Fire safety in Li-ion battery energy storage systems

Confidential

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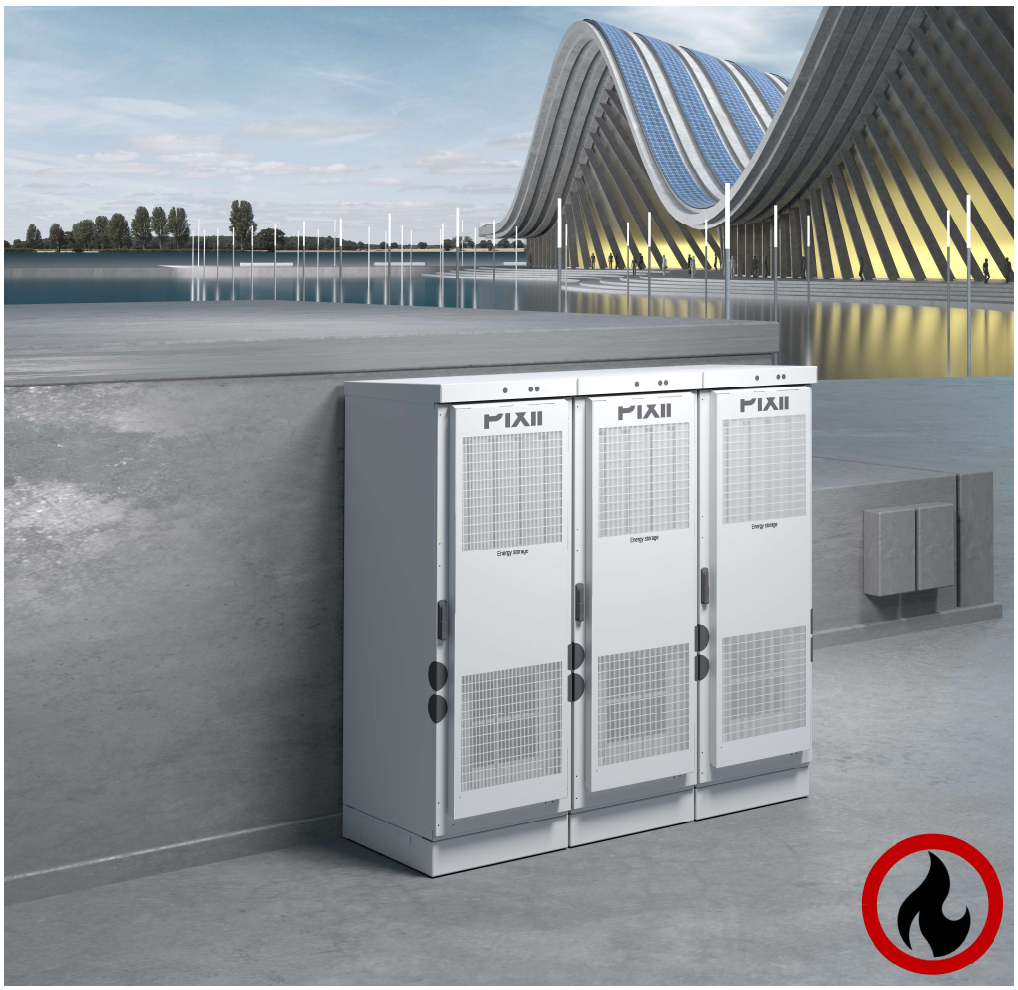
December 2021



Introduction

Deployment of Battery Energy Storage Systems (BESS) is expected to be a key part to enable the transition from fossil-fuel-based sources of energy to renewable energy sources. The resent years rapid development of Li-ion batteries with high energy density and decreasing cost, increases the potential applications, but also inherently poses a significant safety hazard. Rules and regulations for installation and operation of Energy storage systems are still under development and continually evolve, leaving the industry left with best engineering practice while keeping attention to the published and ongoing work and learning from previous incidents.

This paper gives an overview of how fire safety is implemented in Pixii's energy storage systems and provides recommendations on measures to take on the installation level.

The hazards of Li-ion batteries

The very high energy density of Li-ion batteries comes at a cost. If an internal short occurs in a cell, all electrochemical energy in that cell will be released as heat. At the same time this may cause the release of toxic (like HF) and flammable gasses (like CO, H2 and CH4). Such an event is commonly called a thermal runaway event.

A thermal runaway event may be caused by production weakness or misuse (i.e. electrical, mechanical, thermal) of the batteries. This situation can be difficult to handle since a thermal runaway event is a self-supplying fire that generates its own fuel (oxygen and heat) to keep it running.

Based on the large number of batteries of this type produced worldwide compared with the few reported incidents, it is obvious that the probability for a thermal runaway event is very low. Only a few battery cells out of a million produced ones will cause a thermal runaway.

Although the probability is low, the consequences of an uncontrolled thermal runaway event may be severe. It is therefore important to build several layers of safety in and around battery systems to reduce the likelihood of and consequences If such an event happens.

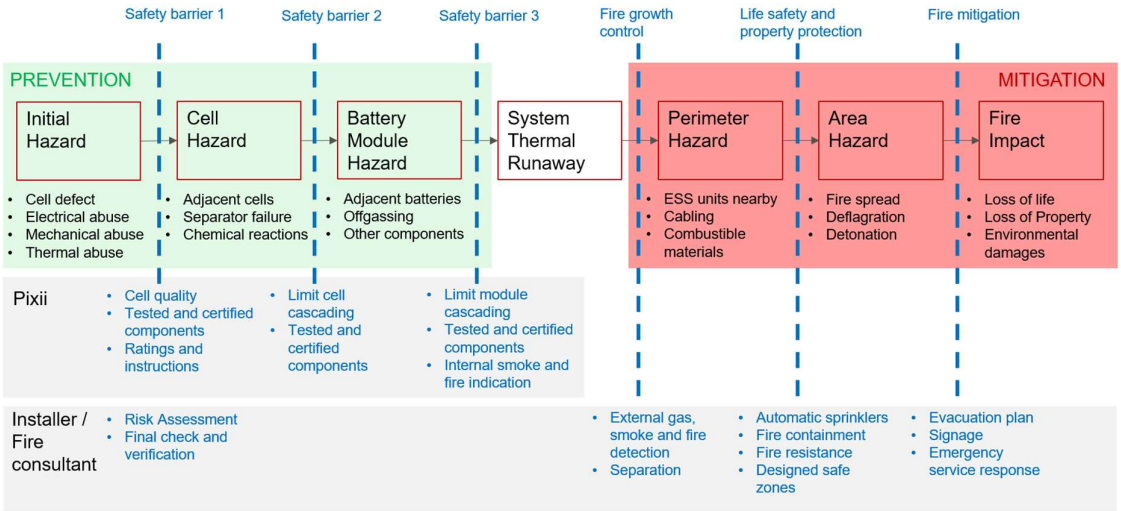
Layers of fire safety

The Fire safety measures can generally be divided into two main parts:

- Preventing measures
- Mitigating measures

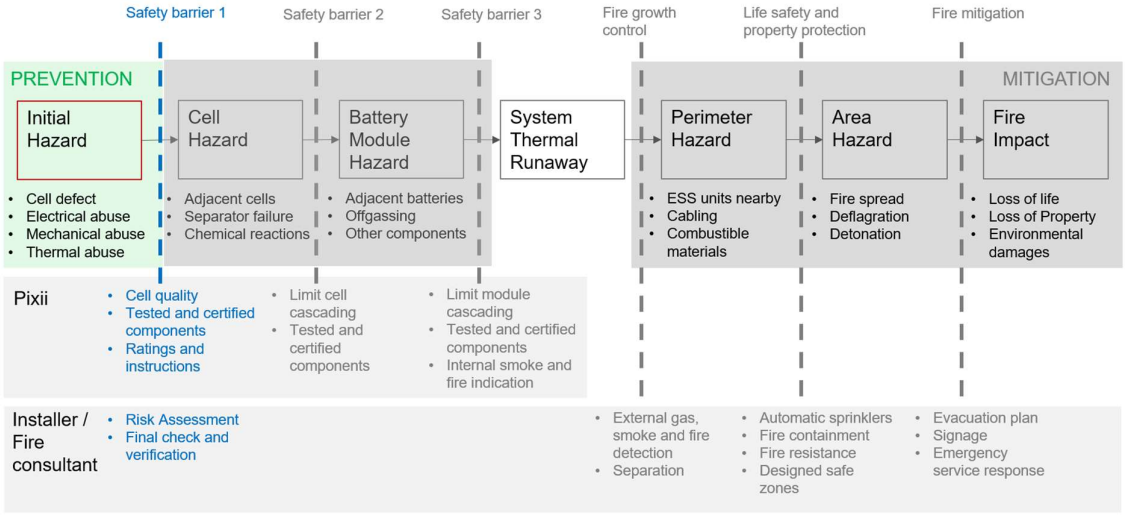
The preventing measures are those that can be taken in advance to reduce the likelihood of an incident occurring in the first place.

The Mitigating measures are different barriers that are put in place to ensure that the consequences of an incident are reduced to a minimum.



Safety barrier 1

The first safety barrier is the most important as having this in place will reduce the chances of any incidents to a minimum. To ensure that the battery system is suitable for the intended application and fulfills the customers' expectations, an introductory conversation is crucial. The installation must ensure that the battery system is installed and operated according to the manufacturer's instructions.



Cell quality

Cell defects do occur, but the manufacturing processes are constantly improving. By using trusted manufacturers that have the quality system in place and share the same focus on safety as us, the chances of having a defect cell in the field that can cause an internal short are minimized.

Tested and certified components

Even if the cell quality is perfect, it must be used within its operating ranges for electrical, mechanical, and thermal impacts. This is in the first level taken care of by the BMS in the battery module and the construction of the battery module itself. With significant safety margins and with single failure proof protection, the BMS makes sure that the cells are protected and in well-conditioned state. Performing third party accredited testing and certification is the preferred way to ensure that it will operate safely under normal and abnormal conditions.

Ratings and instructions

For the installer / fire consultant to install, dimension and design the installation correctly, the proper installation instructions must be available as well as the operational conditions and necessary maintenance for the battery system. Having this information, a suitable environment both thermally and mechanically can be ensured and the battery system able to perform according to the intended application.

Risk assessment

A risk assessment during installation is critical and is intended to detect possible issues that may jeopardize the safety of the installation. The installer / fire consultant must ensure that the environment where the battery system is placed is suitable and according to the ratings and

specifications of the system. Some examples of considerations are how the temperature is controlled and if the ventilation in the room is sufficient.

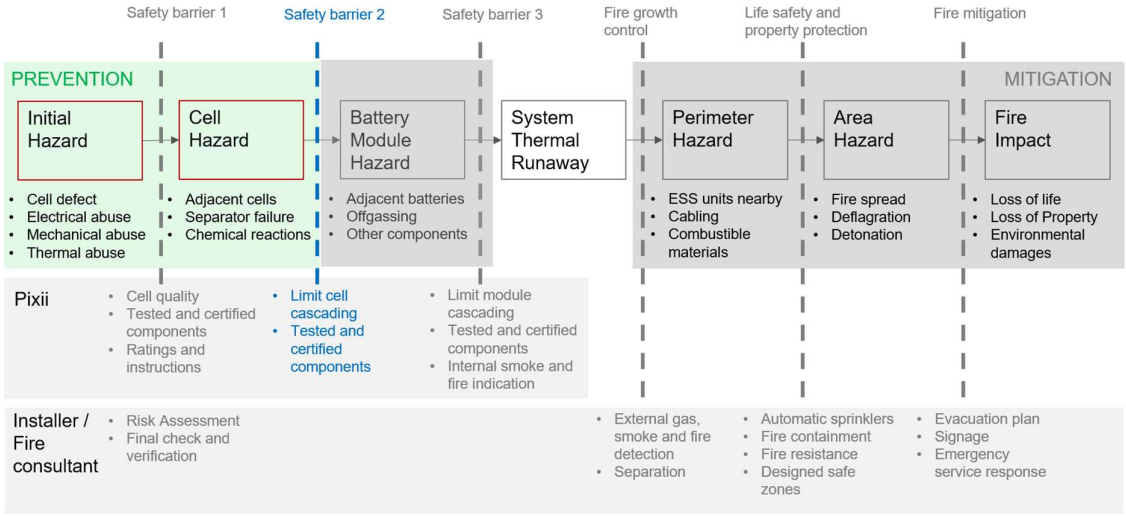
This documentation shall be stored in a suitable location. A template of a risk assessment is provided with the battery systems, but it is the responsibility of the installer / fire consultant to evaluate if it is sufficient and that it fulfills local regulations.

Final check and verification

After the installation is completed but before commissioning, a final check and verification is required. This is a checklist to verify that everything is safe and work as intended at start-up of the system. This documentation shall be stored in a suitable location. A template of a final check and verification is provided with the battery systems, but it is the responsibility of the installer / fire consultant to evaluate if it is sufficient and that it fulfills local regulations.

Safety barrier 2

If the first safety barrier is broken so that a short-circuit occurs in a cell, the next barrier is to isolate the fault so that it does not propagate outside that damaged cell.



Limit cell cascading

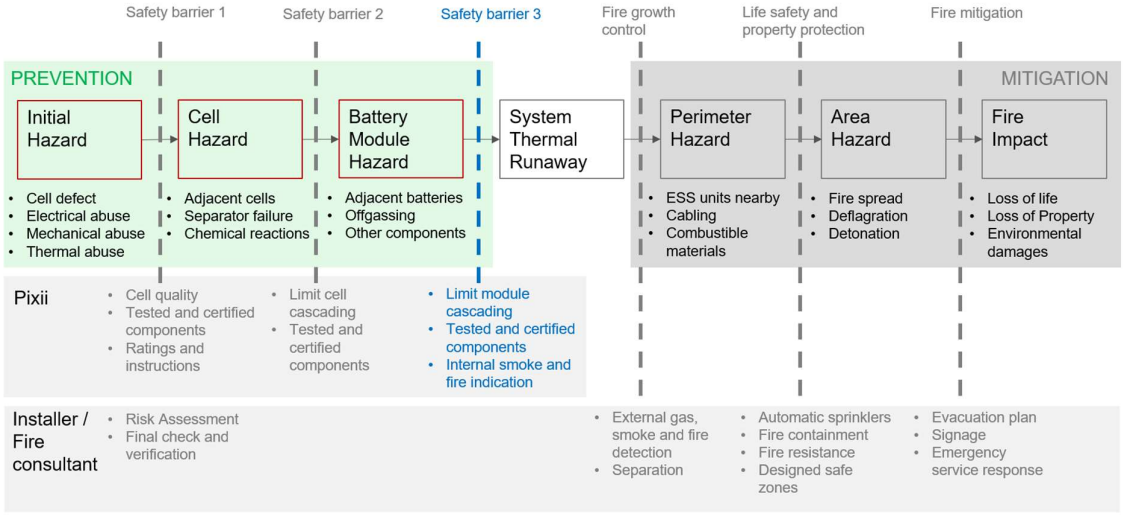
One of the most recognized safety tests on battery cells is the nail penetration test. In this test no fire or explosion are permitted. Cells passing this test are less susceptible to be involved in a cell-to-cell cascading situation. Additionally, the battery modules are often constructed so that the heat released by one cell in thermal runaway is not transmitted easily to the neighboring cell.

Tested and certified components

A short circuit in a battery cell will usually be detected by the BMS and will cause the battery module to be isolated from the rest of the system. Performing third party accredited testing and certification is the preferred way to ensure that it will operate safely under normal and abnormal conditions.

Safety barrier 3

If the second safety barrier is broken so that several cells in a battery module are heated, the next barrier is to isolate the fault so that it does not propagate outside that battery module.



Limit module cascading

If cell to cell cascading is not addressed, a total battery module breakdown and potential fire must be expected. Certified battery modules are not permitted to have flames coming out of their enclosures even during an internal thermal runaway event. They may still get hot so proper physical spacing between the battery modules must be maintained according to the manufacturer's instructions. The means for battery module separation must be able to withstand the high temperatures that can be expected. Steel frames are suitable for this purpose.

Tested and certified components

The complete system with battery modules and all protection and monitoring devices in place should be tested together. Performing third party accredited testing and certification is the preferred way to ensure that it will operate safely under normal and abnormal conditions.

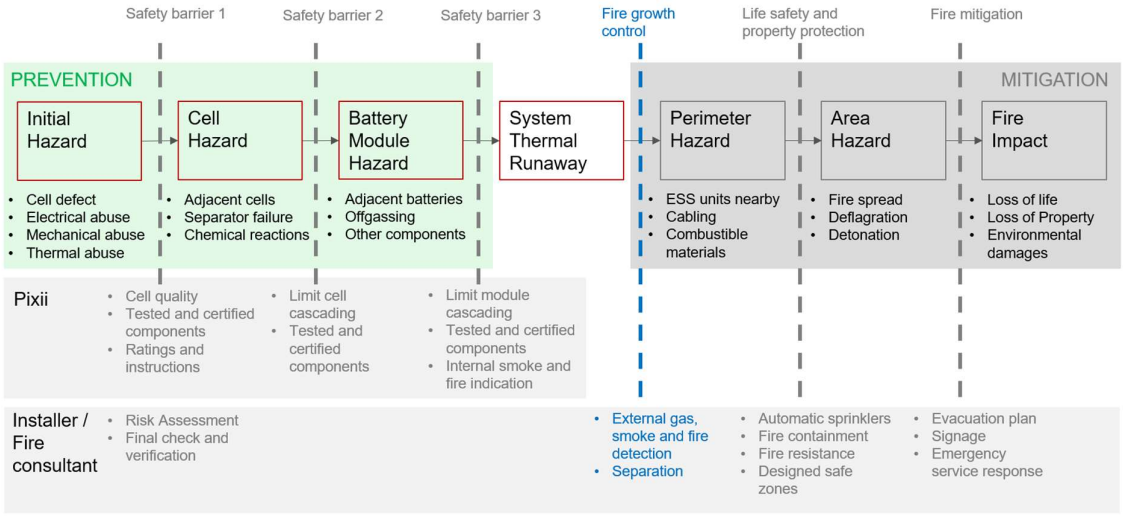
Internal smoke and fire indication

All Pixii PowerShaper systems are fitted with a smoke detector located in the door close to the air outlet. If activated, the power reference to the converters will be set to zero and a Fire alarm will be displayed on the user interface on the web. The alarm information may also be sent through email, SMS or by activating an output relay on the Pixii Gateway.

It is however important to note that these fire detection systems are not fail proof and may not fulfill local requirements to fire detection systems. They may still be useful in order to get an early indication of a fire.

Fire growth control

If several battery modules end up in thermal runaway and possibly catches fire, measures must be taken to prevent or delay the fire from spreading to adjacent systems and devices.



External gas, smoke, and fire detection

If the system is installed indoor it is highly recommended to use an approved, fail-proof gas, smoke, and fire detection system.

Separation

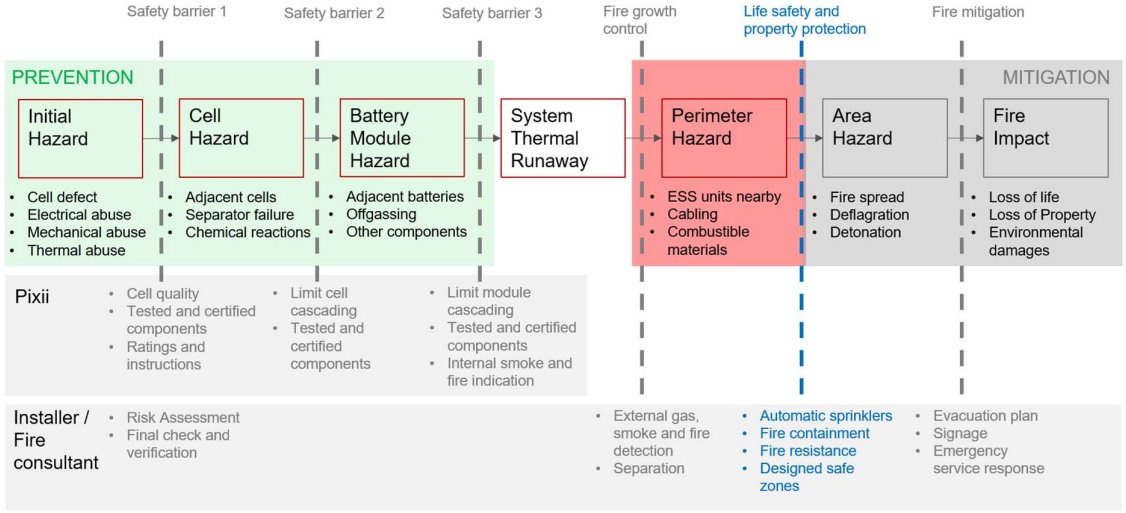
Even though the Pixii PowerShaper is constructed of a metallic cabinet with the only opening in the front, measures must be taken to limit the probability of a fire in one cabinet from spreading to another or to the surroundings. The UL standard UL 9540 is one of a few standards stating minimum separation distances around Energy Storage Systems. For some applications it may not be practical to comply with the large individual separation requirements of UL 9540 (i.e., 3 feet between each cabinet), but there must be at least 5 cm separation between each cabinet, preferably 25 cm or more.

For larger multi-cabinet installations, the cabinets should be divided into groups not exceeding 600 kWh and with 3 feet separation to other groups and to the surroundings.

There should also be ensured that there are at least 900 mm free clearance above the cabinets.

Life safety and property protection

A situation where several energy storage systems are involved in a fire is a challenge, but if the installation is designed well, the fire can still be contained in the room/area where the system is installed.



Automatic sprinklers

If installed indoor, an automatic sprinkler system is highly recommended and sometimes required. There have been many tests of different extinguishing agents to find a suitable type, but as the main focus is to cool down the batteries, water is usually the recommended one.

Fire containment

The Pixii PowerShaper has the benefit of the modular design divided into relatively small metallic enclosures. This will limit the likelihood of the fire from spreading to neighboring systems and surroundings and ease the accessibility for the firefighters.

Fire resistance

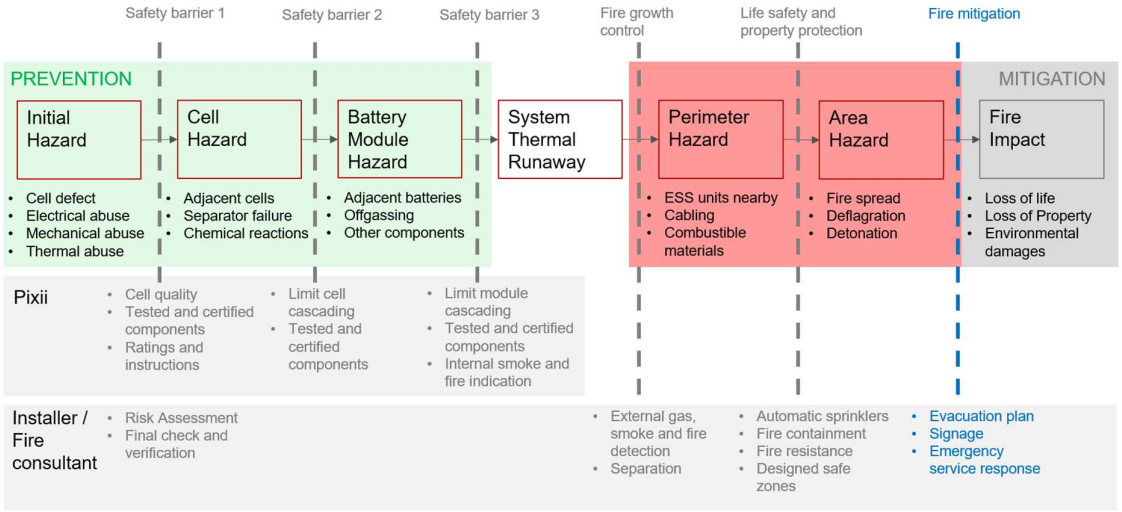
The Pixii PowerShaper is made of an aluminum enclosure with the frames supporting the batteries made of high temperature resistive steel. The walls, floor and ceiling of a battery room must also be made of non-combustible materials.

Designed fire zones

Battery storage systems installed indoor, should be located in separate battery rooms having proper ventilation and signage.

Fire mitigation

If the fire expands further, there is danger for life and property. The means for ventilation may already be damaged and gas concentrations above the Lower Explosion Limits may be present. The last barrier is to safeguard people, property and the environment.



Evacuation plan

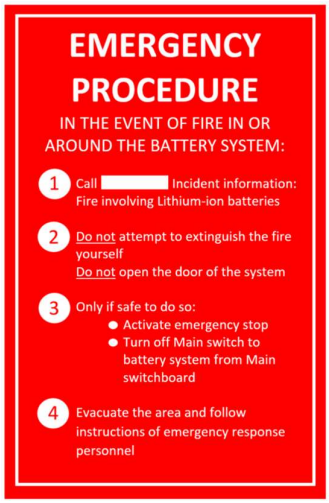
Upon installation of a battery energy storage system, an evacuation plan should be made or updated if it already exists. This should be visible from the outside of the battery room if installed indoor.

Signage

The building where the battery system is installed shall be properly marked so that it is clear to first responders that there is a battery system inside. The disconnection devices in the main switchboard must be labeled with a warning that there are dual sources of power.

Emergency service response

The Pixii PowerShaper may be delivered with an example of an Emergency Procedure sign that can be placed outside the battery room or at another suitable location where easily accessed by first responders. This is only an example, and the Fire consultant is responsible for the actual Emergency Procedure to be used.



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