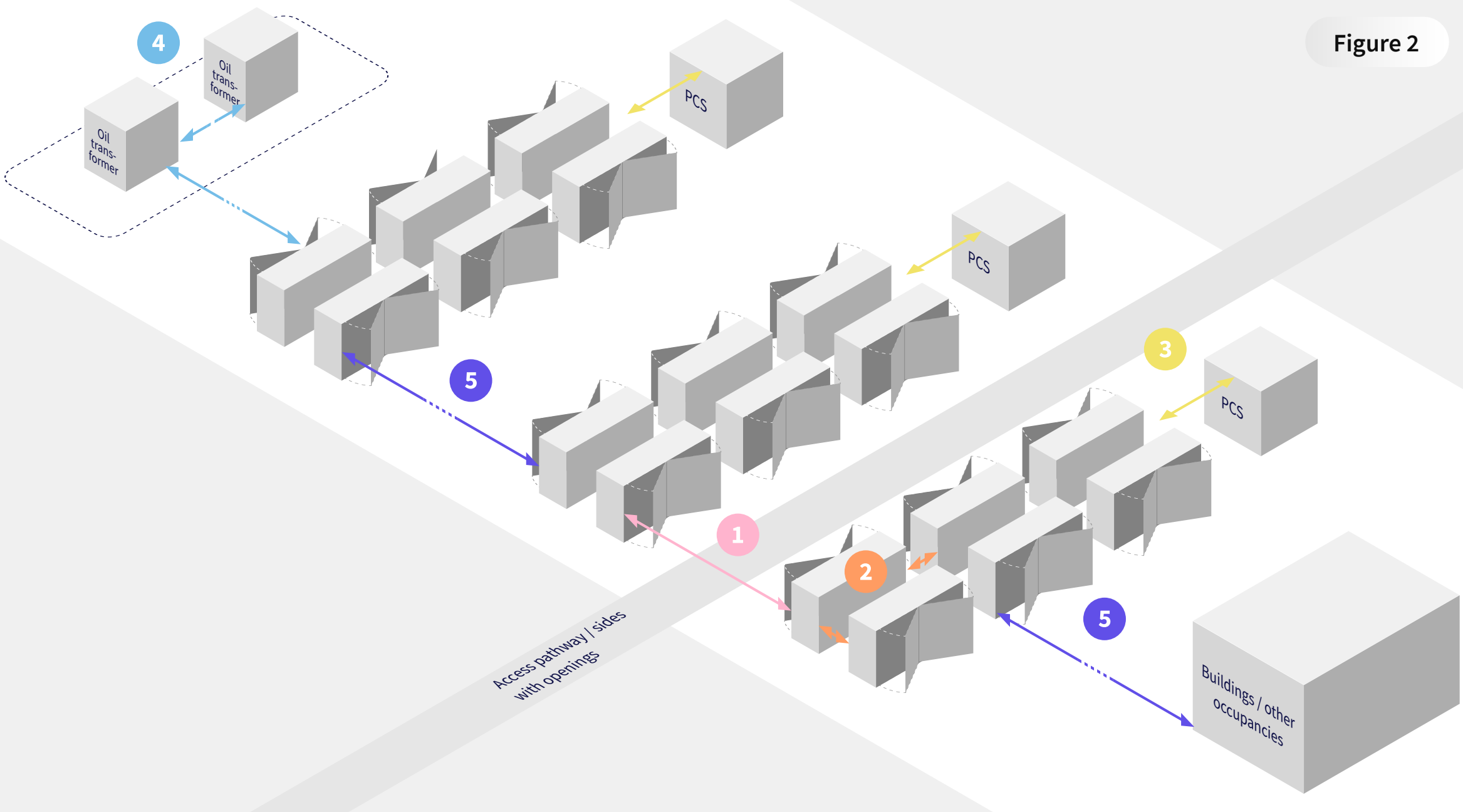
Minimum recommended design separation distances

Element	Distance
1 Sides with openings/access pathways:	3m/10ft
2 Sides with no openings:	3m/10ft, can be reduced with LSFT
3 For PCS/dry transformers:	1.8m/6ft
4 For oil transformers:*	See Table 6.1.4.3 from NFPA 850 (e.g 15m/50 ft for oil capacity >18,925 L/5000 gal)
5 Buildings/other occupancies or between BESS fire areas:	20m/67ft**

*depends on active and passive fire protections.

** might need to be increased or could be reduced depending on specific circumstances.

Please contact us for more information.



BESS containers

- Follow the manufacturers' installation, maintenance and operation guidelines.
- BESS containers should be single story and not stacked to prevent the spread of fire.
- BESS containers should be installed on foundations designed for the specific ground and local conditions (flood and earthquake risk should also be considered here).
- Explosion/deflagration panels should be directed towards a safe area.
- Vents and panels should be regularly inspected to ensure nothing (e.g. debris, snow, ice) is blocking the vents or panels.
- Cooling (and heating where applicable) systems are crucial to keep within the design temperature of

the battery. All cells should ideally be cooled evenly. Liquid cooling systems are usually preferred to air cooling systems for effectiveness and review the quality and condition of the cooling piping assembly to ensure there is no leakage.

- All cooling, ventilation and safety protection systems should be powered by a reliable external source (not by the BESS itself).

Battery Management Systems (BMS) and controllers

- The BMS ensures protection against over- and under-voltage, over-and under-charging, manages cell imbalance, and monitors temperatures of each cell, module and rack to keep them within safe limits.
- The BMS and controllers ensure proper interlock functionality (e.g., active ventilation with off-gas

detection) and will isolate cells, modules or racks in response to emergency alarms or safety concerns.

- An additional layer of predictive maintenance, enabled by advanced data analytics is recommended to detect and prevent thermal runaway or other failures before they occur.
- These systems should be sourced from reputable and trusted providers with an extensive, proven track record, in accordance with local and international best practices (e.g., IEEE 2686).

Cables

- Wherever feasible, cables leading to the substation should be buried and properly installed.
- All cable penetrations must be sealed using non-combustible materials that have a fire resistance

rating equivalent to that of the container or building material.

- Electrical cables should be subjected to preventive maintenance after installation per acceptable codes and standards (NFPA 70B, ANSI, NETA, etc.)

Power Conversion Systems (PCS) and LV to MV transformers

- These systems produce heat. Therefore, adequate ventilation needs to be provided.
- They should be protected from direct sunlight and have a minimum of an IP64 protection grade (for dust and water resistance).
- PCS and Transformers should undergo preventive maintenance after installation per acceptable codes and standards (NFPA 70B, ANSI, NETA, etc.).

Substation and MV to HV/GSU transformers

- Failure of MV to HV transformers can lead to long duration business interruption due to supply chain

Detailed AXA XL Risk Consulting Guidelines are available for most systems and components.



- constraints or the transformer being an uncommon size/rating. To mitigate this risk, design the project with redundancy (two or more GSU transformers) and/or maintain a spare transformer on site that is kept in good working conditions and ready for immediate use.
- Transformers should undergo preventive maintenance and regular inspection after installation per acceptable codes and standards (NFPA 70B, ANSI, NETA, etc.)
 - Refer to AXA XL Risk Consulting Guidelines on electrical equipment.



Operation and maintenance

- For all components and systems, installation, operation and maintenance must be conducted in strict accordance with the manufacturer’s guidelines and recommendations.
- Long-Term Service Agreement (LTSA) with the Original Equipment Manufacturer (OEM) is considered a best practice to ensure performance and risk management.
- Regular inspections and maintenance should be completed by qualified personnel. This includes visual, functional, and ad-hoc inspections.

- The owner should be active in reviewing maintenance records, and performance of systems, even if maintenance is outsourced to the OEM.

Cyber security

- Procedures should be in place to reduce exposure to cyber threats.

Natural Catastrophe (NAT CAT) hazards

- The first measure is to avoid planning a BESS project in an area with elevated NAT CAT risks.
- All necessary precautions and protection systems (including lightning protection) should be adopted to mitigate all potential risks related to any NAT CAT risks that are present and include these in emergency planning.

Site security

- Fencing, controlled access gates, and video surveillance systems should be in place to avoid unauthorized access.
- 24/7 personnel presence is also recommended where possible and will ideally be supplemented with offsite monitoring.

Vegetation management

- A vegetation management program should be adopted to limit the spread of fire. Site ground should be covered with ballast type material.

Management programs

Management programs for loss prevention and control should be in place.

Emergency Planning, including intervention by Fire Department and/or other organizations:

- The local fire department should be consulted from the planning stage of the BESS project, through to operation, and regularly afterwards.

- Preplanning with the fire department can take on an elevated importance depending on: if the site is occupied or remotely monitored, site access, firefighting techniques and training for BESS, and the availability of fire detection/protection and water supply for remote locations.
- An annual visit with the Fire Department should be organized to make sure they are fully familiar with the site and technology.
- A reliable emergency power supply system (EPSS) should be in place providing power to critical safety systems such as the BMS, thermal management /HVAC and fire detection systems.
- Emergency planning should take into account all risks, including the site’s risk of flood, earthquake, hurricane, wildfire or other NAT CAT hazards.

Note that BESS operations may have a small number of personnel associated with Operations and Maintenance (either onsite and/or offsite) and a numerous of stake-holders (the owner, the operator, the equipment manufacturer) that will have a role during an emergency situation, and these should be outlined.

Business Continuity Management (BCM)

- For BESS installations, the most effective Business Continuity Management (BCM) approach is to integrate resilience into the design process. This proactive strategy ensures that the system is built to withstand potential disruptions, thereby enhancing overall operational resilience and minimizing downtime.

For detailed protection requirements, contact your local AXA XL Property Risk Consulting Office.



References

AXA XL Property Risk Consulting Guidelines

NFPA Standards that address Energy Storage Systems

NFPA 68, Standard on Explosion Protection by Deflagration Venting
NFPA 69, Standard for Explosion Prevention Systems
NFPA 70B, Standard for Electrical Equipment Maintenance.
NFPA 850, Recommended Practice for Fire Protection for Electric Generating Plants and High Voltage Direct Current Converter Stations.
NFPA 855:2026, Standard for the Installation of Energy Storage Systems

UL

UL 1973, Standard for Batteries for Use in Stationary, Vehicle Auxiliary Power and Light Electric Rail (LER) Applications.
UL 1642, Standard for Lithium Batteries
UL 9540, Standard for Energy Storage Systems and Equipment
UL 9540A, Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems

IEC

IEC 62933 Global Standard for Electrical Energy Storage Systems
IEC 60364, Low-voltage electrical installations - Part 1: Fundamental principles, assessment of general characteristics, and definitions

IEEE

IEEE 2686, Recommended Practice for Battery Management Systems in Stationary Energy Storage Applications

Large-Scale Fire Testing

CSA TS-800:25 – Large-Scale Fire Test (LSFT) Procedure
UL 9540A, Standard for Test Method for Evaluating Thermal Runaway Fire Propagation in Battery Energy Storage Systems



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