SIEMENS

WHITE PAPER:

Fire protection strategies for lithium-ion battery cell production

To be able to meet the rising global demand for renewable, clean, and green energy there is currently a high need for batteries, and lithium-ion batteries (LIB) in specific. This is because LIB can be used for a wide range of applications such as stationary energy storage systems, in the E-mobility industry and for other transportation means, as well as in consumer electronics such as laptops and cell phones.

34 → 600

In 2020, it is estimated that Europe alone will increase its production capacity of LIB from around 34 gigawatt hours (GWh) in 2020, to around 600 GWh in 2030.

+25%

Global battery demand is expected to grow by 25% annually to reach 2,600 GWh in 2030.

The fast pace of developments in the field of LIB cell production brings along new tasks in fire protection. High hazard potentials are associated with the manufacture of LIB cells in production facilities. As with other manufacturing processes, the fire hazard potential varies in each step of the manufacturing processes, and appropriate measures must be taken in consideration for each associated risk.

Without any fire protection measures, a thermal runaway could lead to an electrochemical chain reaction with high energy and heat release by means of fire, explosion, and toxic gases with a rapid propagation to other LIB cells and / or production parts.

This White Paper is solely focused on the cell production of LIB within the legal framework of Europe, with a special emphasis on Germany. The ambition of this paper is to provide a deep-dive into the the two most critical production process steps of battery formation and aging, from a fire safety view. It is prepared by Siemens, TÜV SÜD and PEM RWTH Aachen University. Three parties that all have experience and knowledge within the area of LIB, their production process, and the associated fire risks as well as the appropriate fire protection strategies.

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The production process of lithium-ion cells

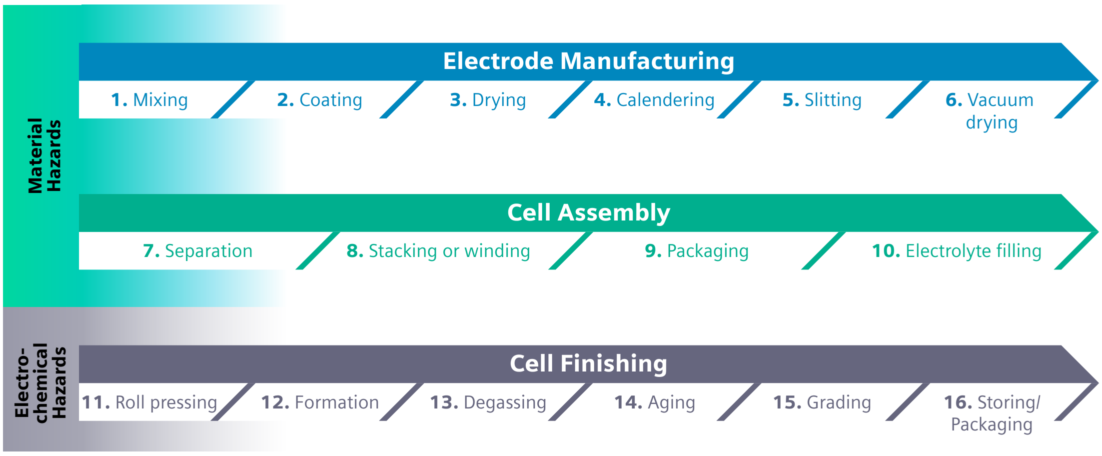


Figure 1: Process overview

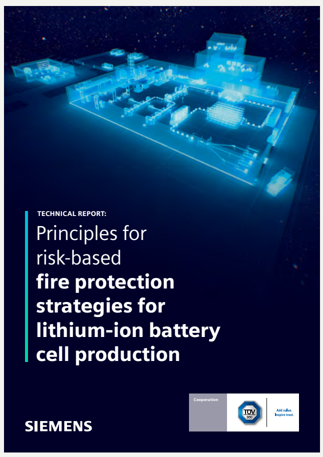
A LIB cell are produced in three different variants; cylindrical, prismatic or pouch. Independent of type the production process is divided in three high-level process steps; Electrode Manufacturing, Cell Assembly and Cell Finishing. A generic overview is presented in Figure 1, however please note that it might be the case that all process steps are not applicable for each variant of cells.

From a safety-oriented point of view, the three high-level process steps can be divided into 2 hazard zones:

1. **Electrode Manufacturing and Cell Assembly. In this step there are no electrochemical hazards, but hazards exist due to process steps or intrinsic material properties.**

2. **Cell Finishing. As soon as the cell is filled with electrolyte, a potential of electrochemical hazards is given.**

In this White Paper, the process steps Formation (12) and Aging (14) are explained. If you as a reader would like to know more about other process steps, we recommend our Technical report: Principles for risk-based fire protection strategies for lithium-ion battery cell production. That report covers all steps.



Formation

Battery formation is the process of performing the initial charge and discharge of the battery cell. It is when the cell comes to life. This can take several days depending on the cell chemistry.

The process parameters of formation are very important for the cell manufactures and thus the formation procedures are normally not shared in public. Depending on the cell format it can be generally stated that the formation starts with a pre-charging step, followed by full charge and discharge cycles. Depending on the cell manufacturer there are different techniques like charging to a specific state of charge (SoC) or pulse charging.

While charging for the first time, the solid electrolyte interphase on the anode is built up. This layer is highly important for the functionality and the quality of the finished cell. Defects can be identified via voltage measurement.

The formation process for LIB cells usually takes several days or longer. During this process, the cells are stored in a high-bay storage system or in chambers and applied with a current. The manufactured cells are charged and discharged several times.

The formation process is necessary to form a stable and efficient solid electrolyte interphase at the anode at low potentials vs. Li/Li+ to prevent irreversible consumption of electrolyte and lithium-ions. An analogous layer, the so-called cathode-electrolyte interlayer is formed at the cathode at high potentials vs. Li/Li+. These formation processes lead either to lower production rates or to high investment costs due to high space requirements or machinery costs. The formatted cells are placed automatically into stacks and will stay there up to 15 days.

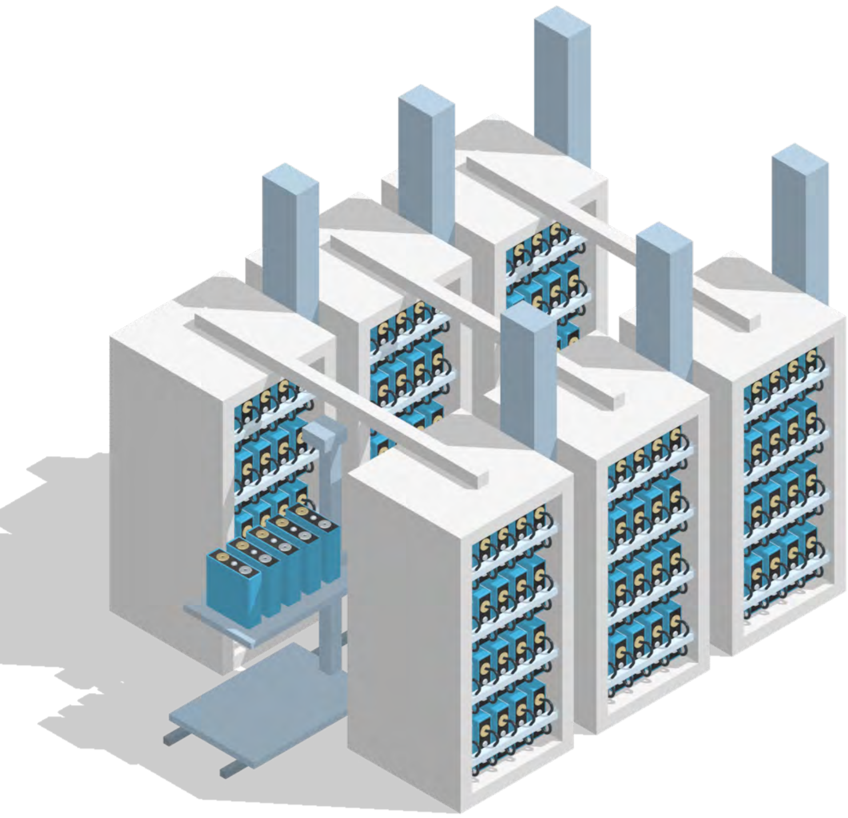


Figure 2: Formation

Aging

The aging process represents the final step in cell production and is used for quality assurance. During this process, the cells are stored for a longer time (up to three weeks) in a high-bay storage. Within this process the cells undergo different phases which are separated by temperature, so the cells undergo high temperature (HT) aging and normal temperature (NT) aging.

During the aging process voltage and impedance measurements are performed regularly at intervals to identify changes in cell properties or performances which are to be detected by regularly measuring the open circuit voltage of the cell over a period of up to three weeks. It is also an option to have no constant monitoring and measurement during the whole aging process, but only at the beginning and the end.

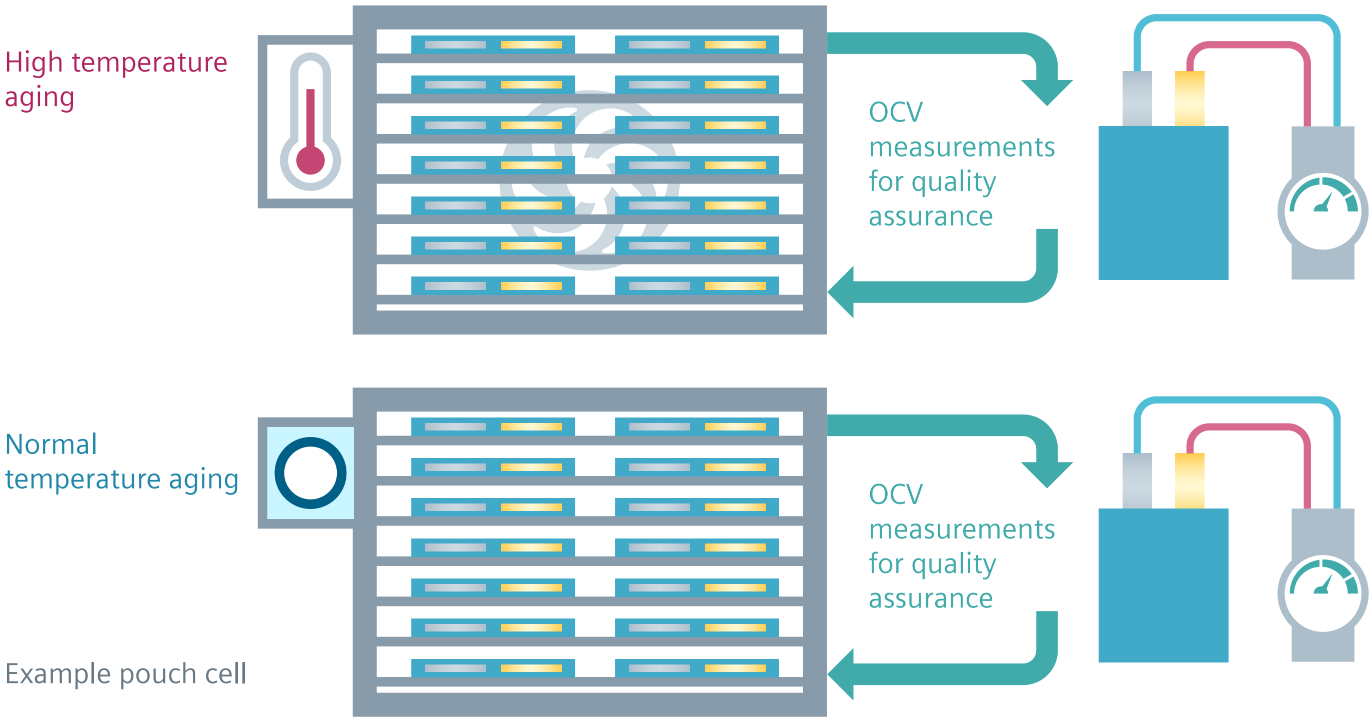


Figure 3: Aging, Source: PEM RWTH Aachen University

Fire protection measures and the approach for the process steps formation and aging

Figure 4: Fire protection categories

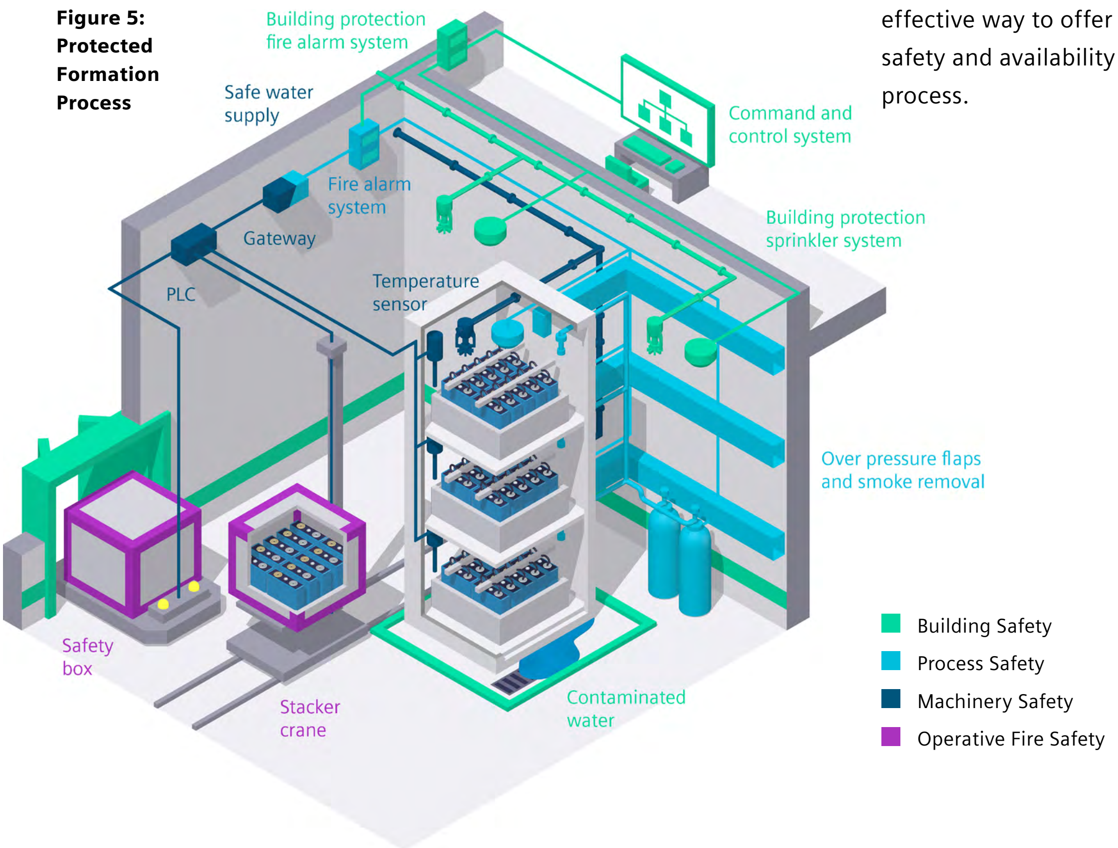
Fire hazards in cell production can be mitigated by a wide variety of measures. Besides typical structural and technical fire protection measures, protective measures can also be taken within machines and processes. The measures applied for the LIB cell production in the context of this White Paper are divided into following four categories, mentioned in Figure 4.

Formation

With the start of the first charging cycle, production errors in previous process steps can have potentially very dangerous consequences. As several cells are charged, and discharged at the same time, there is also an increased risk of fire due to the large quantity of cells. Considering all production processes, the formation process is the one with the highest risk potential, as it is the first time the cells are charged, and discharged, and an electrochemical hazard is present for the first time.

In addition to the cells themselves, the arrangement of the cells (high bay) also contributes to the risk. In Figure 5, we give recommended measures, which can be allocated to the four categories (Building Safety, Process Safety, Machinery Safety and Operative Fire Safety). The protective measures must take this high-risk level into account, and represent the most efficient and effective way to offer an appropriate level of safety and availability of an on-going production process.

Figure 5: Protected Formation Process



Following measures should be applied:

Additional measures for Building Safety

The formation process must be separated from other cell production processes and, depending on the floor area of the respective compartment, within the process area because of the enormous fire hazard. As a minimum, fire-resistant walls are recommended for separation and enclosure of the production process. The use of fire-resistant walls for the separation correspond with the requirements of the German model building code for areas of increased fire hazard and with the guideline VDI 3564. Fire walls may also be required for partitioning in some circumstances.

Regarding this production process, analogies can be drawn to Energy Storage Systems (ESS). In accordance to the international standard for ESS, the standard NFPA 855, structural separation of a fire resistance of 120 minutes is required. Even if the fire resistance rating based on US-American codes and standards cannot be compared directly with the one of German or European codes and standards due to different test procedures for analysing the fire resistance rating of structural components or building products, the value of 120 minutes represents a helpful point of reference.

The FM-Global Data Sheet 5-33, another standard for ESS, specified minimum separation distances from non-combustible construction elements and between the aisle faces of adjacent racks of 1.8 m (6 ft).

In general, as part of the structural safety, the limitation of the quantity of hazardous materials and / or equipment shall be considered and reduced wherever possible.

It is recommended to connect the fire detection systems with an automatic fire extinguishing (e.g. gas extinguishing) and suppression system. An appropriate suppression system for the formation process on a building level is a sprinkler system (water fire suppression system). These fire suppression systems can be allocated to Process and / or Machinery Safety. Therefore, they are no longer seen as additional measures under Building Safety.

Process Safety

The decisive point in Process Safety is the early and precise detection of the off-gas event with a special fire detector. The signal arriving in the fire detection system is forwarded once to the PLC control for shutdown of the formation process and typically used for immediate activation of the nitrogen extinguishing system. The discharge of the extinguishing agent prevents the formation of an explosive atmosphere. Attention must be paid to the tightness of the formation box as well as the air flow within the formation tower - these two requirements are necessary prerequisites for an effective gas extinguishing system.

Machinery Safety

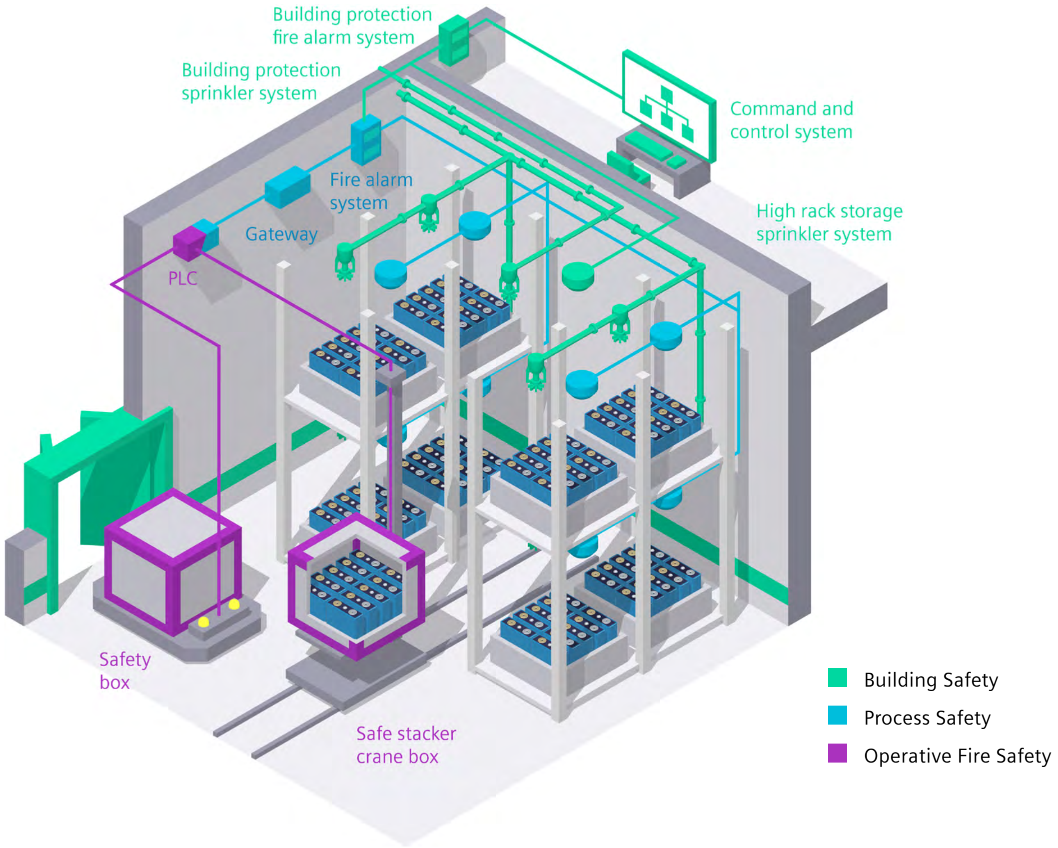
To ensure that the requirements of the Machinery Directive are met even if the gas extinguishing system is ineffective, a temperature-controlled water extinguishing system must be provided for the high bay storage. However, this should only ever be the last of all measures to avoid any damages to the machine caused by extinguishing water.

It is recommended to connect the fire detection systems with an automatic fire extinguishing system. While reducing or displacing oxygen, gas extinguishing systems are a very effective measure.

Operative Fire Safety

To ensure the protection of all employees and the environment, the safe handling of affected LIB cells must be regulated. If possible, the affected LIB cells are to be picked using a stacking crane and removed from the affected area and disposed of properly. By automating this process, risks of personal injuries can be pared down to a minimum.

Figure 6:
Protected Aging Process



Aging

As no real-time voltage and impedance measurements are carried out, a thermal runaway might be difficult to detect. Obviously, cells with a previous damage may subsequently become conspicuous during the formation process, but there is still a low probability that a cell which has survived the formation process will become conspicuous during the aging process step. However, due to the very large quantity of cells, in the aging process, it still exists a considerable high fire risk in this step. Hence, appropriate action needs to be taken.

Following measures should be applied:

Additional measures for Building Safety

The aging process must be separated from other cell production processes and, depending on the floor area of the respective compartment, within the process area because of the enormous fire hazard. As a minimum, fire-resistant walls are recommended for separation and enclosure of the production process. The use of fire-resistant walls for the separation correspond with the requirements of the German model building code for areas of increased fire hazard and with the guideline VDI 3564. Fire walls may also be required for partitioning in some circumstances.

The following guidelines should only be seen as reference as, during the aging process, no further charging will take place; nevertheless, the process itself with heating and cooling of the LIB cells and without monitoring via PLC contains a very high risk. These following guidelines can be applied as recommendation.

Regarding this production process, analogies can be drawn to Energy Storage Systems (ESS) – similar to the process step formation. In accordance to the international standard for ESS, the standard NFPA 855, structural separation of a fire resistance of 120 minutes are required. The value of 120 minutes represents a helpful point of reference even if the fire resistance rating based on US-American codes and standards cannot be compared directly with the one of German or European codes and standards.

The FM-Global Data Sheet 5-33, another standard for ESS, specified minimum separation distances from non-combustible construction elements and between the aisle faces of adjacent racks of 1.8 m (6 ft).

In general, as part of the structural safety, the limitation of the quantity of hazardous materials and / or equipment shall be considered and reduced wherever possible.

The area of the aging must be considered and designed like a high-bay warehouse in the fire protection assessment. For limiting any possible fire propagation as a result of a thermal runaway e.g., due to defective LIB cells the installation of an automatic fire suppression is recommended. An appropriate suppression system for the aging process is a sprinkler system; therefore, besides having a ceiling protection, it is necessary that each rack is equipped with sprinkler nozzles. For the dimension of the sprinkler system the standard NFPA 855 and the technical rule VdS CEA 4001 should be considered.

Process Safety

The decisive point in Process Safety is the early and precise detection of the off-gas event of the affected LIB cell with a suitable fire detector. The exact positioning of the individual fire detectors within the aging rack must be ensured. The signal arriving in the fire alarm system is forwarded to the PLC control for activating the stacker crane.

Operative Fire Safety

To ensure the protection of all employees and the environment, the safe handling of affected LIB cells must be regulated. If possible, the affected LIB cells must be picked and removed from the affected area using a stacker crane and disposed of properly to a designated area. This procedure must be carried out quickly after detection to avoid deformation of the trays in the rack, which would then make removal impossible. From a fire safety point of view, it is recommended to use metal trays and not plastic trays. By automating this process, risks of personal injuries can be pared down to a minimum.

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