# Environmental Simulation Safeties for Battery Testing

## Understanding the Ancillary Equipment that Keeps Personnel and Product Safe

Weiss Technik North America, Inc.

White Paper
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**Stand the Test of Time**
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**Summary**

A battery is a device that can convert chemical energy into electricity by means of a chemical reaction and power a device. Once some batteries are depleted, they cannot be reused, but many batteries can now be recharged, which has made them very popular in a variety of market sectors.

The need for higher performing, lower weight batteries has increased as the design and production of electric vehicles and other devices has greatly expanded over recent years. Now more than ever, industries are looking to batteries as an answer to their energy storage problem.

While battery manufacturers have spent years developing safe and reliable energy storage technologies, certain risks are always present. These risks are amplified if the battery being used is subjected to extreme conditions such as physical impact, puncture, overheating, overcharging, etc.

The possible risks have been classified into a hazard level list developed by the European Council for Automotive R&D, also known as EUCAR, and their classification of hazard levels has become so popular, that it now has widespread use in many other market sectors. Each hazard level has been assigned a number 0 to 7, with 0 being no risk and 7 being the highest risk. Once the required hazard level is known, a specific safety package is added to the test chamber.

Whether it is to test energy storage solutions for today's needs or new chemistries and technologies for the future, Weiss Technik North America, Inc. has the knowledge and experience to help keep personnel and product safe during all stages of battery testing.

**How Batteries can be Dangerous**

Battery manufacturers have spent years developing safe and reliable energy storage technologies, but certain risks are always present. These risks are amplified if the battery being used is subjected to extreme conditions such as physical impact, puncture, overheating, overcharging, etc.

If a battery is dented or punctured there is a chance harmful fluids can leak. If the battery is used outside its functional temperature range, or if it is overcharged, there is a chance of overheating. Under certain circumstances the battery can undergo a thermal runaway event, which is an uncontrolled exothermic chemical reaction that produces enough energy to maintain itself. The battery produces more heat and energy than what is displaced, so its internal temperature continues to increase until the chemical reaction finishes. A simple example is shown in Figure 1.

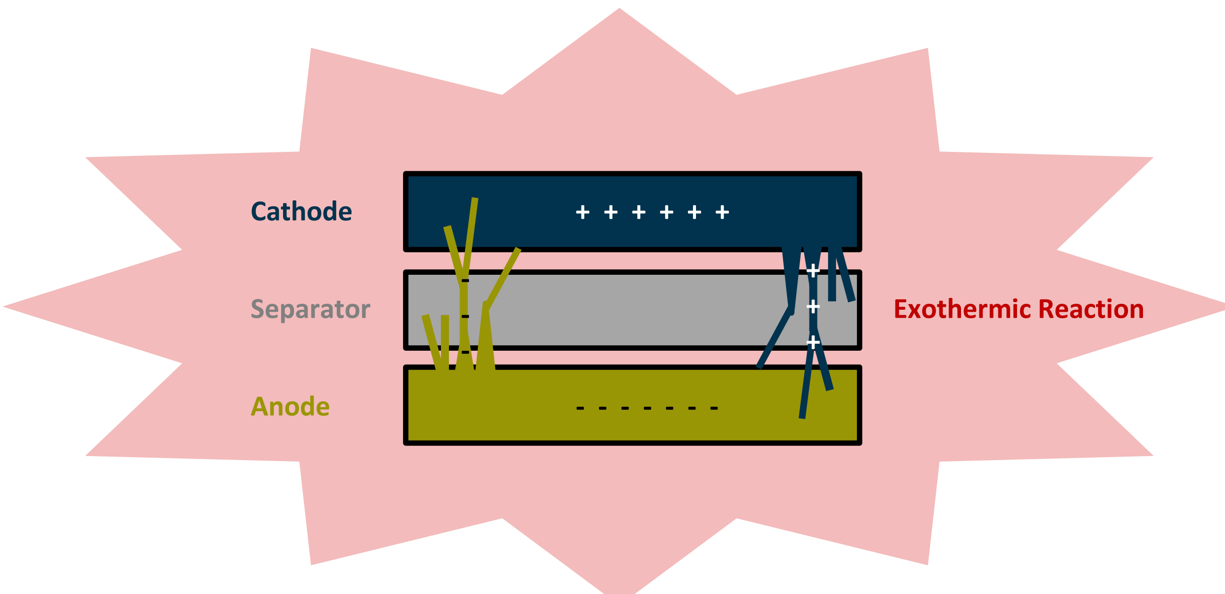


Figure 1: Simple Thermal Runaway Example

Thermal runaways are a major concern, which is why it is critical that indicators of a possible thermal runaway are detected early and acted on quickly. Domestic and international groups such as the American National Standards Institute (ANSI), the Institute of Electrical and Electronics Engineers (IEEE), the International Electrotechnical Commission (IEC), the Society of Automotive Engineers (SAE), Underwriters Laboratories (UL), and the United Nations (UN) have compiled many standards outlining how batteries should be tested, and some of them are listed in Table 1. Batteries need to undergo extensive examination to ensure both new and existing chemistries are safe for consumer use. Whether a battery is being tested to a standard outlined in Table 1 or another standard not mentioned, environmental test chambers can aid in this analysis, but special features have to be put in place first.

Table 1: Example of Battery Testing Standards

| | |
|---|---|
| **ANSI C18.3M, Part 2-2019** | Portable Lithium Primary Cells and Batteries - Safety Standard[1] |
| **IEC 60086-4:2019** | Primary batteries - Part 4: Safety of lithium batteries[2] |
| **IEC 61960-4:2020** | Secondary cells and batteries containing alkaline or other non-acid electrolytes - Secondary lithium cells and batteries for portable applications - Part 4: Coin secondary lithium cells, and batteries made from them[3] |
| **IEC 62133-2:2017** | 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 - Part 2: Lithium systems[4] |
| **IEC 62281:2019** | Safety of primary and secondary lithium cells and batteries during transport[5] |
| **IEEE 1625-2008** | Standard for Rechargeable Batteries for Multi-Cell Mobile Computing Devices[6] |
| **IEEE 1725-2011** | Standard for Rechargeable Batteries for Cellular Telephones[7] |
| **SAE J2289** | Electric-Drive Battery Pack System: Functional Guidelines[8] |
| **SAE J2464** | Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing[9] |
| **SAE J2929** | Electric and Hybrid Vehicle Propulsion Battery System Safety Standard - Lithium-based Rechargeable Cells[10] |
| **UL 1642** | Lithium Batteries[11] |
| **UL 2054** | Household and Commercial Batteries[12] |
| **UL 2580** | Batteries for Use In Electric Vehicles[13] |
| **UN 38.3** | Covers transportation safety testing for all lithium metal and lithium ion cells and batteries[14] |

**How Environmental Test Chambers Keep Personnel and Product Safe**

Environmental test chambers keep personnel and product safe by adding specific features based on the battery sample (size, weight, chemistry, etc.) and the possibility of an event occurring. These possible events have been classified into a hazard level list developed by the European Council for Automotive R&D (EUCAR). EUCAR is a group of automotive manufacturers, shown in Figure 2, and their classification of hazard levels has become so popular, that it now has widespread use in many other market sectors. Each hazard level has been assigned a number 0 to 7, with 0 being no risk and 7 being the highest risk (Figure 3).

Each level of EUCAR presents a new challenge in containing the hazard, and Weiss Technik North America, Inc. has implemented global solutions for customers that test batteries. Some EUCAR levels only require simple monitoring, while higher EUCAR hazard levels require more robust containment. In some unique instances, containment is best accomplished by isolating the test cell from personnel completely.


Figure 2: Members of EUCAR[15]

**External influences, such as**

- External heating
- Overcharging
- Deep discharge
- Excessive charging current
- External short-circuit

**Internal events, such as**

- Electrode-electrolyte reactions
- Electrochemical reactions

Impacts on the lithium battery

| Hazard Level | Description | Classification Criteria & 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 | Leakage<br>$\Delta$ mass < 50% | No venting, fire or flame*; no rupture; no explosion. Weight loss < 50% of electrolyte weight (electrolyte = solvent + salt). |
| 4 | Venting<br>$\Delta$ mass ≥ 50% | 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) |

*Condition: Gas or liquid expelled from the cell is not flammable

Figure 3: EUCAR Hazard Levels[16]

*Package I: EUCAR 0 – 3*

Package I is intended for applications where there could be leakage, but there is no venting, no fire or flames, no rupture, and no explosion. The weight loss is less than 50% of the electrolyte weight, and the liquid expelled from the cell is not flammable. This covers EUCAR hazard levels 0 to 3, and this package includes mineral wool insulation, an optical and acoustic alarm, a door lock, an additional temperature limiting device, and an upgrade to sheath heaters.

Mineral wool, shown in Figure 4, is special insulation designed for high temperature applications. It is extremely resistant to moisture, and it is utilized in all non-panelized Weiss Technik battery test chambers.

Figure 4: Mineral Wool Insulation

The optical and acoustic alarm, shown in Figure 5, is sometimes referred to as a light tower or light stack, and it quickly and effectively communicates the test chamber's status. If the test chamber is running there will be a green light. If there is a warning that should be reviewed, there will be a yellow light. Finally, if there is an alarm the red light and audible buzzer will be active. If the test chamber is large enough for personnel to enter, a blue light will be added, shown in Figure 6, which indicates that a person initiated the alarm (e.g., the emergency stop push button) and that the situation should be immediately addressed.


Figure 5: Optical and Acoustic Alarm


Figure 6: Optical and Acoustic Alarm (Walk-In Test Chambers)

The door lock is shown in Figure 7. This prevents the door from being opened while the test chamber is running, and it also keeps the door locked after an alarm or event occurs. The additional temperature limiting device is shown in Figure 8. It is an independent safety device, meaning it is not wired through the test chamber's controller, and the temperature sensor can be placed on or near the product being tested. If the sensor detects a temperature higher than the set value, an alarm will be issued, and the test chamber will shut down.

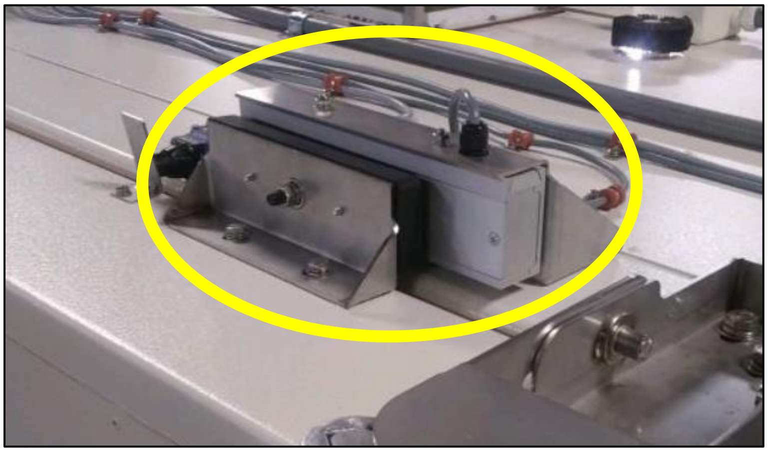

Figure 7: Door Lock

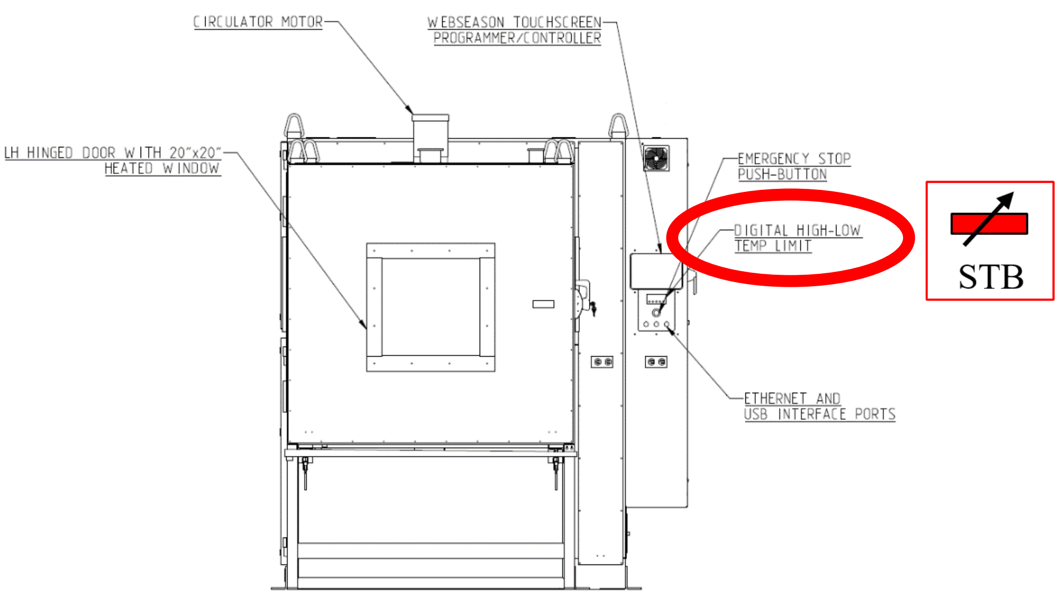


Figure 8: Additional Temperature Limiting Device

The final Package I safety feature is an upgrade to sheath heaters. Weiss Technik uses nichrome wire heaters, shown in Figure 9, for non-battery applications because the very high surface temperature of approximately 700°C effectively increases the air temperature, but this could possibly lead to an auto-ignition event. To prevent this, sheath heaters, shown in Figure 10, are used instead. The sheath heaters have a lower watt density and a surface temperature of approximately 450°C, and this greatly reduces the chances of an auto-ignition event.

Figure 9: Nichrome Wire Heaters

Figure 10: Sheath Heaters

*Package II: EUCAR 0 – 4*

Package II is intended for applications where there could be venting, but there is no fire or flames, no rupture, and no explosion. The weight loss is greater than or equal to 50% of the electrolyte weight, and the gas or liquid expelled from the cell is not flammable. This covers EUCAR hazard levels 0 to 4, and this package includes all EUCAR 0 to 3 safeties as well as a venting duct with mechanical check valve, port plug retention bars, and a fresh air purge.

The venting duct with mechanical check valve, shown in Figure 11 is installed on the top of the test chamber, and it is designed with a weighted pressure release flap. It allows outgassed vapor to safely exit the workspace to the on-site exhaust system. The size and quantity of the venting duct with mechanical check valve is calculated for each project, as every application could be unique. If the venting duct with mechanical check valve has an indirect connection to the on-site exhaust system, it must have permanent ventilation to the hood with a fan, as shown in Figure 12. If there is a direct connection, permanent ventilation is not required (Figure 13).

Figure 11: Venting Duct with Mechanical Check Valve

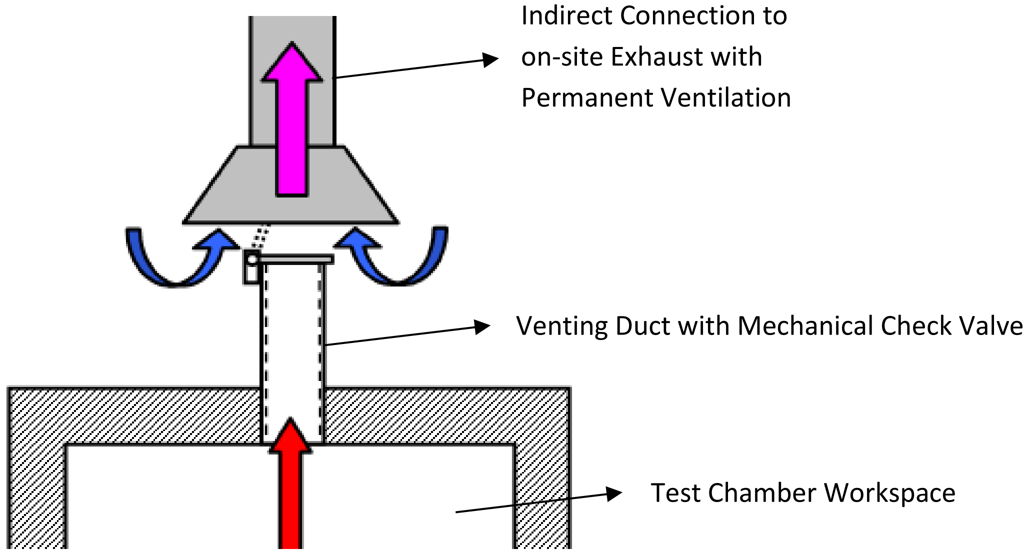


Figure 12: Indirect Connection to Venting Duct with Mechanical Check Valve

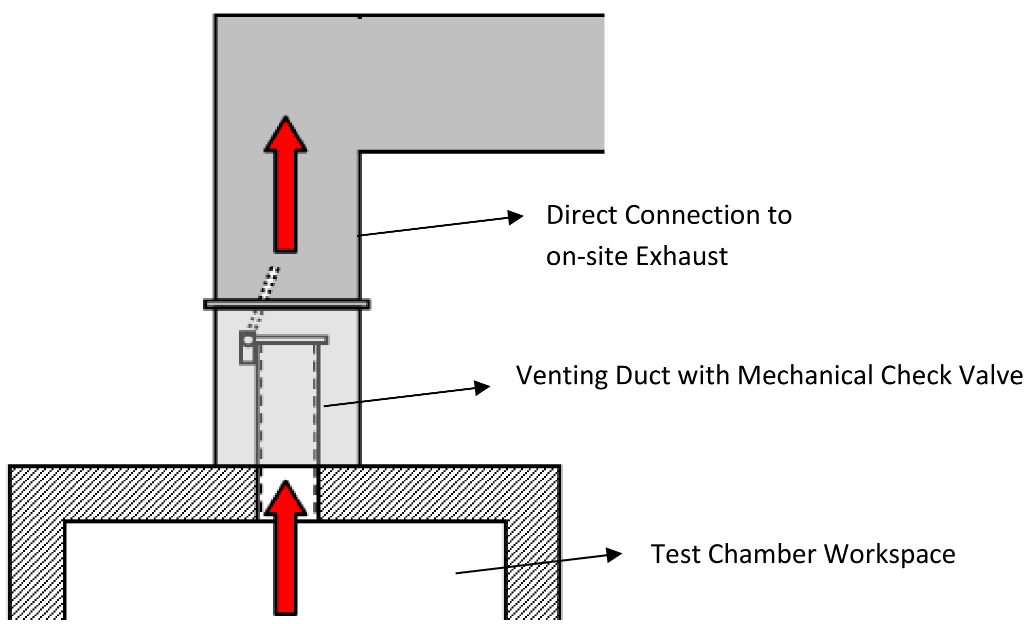


Figure 13: Direct Exhaust Channel to Venting Duct with Mechanical Check Valve

As there could be venting with EUCAR 0 to 4 applications, there is a possibility that port plugs could be ejected from the walls. To prevent possibly injury, a retention bar, shown in Figure 14, is added to all ports. This keeps the port plugs in place during a venting event.

Figure 14: Port Plug Retention Bar

The last Package II safety feature is a fresh air purge, shown in Figure 15. If a venting event occurs, there could still be outgassed vapor inside the workspace after it concludes, so the fresh air purge will force out any remaining outgassed vapor through the venting duct with mechanical check valve.

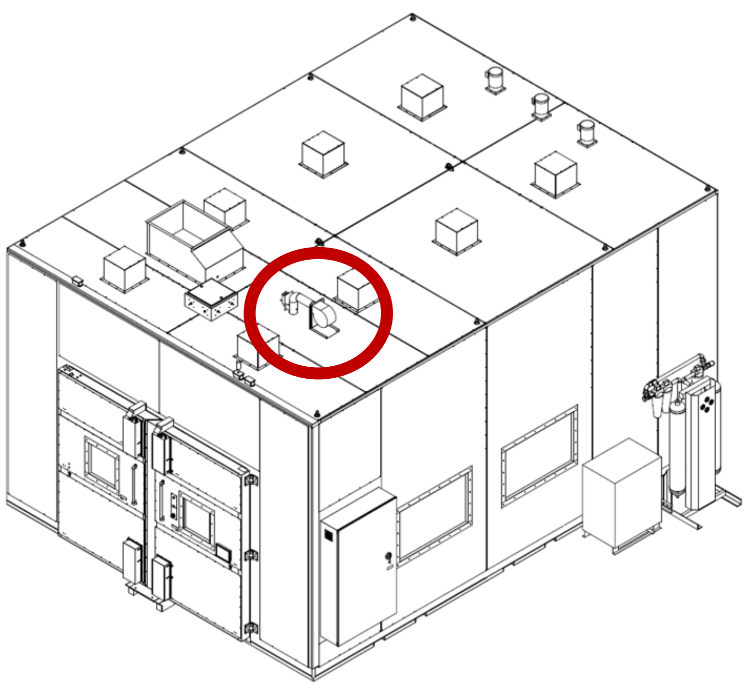

Figure 15: Fresh Air Purge

*Package III: EUCAR 0 – 5*

Package III is intended for applications where there could be fire or flames, but there is no rupture and no explosion, meaning no flying parts. This covers EUCAR hazard levels 0 to 5, and this package includes all EUCAR 0 to 4 safeties as well as fire detection via gas monitoring, a gas monitoring specific optical and audible indicator, and workspace inertization with oxygen ($O_2$) monitoring.

The fire detection via gas monitoring, shown in Figure 16, draws vapor samples from the workspace and an electrochemical sensor is used to measure the quantity of certain substances in the sample, typically carbon monoxide (CO). If the value is too high, an alarm is issued, the test chamber is shut down, and the workspace inertization safety feature is activated. The gas monitoring specific warnings and alarms are displayed in a separate optical and audible indicator, shown in Figure 17.

Figure 16: Fire Detection via CO Gas Monitoring

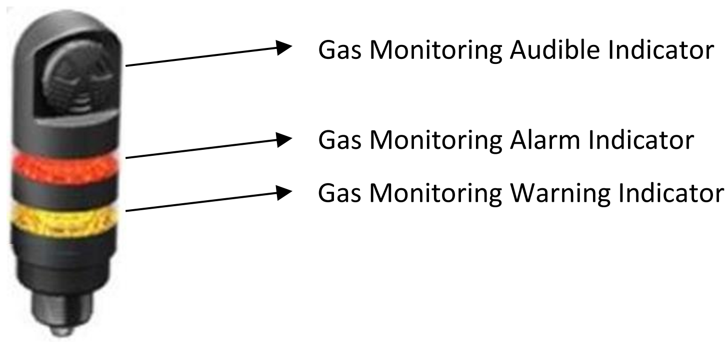


Figure 17: Specific Optical and Audible Indicator for Gas Monitoring

The workspace inertization with $O_2$ monitoring safety features, shown in Figure 18 and Figure 19, first floods the workspace with an inert gas, typically carbon dioxide ($CO_2$) or nitrogen ($N_2$) for reach-in test chambers, when a fire is detected. As $O_2$, heat, and fuel are needed for a fire to sustain itself, this removes $O_2$ from the system as it is replaced with an inert gas. After the event concludes, the fresh air purge returns the workspace to normal $O_2$ levels, which is confirmed with the $O_2$ monitoring device.

Figure 18: Workspace Inertization

Figure 19: $O_2$ Monitoring

*Package IV: EUCAR 0 – 6*

Package IV is intended for applications where there could be rupture, but there is no explosion, meaning no flying parts. This covers EUCAR hazard levels 0 to 6, and this package includes all EUCAR 0 to 5 safeties as well as a burst disc, reinforced test chamber liner, pneumatic door latches or manual clamps, an upgrade to explosion resistant sheath heaters, and an upgrade to explosion resistant interior lighting.

A burst disc is a sheet of metal that breaks at a very specific pressure limit. They are used in Weiss Technik test chambers as a purposely designed weak point so violent outgassing from several cells rupture the burst disc instead of breaking a window or forcing a door open. It is housed in a chimney on the top of the chamber, and Figure 20 shows an example. The dimensions and quantity is specifically sized for each test chamber as the chimney would need to be connected to the on-site exhaust system, similar to the venting duct with mechanical check valve. Note that if an event occurs, the burst disc will need to be replaced as it cannot be repaired or reused. To further ensure that violent outgassing is directed through the burst disc, the test chamber liner is reinforced to withstand overpressure beyond the burst disc's rating.

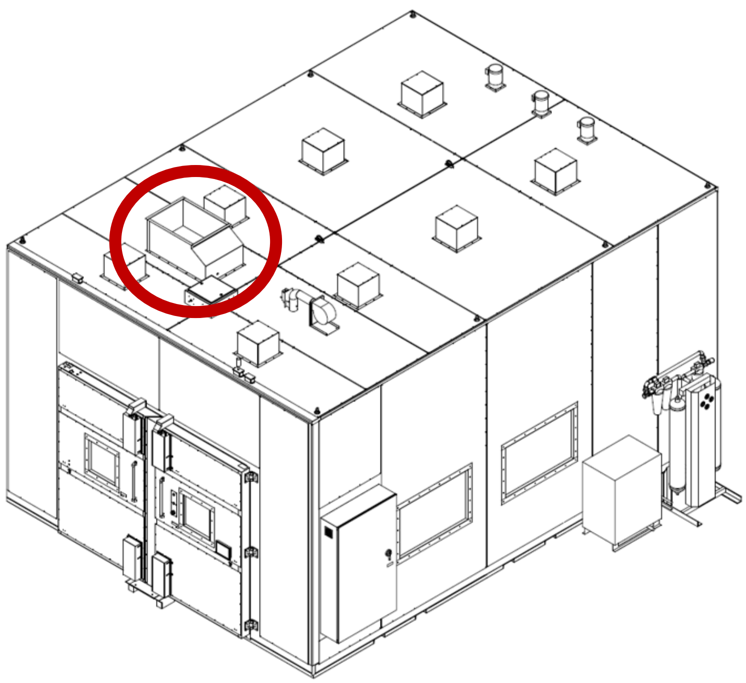

Figure 20: Burst Disc Chimney

While the burst disc is designed to rupture at a set overpressure value, an event could occur so rapidly that another safety feature needs to be in place. To make certain that workspace doors are not forced open, they are either manually clamped (reach-in test chambers), shown in Figure 21, or pneumatically locked (walk-in test chambers), shown in Figure 22.

Figure 21: Manual Door Clamps for Reach-In Test Chambers

Figure 22: Pneumatic Door Latches for Walk-In Test Chambers

To extend protection, the previously mentioned sheath heat in Package I is upgraded to explosion resistant sheath heat, shown in Figure 23. It is still a low watt density heating system, but all electrical connections are now made outside of the workspace. A temperature limiting device is then clamped to the heaters so that the surface temperature can be limited to a value below the auto-ignition temperature of the substance being tested. The lighting system is also upgraded to an explosion resistant style, shown in Figure 24. Similar to the explosion resistant sheath heat, all electrical connections are made outside the workspace.

Figure 23: Explosion Resistant Sheath Heat

Figure 24: Explosion Resistant Interior Lighting

*Optional Accessories*

While Packages I – IV include set features, some applications may require additional equipment. Upon request, a constant air purge, a water spray system, sprinklers, a deluge system, and / or intrinsically safe barrier relays can be added to Weiss Technik test chambers.

The constant air purge continuously introduces fresh air into the test space to keep the workspace below the lower explosion limit of the vapor that could be outgassed. The heating and cooling systems will need to be sized appropriately because this option could introduce additional air exchanges, and the fresh air would need to be conditioned to the test profile being conducted.

The water spray system includes nozzles so that cooling water can be directed at each battery. This option is increasing in use as it can help prevent a thermal runaway and extinguish fires.

Sprinklers or a deluge system use additives such as foaming agents or gelling agents that can assist the extinguishing process if an event occurs.

Finally, all sensor wires that enter the workspace can have an intrinsically safe barrier added so they do not inadvertently become an ignition source.

**Information Needed to Obtain the Proper Battery Test Chamber**

When talking with a sales representative or a contact at Weiss Technik North America, Inc., certain information should be provided so that the correct test chamber can be specified for the intended application. Some, but not all, of this information includes:

- Battery Sample
    - Chemistry Type
    - Size / Weight
    - Design Phase
    - Quantity
- Test Type
    - Temperature Cycling
    - Stability
    - Vibration
- Test Intention
    - Abuse Testing
    - Functional Range
- Surrounding Environment
    - Personnel
    - Location
- EUCAR hazard level

All of this information is contained in a battery checklist document that can be provided once it is known a battery test chamber is needed. The EUCAR hazard level and other battery information needs to be provided in advance because Weiss Technik North America, Inc. cannot specify the safety features that customers should use. To help educate customers, each safety feature can be described so that customers understand why it is required and how it operates. If there are concerns regarding the proprietary nature of the battery to be tested, Weiss Technik North America, Inc. can provide a mutual non-disclosure agreement. Please consult your sales representative for additional details.

**Conclusion**

Batteries continue to be a highly sought after energy storage solution, and they require continued testing to ensure they are safe for consumer use. Many domestic and international groups have developed standards to aid manufacturers in analyzing their batteries, and Weiss Technik North America, Inc. has developed several packages for environmental test chambers that align with the EUCAR hazard levels. Whether there are low risks or chances of violent outgassing with the battery, Weiss Technik North America, Inc. has the knowledge and experience to help keep personnel and product safe.

**Additional Information**

Each environmental test chamber is designed and manufactured so that it meets the customer's specific requirements, and Weiss Technik North America, Inc. continues to research battery testing technology. Check back often as announcements of completed projects are released.

Test chambers that include battery safeties are also available with LEEF® Technology and R-449A refrigerant. Please consult your sales representative for more information.

For any questions, please visit the Weiss Technik North America, Inc. website at www.weiss-na.com, call 616-554-5020, or email sales.na@weiss-technik.com.

***The information included in this white paper is for educational purposes only and should not be used as an engineering design guide. Weiss Technik North America, Inc. should be consulted if a battery test chamber is needed.***

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**Appendix I: Battery Basics**

A battery is a device that stores chemical energy. When needed, the chemical energy can be turned into electricity by means of a chemical reaction. This is possible because a positively charged cathode is connected to a negatively charged anode, with a separator installed between them, shown in Figure 25. When electricity is needed from the battery, a connection needs to be made between the cathode, the device to be powered, and the anode. The electrons ($e^-$) will then flow from the anode, through the device to be powered, and to the cathode because there is a net difference in charge. This discharges the battery, shown in Figure 26, and after a certain amount of time the battery will no longer be able to power the device as all of the electrons have moved through the circuit, which is shown in Figure 27.


Figure 25: Basic Battery Example

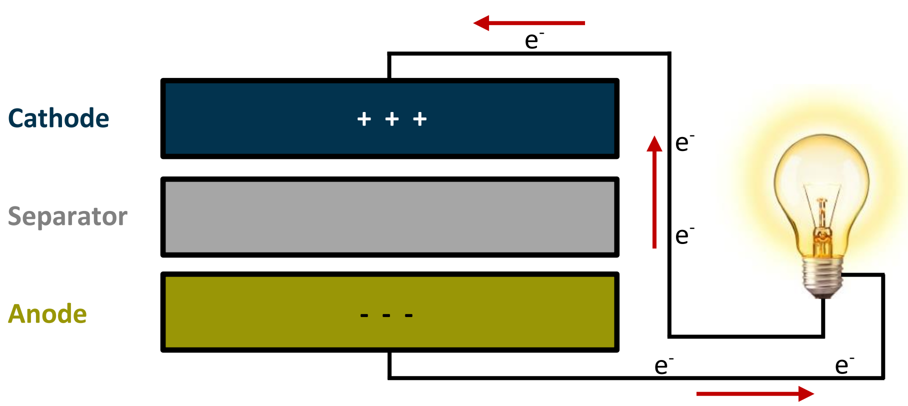


Figure 26: Battery Discharge – Basic Circuit[17]

Once some batteries are depleted, they cannot be reused, but many batteries can now be recharged with a power supply. This forces electrons back to the anode, thus recreating a net difference in charge, shown in Figure 28. Once the battery is recharged, it can once again be used to power a device. The ability to reuse batteries has made them very popular in a variety of market sectors and in many products.


Figure 27: Depleted Battery[1]

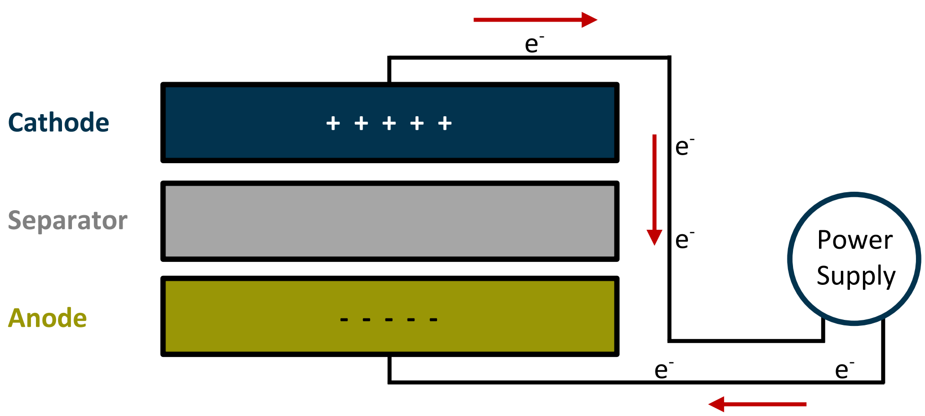


Figure 28: Recharging a Battery – Basic Circuit

**Appendix II: Where Batteries are Used**

Batteries are used in a variety of residential, commercial, and industrial products, and Weiss Technik North America, Inc.'s website showcases many applicable industries (Figure 29). Smaller batteries are used in cell phones and laptops, and larger batteries are be used in storage systems and even full vehicles, to name a few examples.

The need for higher performing, lower weight batteries has increased as the design and production of electric vehicles and other devices has greatly expanded over recent years. Now more than ever, industries are looking to batteries as an answer to their energy storage problem, and while many different chemistries exist, lithium-ion (Li-ion) batteries are currently a market leading solution.

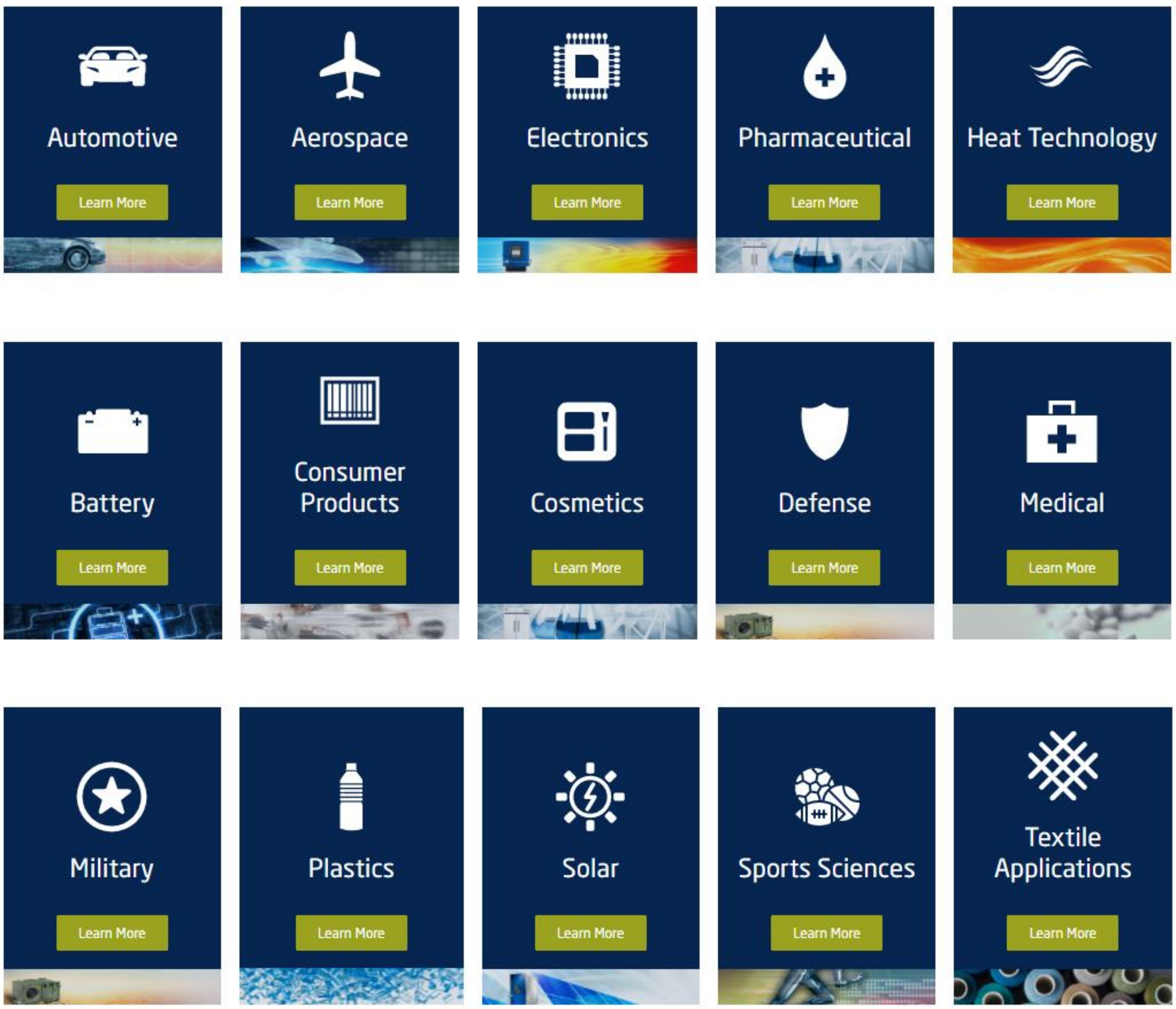


Figure 29: Various Industries Where Batteries Could be Used

**Appendix III: The Current Emphasis on Lithium-Ion Batteries**

Some popular battery chemistries are lead acid, nickel-cadmium (Ni-Cd), nickel-metal hydride (Ni-MH), and Li-ion. Lead acid batteries are used in automobiles with internal combustion engines, Ni-Cd batteries could be used in portable power tools, and Ni-MH batteries could be used in digital cameras. While they are not perfect for every application, Li-ion batteries have been widely selected over other battery chemistries as an energy solution because they store a great deal of energy for their size and weight, shown in Figure 30. The high energy density of Li-ion batteries means that they can power the same device for longer periods of time compared to lead acid, Ni-Cd, or Ni-MH batteries when using a battery of the same size or weight.

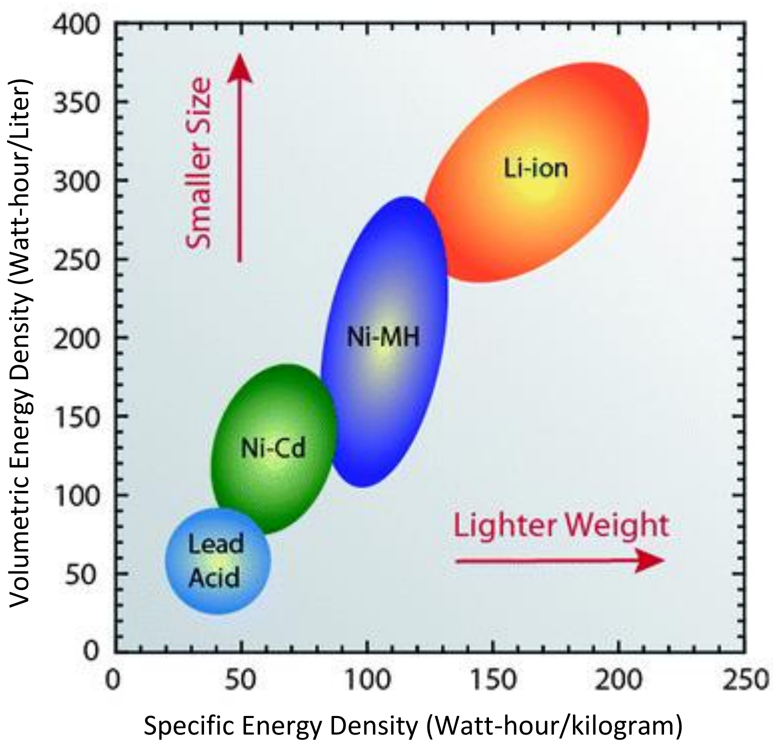


Figure 30: Energy Density Comparison of Different Battery Types[18]

To further illustrate the high energy density of Li-ion batteries, Table 2 and Table 3 show a hypothetical example for an electric vehicle battery. The tables take approximate average values for the different battery chemistries in Figure 30, and if a manufacturer needed to construct a 65 kilowatt-hour battery, they could save over 2,700 pounds (1,225 kilograms) by using Li-ion batteries instead of lead acid.

While the tables are approximations for only a single example, the high energy density of Li-ion batteries remains a noteworthy feature. Manufacturers spend significant resources to develop and test these batteries properly, but there are always inherent risks that need to be considered.

Table 2: Energy Density Comparison

| Battery Type | Volumetric Energy Density (Watt-hour/liter) | Specific Energy Density (Watt-hour/kilogram) |
|---|---|---|
| Lead Acid | 60 | 40 |
| Ni-Cd | 130 | 65 |
| Ni-MH | 200 | 110 |
| ***Li-ion*** | ***305*** | ***170*** |

Table 3: 65 Kilowatt-hour Battery Example

| Battery Type | Volume (liters) | Mass (kilograms) | Volume (cubic feet) | Mass (pounds) |
|---|---|---|---|---|
| Lead Acid | 1,093.3 | 1,625.0 | 38.3 | 3,582.5 |
| Ni-Cd | 500.0 | 1,000.0 | 17.7 | 2,204.6 |
| Ni-MH | 325.0 | 590.9 | 11.5 | 1,302.7 |
| ***Li-ion*** | ***213.1*** | ***382.4*** | ***7.5*** | ***842.9*** |