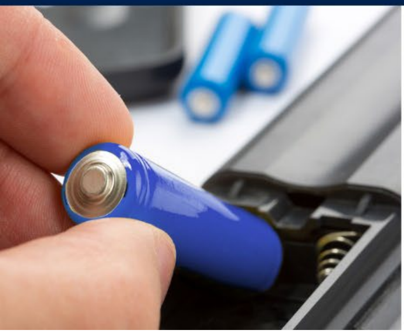
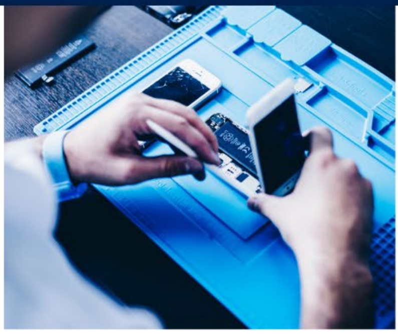
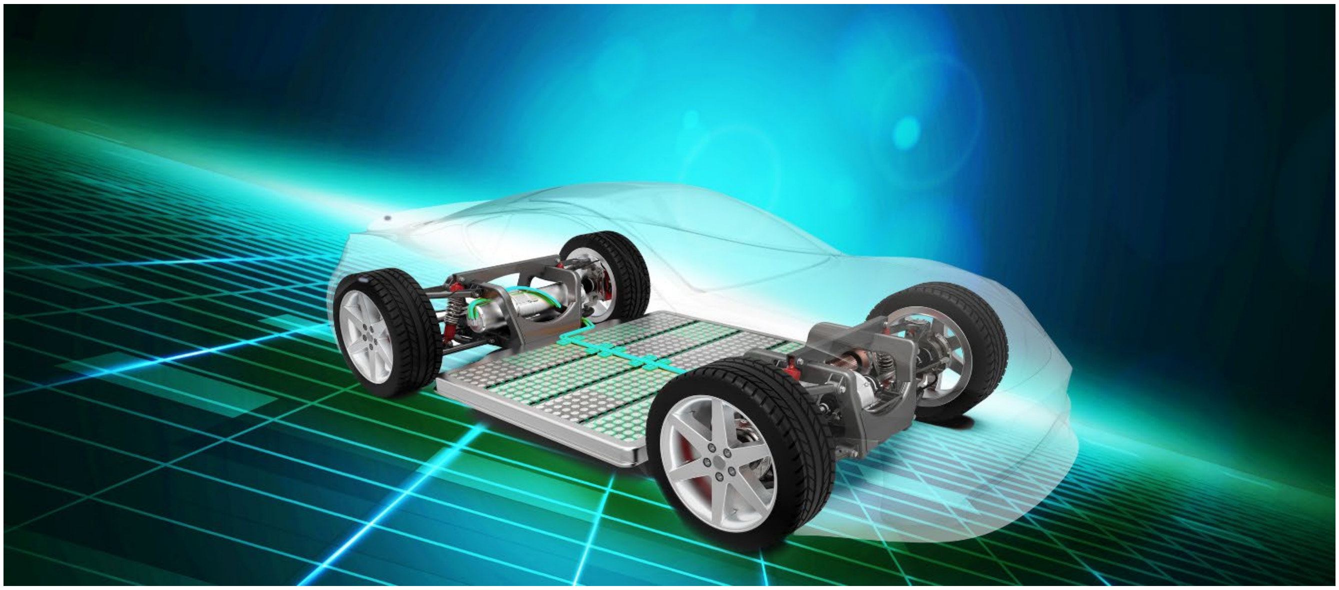




Environmental Test Chambers: The Essential Ingredient for Safer Li-ion Batteries



Lithium-based battery technology is undergoing a remarkable surge, a trend projected to rapidly escalate from its current USD $54.36 billion global market value to $182.53 billion by 2030, according to Grandview Research[1]. Lithium-ion (Li-ion) batteries have emerged as the leading choice for use in electric vehicles, renewable energy storage, and countless consumer devices from smartphones to flashlights. In the future, more thermally stable variations such as lithium iron phosphate (LiFePO4) or lithium ferrophosphate (LFP) will complement Li-ion, necessitating extensive testing to ensure their safety.

Despite its advancements, concerns remain over fires caused by Li-ion batteries. When undercharged, overcharged, overheated, or cracked, they can enter a condition known as thermal runaway, a rapid, violent, self-propagating chain reaction.

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For example, increases in temperature within individual cells in a battery pack can lead to rupture that further increases temperature and ultimately results in catastrophic failure: --fire, explosion, and the release of toxic gases. It is a potentially dangerous scenario, considering these batteries burn at temperatures up to +1000°C and can generate about 100 toxic organic chemicals including carbon monoxide and hydrogen cyanide.

To illustrate this process, consider an electric vehicle in which hundreds of individual battery cells are interconnected in series and parallel. When a single cell fails, it swells, initiating a rapid increase in temperature. This self-heating process then begins to vent gases, and as the process of deterioration spreads, these reactions produce even more heat to adjacent cells, until the entire battery system is affected. Fortunately, battery management systems, which have become more advanced in recent years and rely on several new technologies for sensing, can execute predefined actions such as activating cooling or interrupting the circuit.

This dire scenario doesn't mean that Li-ion battery chemistry is inherently unsafe but rather that if battery cells and battery packs are poorly constructed, the results can be devastating. In fact, studies have shown that vehicles powered by Li-ion catch fire at a lower rate than their gas-or diesel-powered counterparts. [2]

The key is to ensure that they remain safe in any environment and conditions in which these batteries operate. To achieve this, it's essential to perform a series of tests within an environmental test chamber. These tests will become even more important as the automotive industry turns almost exclusively to electric power and the disadvantages of solar/wind power are mitigated by storing energy in massive arrays of batteries.

It is questionable that Li-ion batteries require a considerably higher breadth of testing than other battery chemistries, and the fact that every Li-Ion battery manufacturer uses proprietary chemistry and packaging complicates this process. For instance, the unique properties of the gases that can be emitted must be evaluated along with all the materials used in the batteries' fabrication. Consequently, test chambers are customized to meet the specific requirements of each customer. These include chambers that provide temperature cycling, humidity, thermal shock, vibration, altitude, and other factors.

There are many standards created over the years that cover a massive number of requirements that Li-ion batteries must meet in vehicles in virtually every other application, the most common of which are shown in Table 1.

Table 1. Key standards for battery testing and safety

Test Specification	Description
ANSI C18.3M, Part 2	Portable Lithium Primary Cells and Batteries - Safety Standard
ECE R100 Rev2	Uniform provisions concerning the approval of vehicles about specific requirements for the electric power train
IEC 60086-4	Primary Batteries, Part 4: Safety of Lithium Batteries
IEC 61960	Secondary Lithium Cells and Batteries for portable applications
IEC 62133	Secondary Cells and Batteries Containing Alkaline or Other Non-acid Electrolytes – Safety Requirements for Portable Sealed Secondary Cells, and for Batteries Made from them, for Use in Portable Applications
IEC 62281	Safety of primary and secondary lithium cells and batteries during transport (similar to UN/DOT 38.3)
IEC 62660-2	Secondary lithium-ion cells for the propulsion of electric road vehicles – part 2: Reliability and abuse testing
IEEE 1625	Rechargeable Batteries for Multi-Cell Mobile Computing Devices
IEEE 1725	Rechargeable Batteries for Cellular Telephones
RTCA DO-311	Minimum Operational Performance Standards for Rechargeable Lithium Battery Systems
SAE J 2289	Electric Drive Battery Pack System Functional Guidelines
SAE J 2464	Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing
SAE J 2929	Electric and Hybrid Vehicle Propulsion Battery System Safety Standard – Lithium-Based Rechargeable Cells
UL 1642	Used for testing lithium cells. Battery level tests are covered by UL 2054
UL 2054	Household and Commercial Batteries - Component cell level testing covered by UL 1642
UL 2580	Batteries for use in Electric Vehicles
UN/DOT 38.3	UN Lithium Battery Testing Requirements; covers transportation safety testing for all lithium metal and lithium-ion cells and batteries
UNECE Regulation R100	Safety requirements specific to the electric power train of road vehicles including rechargeable battery systems
USCAR	Battery safety and performance from the EV Battery Test Procedures Manual, Battery Technology Life Verification Test Manual

Testing Safely

The EUCAR (European Council for Automotive R&D) has defined hazard levels to assess the level of danger associated with handling batteries, classifying the hazards presented to batteries, and describing the effects.

Hazard Severity Level	Description	Classification Criteria and Effect
0	No Effect	No effect. No loss of functionality
1	Passive Protection Activated	No defect; no leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Cell reversibly damaged. Repair of protection device needed.
2	Defect/Damage	No leakage; no venting, fire, or flame; no rupture; no explosion; no exothermic reaction or thermal runaway. Cell irreversibly damaged. Repair needed.
3	Minor Leakage	No venting, fire, or flame*; no rupture; no explosion. Weight loss <50% of electrolyte weight (electrolyte = solvent + salt).
4	Major Leakage/ Venting	No fire or flame; no rupture; no explosion. Weight loss ≥50% of electrolyte weight (electrolyte = solvent + salt).
5	Fire or Flame	No rupture; no explosion (i.e., no flying parts).
6	Rupture	No explosion, but flying parts of the active mass.
7	Explosion	Explosion (i.e., disintegration of the cell).

As batteries are exposed to the extensive testing detailed in the standards, environmental test chambers must themselves be secure to ensure that if a battery or battery pack fails, there is no danger to technicians in the facility. A large selection of battery safety options is available and tailored to the battery testing application and hazard level.

Table 2. Common Battery Chamber Safeties

Sheath heaters, not temperature limited	Gas monitor	External light (reach-in only)
Product limit with alarm	CO2 fire suppression	LED light with external electrical connections
Non-sparking fan blades	Heated explosive relief	Personnel safety light stack with audible alarm (walk-in only)
Electronic safety door lock	No internal light	Water spray piping & nozzles (turn on at +120C)
Light stack with audible alarm	Reinforced test space (16ga)	Intrinsically safe barriers on sensor wiring (recommended if Hydrogen gas may be present)
Secondary pressure relief vent	Secondary door restraint (safety chain)	Over-pressure burst disk with burst sensor
Fresh air blower or N2 purge or dry air purge	Temperature limited sheath heaters	Explosion resistant internal light

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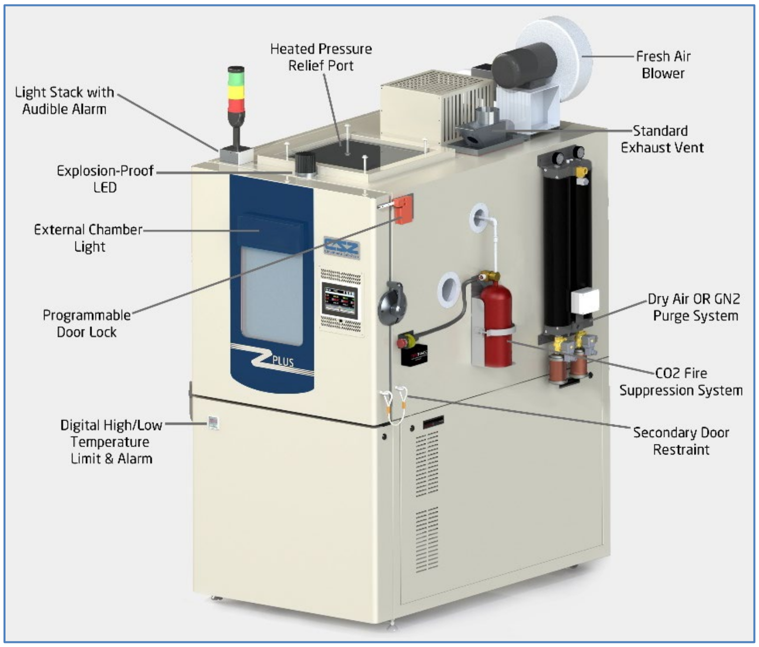
The most common safety feature employed is temperature-limited sheath heaters that are designed to control the surface temperature of the heater to a value that allows the chamber to meet the desired air temperature while remaining below the auto-ignition point of possible flammable gases released from the battery.

In addition to temperature-limited sheath heaters, the chamber can mitigate the risk of spark sources in the presence of flammable vapors by including non-sparking fan blades or blower wheels, installing intrinsic barriers on any wiring entering the test space, and removing internal chamber lights.

When batteries fail, they can release gases that are potentially toxic, or at the very least have an offensive smell and must be vented through an exhaust system. Pressure-relief ports are used for this purpose, reacting to the increased pressure volume caused by the gases. Rupture disks are the most common type of relief system, but more advanced types eliminate the need for manual resetting.

A variety of other safety features can also be employed depending on the anticipated hazard level as defined by EUCAR, including fire detection and suppression systems, H_2, O_2 or CO gas monitors, door safety interlock switches that prevent the door from opening during or after a test or event, and flushing systems for N_2 or CO_2 to reduce the risk of fire and removal of byproducts. Some cases call for a reinforced chamber floor to withstand heavy test loads of the product under test and may also include an internal cooling system to control cell and battery pack temperatures. In the most demanding "test to failure" scenarios, a protective enclosure may be needed to isolate the event.



Other considerations include selecting a control system that integrates with equipment like BMS systems and battery cyclers. It is also essential to size the refrigeration system to accommodate temperature transitions, heat load, and humidity.

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Summary

Two decades ago, few would've imagined that vehicles would soon be powered by batteries or that the electricity generated by the rays of the sun and power of the wind would be stored in battery farms. Yet today, both have become a reality. This transformation is a result of remarkable advancements in lithium-based battery chemistry that are more affordable, longer lasting and have significantly higher power density compared to earlier energy storage methods. Behind the scenes, environmental test chambers have played a vital role in ensuring the safety of these sophisticated batteries, enabling them to endure the challenges of road travel, shipping, and air transport. And as demand grows and new applications emerge for next-generation battery technology, these test systems are prepared to accommodate them.

Over the years, we've provided an extensive range of test chambers to support the evolution of battery technology. Leveraging our expertise, we offer comprehensive testing solutions for battery cells, modules, and packs. Please feel free to reach out to us to discover how we can provide the optimal solution for your battery testing needs.

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