Energy Generation From Renewable Sources

BESS and Li-ion thermal runaway, the critical challenge

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Batterie-Energiespeichersysteme werden zunehmend eingesetzt, um Strom aus erneuerbaren Quellen bereitzuhalten (Foto: LEAG/ Andreas Franke)

The demand for electricity is increasing not only in EU but Worldwide, boosting the expansion of the technologies generating energy from renewable sources: photovoltaic power generation, concentrating solar power generation and wind power generation.

The European Union (EU) recently accelerated the targets which were set in the Renewable Energy Directive and with the European Green Deal commited that the EU Countries shall reach a target of 42.5% of the energy generated from renewable sources by the year 2030.

Although the power generation technologies from Renewable Sources are environmentally sustainable, they face critical challenges. Their intermittent availability requires stabilizing of the power grid and peak power demands require the use of long-duration energy storage solutions.

The BESS (Battery Energy Storage Systems) market continues to expand, not only in EU but Worldwide, as they are called upon to address the critical aspects of the expansion of use of Power Generated from Renewable Sources to achieve a sustainable future.

Li-ion battery technology

Due to the high energy density, lightweight design, and long cycle life, Lithium-ion (Li-ion) batteries have become the preferred choice for applications requiring efficient, compact, and reliable power supply. Their ability to store significant energy in a small form factor makes them ideal for portable electronics like smartphones and laptops, while their lightweight and fast recharge capabilities are crucial for electric vehicles. Additionally, their versatility and scalability have driven their use in renewable energy storage systems, enabling efficient integration with solar and wind power. These characteristics make Li-ion batteries indispensable across modern technologies.

Li-ion batteries are classified into different types, primarily based on their cathode materials and electrolytes. Common cathode materials include lithium cobalt oxide (LCO), lithium iron phosphate (LFP), lithium nickel manganese cobalt oxide (NMC), lithium nickel cobalt aluminium oxide (NCA), and lithium manganese oxide (LMO).

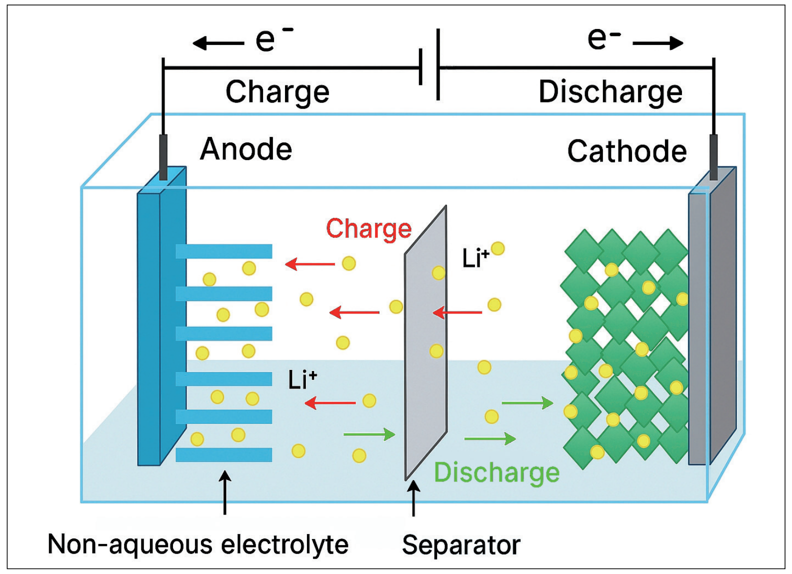
The battery is composed of 4 main components.

- ❏ Anode
- ❏ Cathode
- ❏ Separator
- ❏ Electrolyte

A lithium-ion battery is an electrochemical energy storage device that operates by the movement of lithium ions between the anode (negative electrode) and the cathode (positive electrode) through a conductive electrolyte. When the battery discharges, lithium ions migrate from the anode to the cathode via the electrolyte, while electrons flow through an external circuit, supplying electrical energy to a device. During charging, the lithium ions move in the opposite direction, from the cathode back to the anode, allowing the battery to be reused for multiple cycles.

Separating the anode and cathode is a thin, porous film known as the separator. This component is vital for safety, as it physically prevents the electrodes from coming into direct contact with each other, which could cause a short circuit, while still allowing lithium ions to pass through freely. Together, these components enable lithium-ion batteries to efficiently store and deliver energy, making them indispensable in modern electronics, electric vehicles, and renewable energy systems.

In simplistic terms, the cathode and anode material primarily determine the performance of the battery, whereas the electrolyte and the separator play a considerable role in the safety characteristics of the battery.



Composition of a battery

BESS and Li-ion batteries

The widespread rollout, installation and use of Battery Energy Storage Systems is rapidly increasing.

Li-ion batteries are available in various configurations and chemistries. Their main advantage, compared to other battery technologies, is their enhanced performance in terms of energy density.

Together with the electrical/electronic devices used for battery charging and the battery management system (BMS). The size of a BESS varies from small residential systems to very large sizes/capacities, usually in the shape and form of a steel shipping container, see Figure 1. The latter, sized from 10-ft to 40-ft long and 8-ft wide, which are assembled by an integrator prior to their transportation to the installation site.

BESS thermal runaway, the critical challenge

Battery thermal runaway is a consequence of the battery being subjected to adverse effects. This results in a considerable increase of the battery's temperature, which will cause gasification of the electrolyte and a subsequent rupture of the cells' metal casing or the pouch wrapping, which releases the electrolyte off gases. When these gases come in contact with the atmosphere, they burn (flash fire) at a very high temperature (more than 800 °C).

The main causes of thermal runaway are:

- ❏ Batteries aging and mismanagement.
- ❏ BMS failure resulting in Batteries overheating, and/or overcharging and/or over discharging.
- ❏ Failure of Ventilation or Exhaust System will result in battery overheating.
- ❏ Short circuit on load side of BESS
- ❏ Exposure to heat, for example an external fire.

The fire will involve the battery cells in sequence and the runaway may last for hours. Experience shows that batteries react for hours or even days after the first incident, even when they are apparently under control.

The electrolyte fire will generate substantial amounts of HCl, HF, CO, HCN, and potentially SO_2 , H_2S and H_2

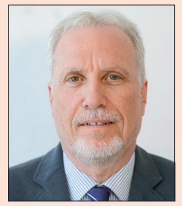
The release of toxic and/or combustible or explosive substances during a fire can evolve forming an explosive mixture.

Through tests performed, it is reported that 120 °C is the critical temperature at which the electrolyte will start to gasify. The battery shall be cooled down to 40 °C to interrupt the thermal runaway sequence, however the remaining power stored in the damaged battery poses an additional potential threat.

The battery thermal runaway may result in serious fires and explosions having catastrophic results if the accident is not contained/controlled.

FirePro R&D Test campaign (ongoing)

From the inception of the R&D test campaign on Lithium-ion battery safety in 2016, FirePro technology has undergone extensive testing in collaboration with leading accredited laboratories, universities, certification bodies, and major Lithium-ion battery manufacturers. These tests included rigorous scenarios designed to replicate real-world failures, such as overcharge, mechanical damage, and thermal abuse, to validate the system's ability to control and suppress fires under various conditions. This article provides some highlights of the testing timeline.



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2016: Safety for storage and transport of Lithium Batteries

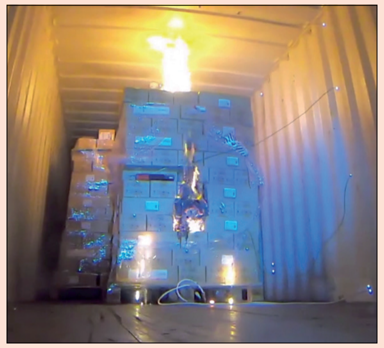
2016: Safety for storage and transport of Lithium Batteries

The R&D journey began in 2016 with the fire safety test performed at the Twente Safety Campus in the Netherlands, which was witnessed by KIWA (Dutch Accreditation Body and designated EU Notified Body). A fully charged 1.9 kWh (51.1 V – 37 Ah) Li-ion battery was placed inside a synthetic barrel within a 40-ft container and the research team used a glow plug to initiate thermal runaway. Various objects were arranged to simulate realistic storage conditions. The FirePro condensed aerosol system demonstrated effective fire suppression and control of the propagation following ignition, achieving an aerosol density of 61 g/m³. This early success was formally documented in KIWA Report 161000995.

2019: Safety for storage and transport of Lithium Batteries, Test no. 2

Building on the earlier findings, the testing continued again in 2019 and the fire suppression system's performance was assessed on a large palletized array consisting of 144 Li-ion batteries, 36 V–14.5 Ah each, resulting in a total energy capacity of 75 kWh. The test was conducted inside a 40-ft metal container at Rely-On Nutec Fire Academy in the Netherlands and was again witnessed by KIWA. Total flooding was achieved within 60 sec after activation, the interior temperature peaked at 799 °C and dropped to below 30 °C within 4 minutes.

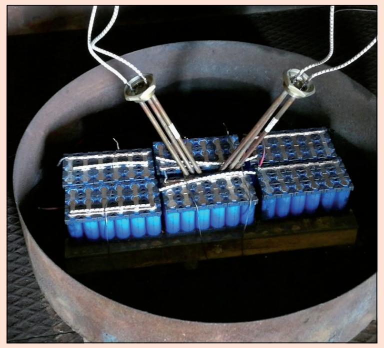
The test was succsefull and the results have been documented in KIWA Report 20190712V3/P190601731 and certified under KIWA Certificate K-0207564/01 in 2022.



2019: Safety for storage and transport of Lithium Batteries, Test no. 2

2019: R&D Test Campaign in Italy with 50 Tests

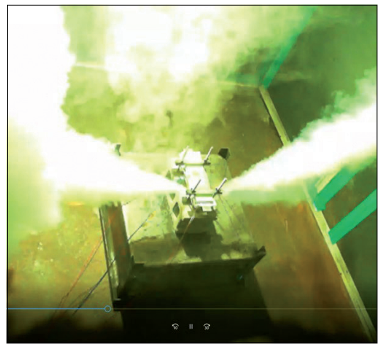
The R&D test campaign for Li-ion batteries gained momentum in 2019 with a series of tests conducted in Italy, at the TCS Fire Test Facilities. A total of 50 tests were performed to evaluate real life accident scenarios involving different Li-ion chemistries and exploring battery failure modes which can lead to thermal runaway. The FirePro Condensed Aerosol technology demostrated its effectivenes in all the extinguishing tests and the results are documented in the 2019 white paper titled "Lithium-ion and Lithium-Polymers Batteries Fire Protection Innovative Engineering Solutions".



2019: R&D Test Campaign in Italy. Example of the 50 Tests

2019: LG-Chem Tests by KFI

Independenant testing was conducted in 2019 by the Korea Fire Institute (KFI). A stack of three LG Chem pouch cells, 4.1 V–54 Ah each, were placed on a heating pad and subjected to gradual heating until thermal runaway occurred. KFI concluded "Li-ion battery fires are challenging and difficult to be controlled. Based on the results, the fire was successfully suppressed, and no re-ignition occurred for the remaining 50min of the test. FirePro condensed aerosol technology managed to suppress and control the li-ion battery fire successfully, with a gross extinguishing density of 200 g/m³."“



LG-Chem Tests by KFI

2020: Series of Tests in Italy

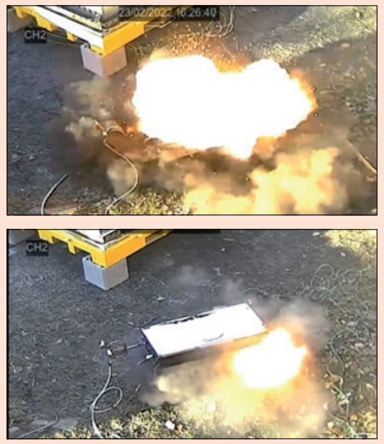
Li-ion battery testing continued in Italy during 2020 and involved a variety of Li-ion and lithium-polymer cells, including pouch, cylindrical, and metallic box types. Conducted at AlbaRubens srl Test Facilities, these experiments concluded that the FirePro Condensed Aerosol demonstrated the ability to control and to further interrupt the thermal runaway, confirming the evidence arose from the research tests performed in 2019 at the TCS Test Facilities in Italy.

2020: Series of Tests in Italy

2022 & 2023: Testing in Italy

A series of tests were conducted to evaluate a FirePro solution which can be incorporated directly into the battery modules. This fire protection solution is intended to be offered to Li-ion battery OEMs.

The tests were conducted inside an experimental box which was equipped with a hinged lid and counterweight allowing for momentary release of overpressure. Each test used two 1.47 kWh Li-ion battery modules with NMC chemistry. The control tests had a comparitive nature, whereby an unprotected battery was subjected to thermal runaway and subsequently compared with an identical battery which was protected with the FirePro engineered solution. The FirePro technology demonstrated the ability of inerting and reducing the magnitude of the deflagaration as well as controling and interrupting the propagation of thermal runaway to the adjacent battery. This was evident by the battery module voltage measurement, which was not affected by the fire.



Tests 2022 und 2023: oben ohne, unten mit integriertem Schutz

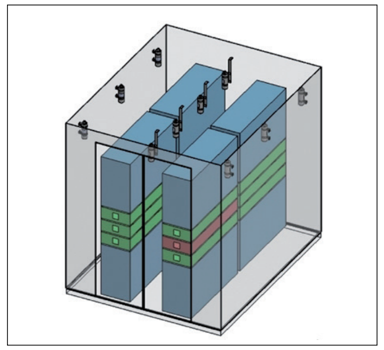
2024: Testing on Simulated BESS

The most recent tests were performed by AlbaRubens srl at the RT CERT s.r.l. Test Facilities in Italy. The primary goal of these tests was the investigation of the ability and efficiency of the FirePro extinguishing system in controlling the thermal runaway of NMC type -Li-ion batteries in a Test rig simulating a full-scale energy storage systgem.

The BESS test rig consisted of four racks containing a combination of Li-ion batteries as well as mock-up (dummy) batteries. The Li-ion batteries used were NMC type LG-pouch cells, each battery module consisted of 12 cells providing a total of 1.47 kWh per module. A total of seven Li-ion battery modules were installed side by side, totaling over 10 kWh, together with a number of dummy batteries which helped simulate a large BESS installation.

A total of two tests were conducted. The one test contained a total of ten FirePro FP-500S aerosol generators and the other test contained the same FirePro aerosol generators together with an additional method of fire protection located within each battery module.

The FirePro condensed aerosol successfully protected the NMC batteries. In both tests, there was no propagation to the adjacent cells/modules. The test setup consisted of aerosol generators utilizing a total FPC Solid Compound Density of 259.7 g/m³, corresponding to a net Condensed Aerosol density of 171.4 g/m³ (these densities included a compensation factor for leakages).



Testaufbau an simulierten BESS. Rot: Batteriemodule, grün: Dummies, grau: Batterie-Racks

Conclusion

Over the past 8 years, FirePro's condensed aerosol fire suppression technology has consistently demonstrated its effectiveness to knock down the flames, significantly reduce heat, control and interrupt the propagation of thermal runaway to nearby Lithium-ion batteries and neutralize flammable and explosive gasses.

2024: Testing on simulated BESS: Battery module voltage – 3 hours after