INDUSTRY INSIGHT

ION THE FUTURE /

CHALLENGING THE SAFETY REGULATIONS AND SETTING NEW STANDARDS FOR LITHIUM-ION BATTERY TRANSPORTATION

Tri-Wall

SMART PACKAGING SOLUTIONS

EXECUTIVE SUMMARY /

THE SAFE TRANSPORTATION OF LITHIUM-ION BATTERIES IS BECOMING INCREASINGLY HIGH ON THE AGENDA DUE TO A NUMBER OF DIFFERENT FACTORS:

- The projected increase of electric vehicles produced to meet the demand for both the UK and export.
- Transportation of cells for new vehicle production, services component and end of life recycling.
- Understanding that lithium-ion batteries which have been through the 38.3 series of tests can still potentially short circuit when damaged, producing all three elements of heat, fuel and oxygen to overheat and cause a major incident.
- Current dangerous goods shipping regulations only stipulate enhanced packaging requirements for batteries that are known to be defective or those that have not yet been 38.3 classified for shipment and do not address the potential transportation hazards. It is suggested that enhanced protection should be paramount for classified batteries and for those greater than 12kg.

THIS PAPER OUTLINES THE HAZARDOUS NATURE OF LITHIUM-ION BATTERIES WHEN UNDER STRESS AND AIMS TO RAISE AWARENESS OF SAFETY IMPLICATIONS THAT COULD ARISE FROM USING PACKAGING NOT DESIGNED FOR, AND TESTED WITH, LITHIUM-ION BATTERIES AND CELLS.

INTRODUCTION /

LITHIUM-ION BATTERY PRODUCTION HAS EXPERIENCED EXPONENTIAL GROWTH IN THE GROWING VEHICLE ELECTRIFICATION MARKET AND STATIC STORAGE. THE UK GOVERNMENT HAS NOW MADE A FIRM COMMITMENT TO BAN THE SALE OF ALL NEW DIESEL OR PETROL CARS FROM 2030, MAKING FULLY ELECTRIC VEHICLES THE ONLY CURRENTLY VIABLE MAINSTREAM ALTERNATIVE.

1.3 million cars were manufactured in the UK in 2019 and if these had all been fully electric, approximately 10 billion cells would be required to meet the demand. The impact of this increased requirement will result in a huge escalation in the handling, shipping and packaging of lithium-ion batteries.

Lithium-ion batteries can become extremely volatile when not handled correctly. In such an event where they are compromised, rapid disassembly can initiate and cells potentially enter a thermal runaway situation.

In these circumstances, the battery cell short circuits itself and creates all the conditions of a fire and explosion including its own fuel and oxygen. The cell rapidly generates enormous amounts of heat and energy which will burn until all fuel is exhausted and this potential chain reaction can last for more than 24 hours.

How the battery cells are manufactured, packaged, stored, handled, and transported, can affect exactly how volatile the event becomes, from minor to catastrophic.

In recognition of this, 2019 saw Tri-Wall, along with partners, initiate LIBRIS (Lithium-Ion Battery Research in Safety), a government funded research and development programme looking into the safe production, handling and transportation of lithium-ion batteries and their components.

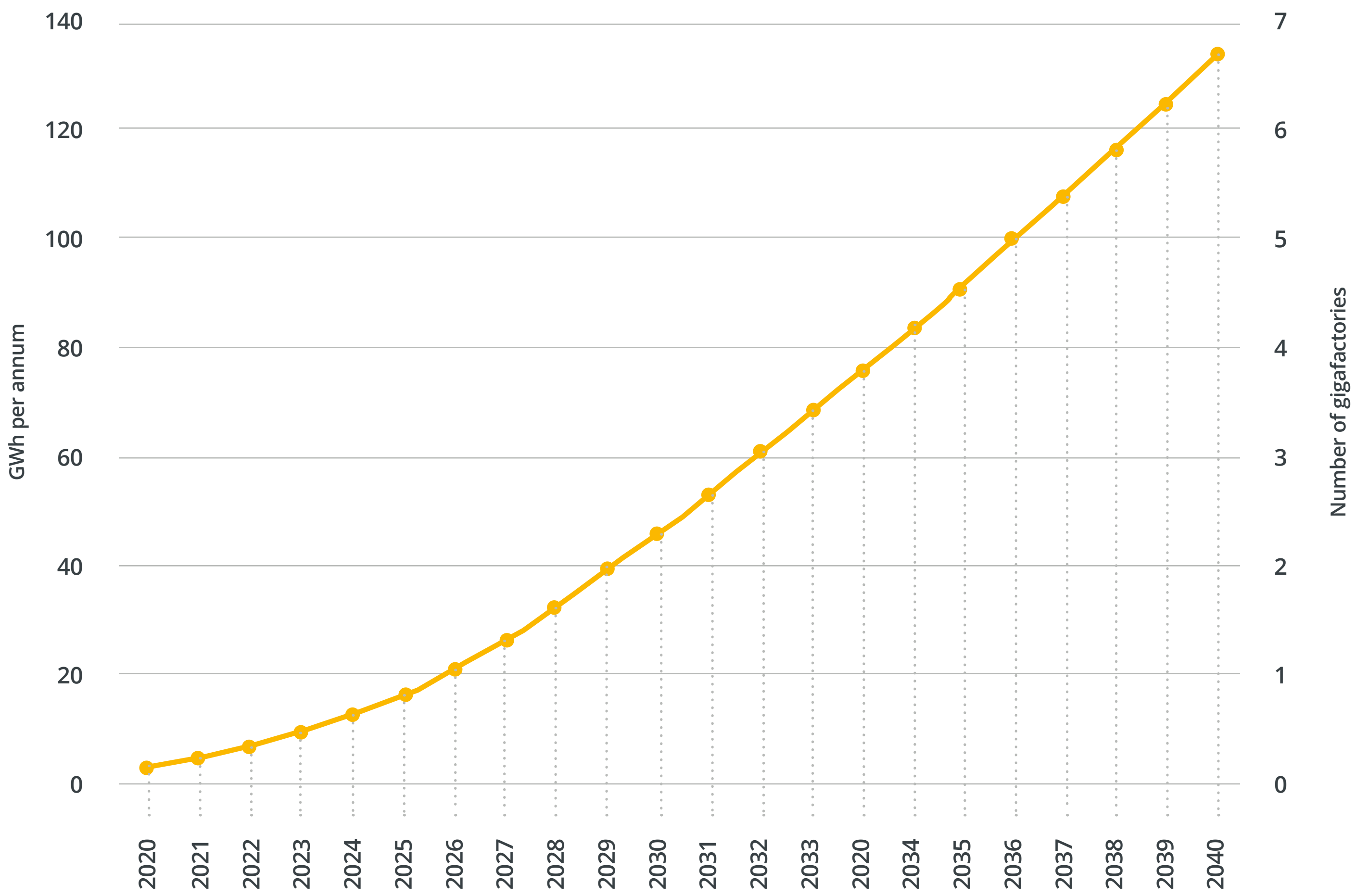
The LIBRIS collaboration made up of industry heads and academia included; Tri-Wall UK, Jaguar-Land Rover, 3M, Warwick Fire, UK Health and Safety Executive, Warwick Manufacturing Group, Denchi Group, Potenza, Innovate UK, and Lifeline.

THE NEED /

- THE ELECTRIFICATION OF VEHICLES IS A MAJOR PRIORITY FOR THE UK GOVERNMENT IN THEIR COMMITMENT TO A LOW CARBON, CLEANER FUTURE.
- THE PRODUCTION OF DIESEL AND PETROL CARS WILL BE BANNED FROM 2030.
- IN 2019, 2.3M VEHICLES WERE SOLD IN THE UK, 1.3M OF WHICH WERE MANUFACTURED HERE.
- BATTERY REQUIREMENTS EXPECTED TO RISE EXPONENTIALLY TO MEET THIS INCREASED DEMAND.
- ASSUMING THE SAME VOLUMES AND AN AVERAGE OF 7,500 CELLS PER VEHICLE, THIS EQUATES TO A REQUIREMENT FOR JUST UNDER 10 BILLION CELLS PER ANNUM TO WITHSTAND THE UK'S MINIMUM AUTOMOTIVE MANUFACTURING REQUIREMENTS

PROJECT DEMAND FOR UK-PRODUCED BATTERIES

This graph shows the expected UK battery requirement from March 2020. We have already exceeded these predictions with British Volt at manufacturing readiness by 2023 and AMTE expected by 2025.



Add to this the requirement for static energy storage needed for reusable clean energy and the end-of-life product moving to re-life or recycle and there is clearly a significant volume of battery product requiring safe transportation.

Source: The Faraday Institution

ELECTRIC VEHICLE LIFE CYCLE /

NEW OR CHANGED SAFETY SCENARIOS

DESIGN AND TESTING	CELL/BATTERY MANUFACTURE		VEHICLE MANUFACTURE	TRANSPORT AND SALE	USE		DISPOSAL	
Cells with new chemistry	Hazards of electrode materials	Battery/cell supply chain	Assembly	Vehicle distribution	Normal use maintenance	Abuse	Second life applications	Scrap
Validation to standards - cell and pack level	Hazards of electrolyte	Cell/battery import	Workplace accidents	Test drives	Dealerships	Arson	Removal of battery packs and disassembly	
New charging methods	Storage of materials	Transport to storage	Cars on assembly with energy	Charging infrastructure at garages	Trained mechanics	Insurance scams	Storage of batteries/cells	
Swappable battery packs	Clean/dry rooms	Battery assembly	Final testing	Transport of damaged/research packs/modules	Breakdown - roadside repair	Modification/ tinkering	Quality assessment of used cells	
EV crash testing	Warehousing	In-factory transport	Storage of eject packs		Aging packs	Involvement in RTA	Sorting of batteries	
Software - testing of functional safety	Highly automated environments				Battery pack replacement	Backstreet/ home repair	Recycling and material recovery	
Validation of software methods	High voltage manufacturing skills			Vehicle resale	Flooding			
	Storage of bulk cells/packs				Events in hard to access places			
					Charging infrastructure			

NB: Need to consider

Environmental impact / Long term health

Dealing with 'Failed' packs or EV's

First responders: Fire and Rescue Services Vehicle Recovery Police Helpful public (!)

Source: HSE

WITH THE CLEAR GROWTH IN ELECTRIFICATION AND THE MANUFACTURING UPSCALE THAT IS REQUIRED TO FACILITATE THIS GROWTH TO MEET GOVERNMENT COMMITMENTS ON CLIMATE CHANGE, THERE IS A STRONG DEMAND FOR THE SAFE TRANSPORTATION OF LITHIUM-ION BATTERIES AND ASSOCIATED ELECTRONICS.

Manufacturers state that lithium-ion cells have a failure rate of less than one in a million and that the worst-case scenario for shipping cells is a single failure at a 30% SOC. Whilst the risk of a recently manufactured 38.3 certified cell entering thermal runaway is extremely low, it can happen if exposed to a significant heat source or penetration. A failure in inadequate packaging can allow such an incident and subsequent propagation with cells in close proximity, not only during storage, but also in the distribution network.

Significant destructive testing within the LIBRIS program has produced a clear data set that concedes to a requirement for a heat energy mitigating material to contain and extinguish any event of this nature, regardless of whether the cell, module or pack has passed the UN38.3 testing criteria and certification.

Tri-Wall are renowned as the largest technical packaging company in the world. Tri-Wall specialise in dangerous goods packaging and were previously involved in developing suitable material for the Ministry of Defence packaging standards (DEFSTAN), with corrugated board specifications originally based on Tri-Wall’s heavy-duty grades.

Tri-Wall identified the need for very specific, safe packaging to meet this projected demand in battery transportation. Something that not only addressed the current regulatory bodies’ certifications but also took a step further in applying very precise, in-built safety aspects founded on evidence-based “live cell” testing data to ensure that the risk of a significant thermal runaway event occurring in a distribution network or warehouse is mitigated to a minimum or indeed eliminated.

INITIAL RESEARCH AND SET-UP /

FROM LONG-STANDING AND HONOURED RELATIONSHIPS WITH THE UK GOVERNMENT, THE JOURNEY STARTED BY ATTENDING AN ARRAY OF STEERING WORKSHOPS SUCH AS THE BRITISH STANDARDS, HEALTH AND SAFETY EXECUTIVE AND UKRI COHORT – TO WORK TOWARDS RAISING THE STANDARD WHEN WORKING WITH LITHIUM-ION BATTERIES.

Having broken the task down into partner allocated work packages Tri-Wall started by identifying the risks and requirements, holding and attending a number of hazard mapping workshops with both industry and the public to identify the concerns and requirements.

They attended many government and university cohort events leading into conversations with the Warwick Manufacturing Group (WMG) as part of the Warwick University Research and training organisation. WMG has strong links to major automotive development and capabilities in cell manufacture, modelling and testing.

It was from WMG that Tri-Wall were introduced to the Pre-Lib's team. Pre-Lib's had already been set up to address the feasibility of safety requirements in battery usage for automotive and military applications but welcomed the addition of Tri-Wall's technical knowledge and capabilities to increase the scope of this work for safe transportation.

This enabled the creation of the full LIBRIS team of industry and academic expertise.

THE LIBRIS TEAM /

LITHIUM-ION BATTERY RESEARCH IN SAFETY

TRI-WALL UK AND ITS PARTNERS BUILT ONE OF THE UK'S STRONGEST COLLABORATIONS WITH THE CAPABILITY TO DELIVER THE NECESSARY RESEARCH, DEVELOPMENT AND DESIGN THAT WOULD LEAD TO UNRIVALED SAFETY IN THE TRANSPORT AND STORAGE OF LITHIUM-ION BATTERIES.

Each of the organisations brought an individual skill set to produce a robust deliverable and lead into the necessary return on investment for the UK. The collaboration included:

UN Dangerous Goods and Technical Packaging Experts

The UK's largest automotive manufacturer

The UK Government Health and Safety Executive

Global specialist materials design and manufacture

Warwick Manufacturing Group / Warwick University / Warwick Fire

A leading provider of energy storage solutions that specialises in high reliability battery systems

Automotive fire experts and FIA Motorsport advisory

The UK Battery Industrialisation Centre.

Electronic battery management (BMS) expertise.

LIBRIS

Lithium Ion Battery Research In Safety

PROJECT.105296

Led by the guidance of Professor David Greenwood, a well-respected UK expert in electrification, the collaboration needed to represent the industry leaders in each of their fields.

There are demanding requirements for each representative industry, from Jaguar Land-Rover's knowledge of high-volume vehicle production to 3M's advanced chemical learnings and the HSE's test and validation facilities linking across the electronics and fire suppression skill set of the other partners. All of this capability was of little value without the ability to transport products safely and so the cross dependencies were established.

The creation of such a large collaboration of industries and academics with a single objective attracted not only government support but also the attention of other organisations and services to share in the collective data outputs so that they too, may be able to operate best practice procedures. This has been a rare and valuable opportunity and has led to some of the most effective research and product outputs designed around the safe use of Lithium-Ion batteries.

The consortium has also hosted a large number of speaker events where they have been able to share the collective findings for the improvement of the country's manufacturing capability.

GOVERNMENT SUPPORT /

UK GOVERNMENT HAS MADE A STRONG COMMITMENT TO THE TAXPAYER TO DELIVER A CLEANER FUTURE WITH THE RELIANCE ON FOSSIL REPLACED WITH SUSTAINABLE ENERGY IN THE FORM OF ELECTRIFICATION FROM SOURCES SUCH AS WIND AND HYDRO. THIS TYPE OF POWER LACKS THE "ON DEMAND" NATURE OF PREVIOUS TECHNOLOGIES AND THEREFORE REQUIRES THE STORAGE OF LARGE VOLUME ENERGY SUPPLIES.

Currently, this comes in the form of battery technology on an unprecedented scale. As with any forced rather than evolved technology, there needs to be industry experts to advise and deliver the programs.
Innovate UK is the UK Government department that has the task of identifying this expertise and conducting studies of the capability to deliver.

Having put the collaboration forward, LIBRIS was awarded a grant of public money to support the £4.6M programme representing government confidence in Tri-Wall and partners.

TESTING AND DATA OUTCOMES /

WHILST WARWICK UNIVERSITIES, "WARWICK MANUFACTURING GROUP (WMG)" AND WARWICK FIRE CONDUCTED A SIGNIFICANT NUMBER OF LIVE CELL DESTRUCTION TESTS TO ESTABLISH THE DEFINITIONS OF BATTERY FIRES, TRI-WALL SOURCED, DEVELOPED AND PRE-SCREEN TESTED MULTIPLE MATERIALS FOR COMPATIBILITY AND SUITABILITY.

The evidence gained produced an event data set that included the following factors:

- Heat and time event mapping: from 0-400 sustained pack heat, 400-800 event momentary and up to 1200 degrees ejected molten casing particulates.
- Jelly roll ejection at 8grams (est) and 33 m/s = 7.7 joules kinetic impact velocity
- Heated gas expansion of approximately 1lt /cell x Volume of cells in pack
- Propagation to neighbouring cells / millimeter incremental spacing
- Sustained "Constant" heat effects.
- Toxicity of discharge gasses
- Potential thermal runaway initiation scenarios

Cell pack testing with the HSE
Six 18650-type cells charged at 100 % and heated simultaneously to thermal runaway (TR) using kanthal wire

Pouch cell testing

UKAS UN4G drop test

TESTING PROCEDURES /

01 /

STEP 1 OF TESTING / BLOWTORCH TEST

The first step in the test procedure was to evaluate the technical data sheet of the material selected to determine whether integration into corrugated packaging could sustain temperatures exceeding 500°C.

To understand if the material had application-suitable fire-retardant qualities, we created a simple simulation using a blowtorch test rig. By placing the blowtorch 10cm away from the material and setting it to burn for 2 minutes (unless the material burnt away or it became unsafe to continue burning), the test recorded an initial data set using the lab camera and a thermal imaging camera.

The purpose of this test was to replicate the heat and flame exhibited when a battery goes into thermal runaway. This was a good initial pre-screen test to eliminate any inadequate materials prior to more extensive testing conducted on site at the HSE.

The temperature of the board (burn side and cold side) was recorded as an indicator of the insulating properties of the material. Thermocouples were placed inside the first layer of fluting and the back of the board, to monitor temperature changes throughout the board.

A pass criterion considered for material that could withstand heat, was approximately 900°**C** for 2 minutes and it could not have any impact on the inner board. The back or 'cold' side of the board could not exceed 100°**C** for a sustained period. Materials that failed to provide sufficient insulation were deemed unsuitable and excluded.

02 /

STEP 2 OF TESTING / LIVE CELL TESTING

For this test, a pass is any material that not only withstands the excessive heat and flame produced by the cell in a thermal runaway event, but also the force generated without any impact to the board or fluting.

The key difference between the Tri-Wall blowtorch test and the HSE live cell test is that the blowtorch test cannot replicate the pressure forces of a lithium-ion battery in thermal runaway. As the cell enters a thermal runaway event, it expels fragments of molten case particulate metals at high speed, which can penetrate the material making it more vulnerable to penetration. This reduces the fire-retardant qualities of some materials once the outer surface has been compromised.

03 /

STEP 3 OF TESTING / PACK DEVELOPMENT STAGE

The third stage of testing involved progressing two materials to the ‘pack development stage’ where they were integrated into corrugated boxes. The two materials selected were 3M derived E-glass and the paper based endothermic material.

Working alongside 3M, Tri-Wall designed E-glass material into a bag with cavities encasing vermiculite; the bag was designed to fit inside the box to encase the cells/module being packed.

The latter endothermic material has been tested to the proposed SAE-G27 standards for transporting lithium-ion batteries by land, sea and air. The test reports supplied from the NRC showed that the material acts as an excellent insulator during a thermal runaway event and its paper-based construction meant Tri-Wall were able to produce box liners using a flat-bed die cutter. Both materials were then integrated into corrugated boxes with foam fittings to hold 64 18650 NCR cells.

OBSERVATIONS DURING TEST OF SPECIMEN 1

Time (min:sec)	OBSERVATION	Temperature (ºC)
00:01	Specimen inserted and heater switched on, test commenced	21
03:05	The specimen began to char	239
03:42	Smoke began to emerge from the specimen	284
03:51	The specimen began to glow	299
04:21	The glowing travelled 50mm down the specimen	331
05:21	The whole specimen began to glow	409
06:32	The specimen was full charred and began to fall	401
07:01	Glowing on the specimen ceased	400

OBSERVATIONS DURING TEST OF SPECIMEN 2

Time (min:sec)	OBSERVATION	Temperature (ºC)
00:01	Specimen inserted and heater switched on, test commenced	21
03:08	The specimen began to char	245
03:45	Smoke began to emerge from the specimen	285
03:55	The specimen began to glow	297
04:23	The glowing travelled 50mm down the specimen	334
05:25	The whole specimen began to glow	412
06:38	The specimen was full charred and began to fall	399
07:05	Glowing on the specimen ceased	398

OBSERVATIONS DURING TEST OF SPECIMEN 3

Time (min:sec)	OBSERVATION	Temperature (°C)
00:01	Specimen inserted and heater switched on, test commenced	21
03:03	The specimen began to char	238
03:43	Smoke began to emerge from the specimen	278
03:57	The specimen began to glow	294
04:20	The glowing travelled 50mm down the specimen	331
05:22	The whole specimen began to glow	410
06:39	The specimen was full charred and began to fall	400
07:04	Glowing on the specimen ceased	399

The specimen fully glowing

The specimen fully charred and falling (just before extinguishing)

The specimen extinguished

Figure 11- 212BC Heat test images.

04 /

STEP 4 OF TESTING / VALIDATION

The final stage involved testing corrugated packs containing live cells at the HSE. The data recorded from these tests allowed us to monitor internal and external box temperatures throughout a thermal runaway event. Tri-Wall designed tests to push the upper limits of the materials with each material being subjected to two identical assessments.

Firstly, a test was conducted in which six 18650 NCR cells at a 30% SOC were set into thermal runaway simultaneously. The remaining 58 cells in the pack were still at a 30% SOC and remained to show whether the mitigating material prevented propagation or not.

The second test was a repeat of the first. However, all 64 cells were at a 100% SOC; this was carried out on both material types. The test was then repeated but only one cell was set into the thermal runaway instead of the previous six, using only the paper-based product as the mitigating material.

Using a current automotive module, the final test was conducted to examine the capabilities on larger packaging. Using the higher energy density 21700 cell in this test along with 'dummy' cells to fill the remaining void space inside the module, seven of these cells were sequentially set into thermal runaway at a 30% SOC.

PACK CONTAINS 64 LIVE CELLS AT 30% SOC

Thermal Runaway initiated in six cells by heating the core. Energy release is contained to the triggered cells with no propagation to the neighbouring cells. Impact velocity is contained and no flame or heat beyond 100 degrees recorded on the outer surfaces.

PRODUCT DEVELOPMENT /

ALL OF THE DATA CAPTURED HIGHLIGHTS THE LACK OF SUITABILITY THAT CURRENT PACKAGING SOLUTIONS OFFER AND THAT CURRENT REGULATIONS HAVE BECOME OUTDATED IN THIS FAST-EVOLVING TECHNOLOGY.

Although current market packaging would appear to adhere to the regulations and certifications, they offer minimal, if any, protection for the risks and effects of thermal runaway within the packaging and the risks of propagation to neighbouring cells.

To address the safety risks involved in transporting cells and batteries, there needs to be levels of mitigation control of the released energy of such adverse events.

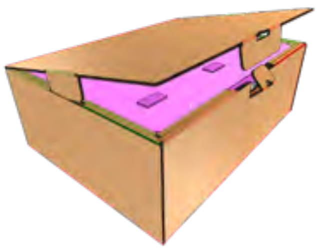
Drawing on 3M's global experts and Tri-Wall Monmouth lab technicians, a portfolio of newly developed packaging with inbuilt energy mitigation properties began to be built. Very specific packaging designs were developed to produce solutions for everything from cylindrical, pouch and prismatic cell transport to module and full vehicle battery packs.

This also included a container constructed with intelligent design and lightweight composite aerospace materials, suitable for cells that are defective or in an unknown state, recycling applications and end of life (EOL) products.

The packaging range created is an industry first, offering significant benefits in risk mitigation, cost reduction, weight reduction for return loops and overall a better carbon reduction efficiency in both the build and the usage lifecycle. It also incorporates sophisticated electronic wireless monitoring equipment to add further layers of safety beyond that seen in currently available products.

DESIGN /

CYLINDRICAL, POUCH OR PRISMATIC CELLS



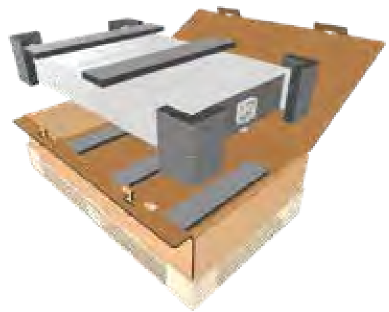
- New Packaging design consisting of:
  - Outer die-cut folder with improved locking tab feature
  - Inner die-cut tray with cut-out to cater for front locking tab
  - Newly designed internal foam fittings

- Corrugated folder and tray are made from kraft C flute material; and foam fittings are made from 25mm anti-static Novastrat.
- New pack factor 16 pouch cells per box to adhere to manual handling limits.

- Approx. weight and size: 14.7kg and 600 x 460 x 220mm (LxWxH)
- Scalable and with the option of thermal mitigation wrap

- Corrugated outer box
- Internal foam fittings
- Inner tray with four layers of board
- Fully scalable and customisable

- Timber outer with locking lid
- Internal mounting points
- Built in pallet system
- Fire retardant timber
- Fully scalable and customisable



- Up to 300kg weight
- Corrugated outer box
- Internal foam fittings
- Pallet system
- Fully scalable and customisable

DESIGN /

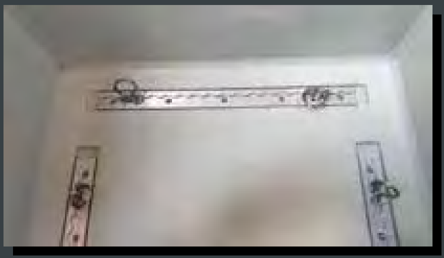
FOR DEFECTIVE AND END OF LIFE PRODUCTS

Tri-Wall have gone back to the drawing table on this to redesign a Group 1 box suitable for the current requirements of shipping Lithium-Ion batteries. We have developed a new lightweight composite material that will offer cost and weight reduction whilst still being able to meet the requirements of the following:

- Heat resistance of up to 800°C with a sustained outer pack temperature below 100°C
- Internal resistance of ejected internal particle velocity of 10 Joules (8 grams at 33 mtrs/sec = 7.7 Joules).
- Gas release valves with flame arrestors to ensure no flame outside of the pack.
- Electronic Bluetooth pack monitoring capability.


Composite pack external design.


Composite pack without lid.


Composite pack internal design.

TECHNICAL KNOWLEDGE /

SUPPORT

LIKELY TO DISASSEMBLE?

YES — **G1 box required**

NO

IN GOOD CONDITION? (NOT DAMAGED OR DEFECTIVE) & UN38.3 TESTED?

IF YES TO BOTH

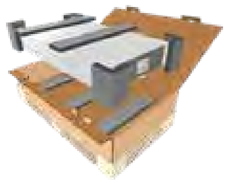
IF NO TO EITHER

CORRUGATED

Limit of 300kg. Pack options for cells, modules and full vehicle battery packs.

PACKING INSTRUCTIONS P903 / LP903

CORRUGATED



Limit of 300kg. Pack options for cells, modules and full vehicle battery packs. Thermal runaway mitigation wrap is required.

PACKING INSTRUCTIONS P908 / LP9034

TIMBER

Bespoke pack designed for modules or full vehicle battery packs.

PACKING INSTRUCTIONS P903 / LP903

TIMBER

Bespoke pack designed for modules or full vehicle battery packs. Thermal runaway mitigation wrap is required.

PACKING INSTRUCTIONS P908 / LP9034

MITIGATION MATERIAL

Thermal runaway mitigation wrap is optional and can be included within all packs. The wrap displaces energy and rapid head dissipation, releasing a colling medium. 100% recyclable.

G1 BOX

Range of lightweight, ultra-strength G1 boxes, fitted with gas release valve. Suitable for all purposes.

PACKING INSTRUCTIONS P908 / LP9034

CONCLUSION /

BEFORE THE LIBRIS PROJECT COMMENCED, IT WOULD BE DIFFICULT TO CONCLUDE THAT ANY ADEQUATE CORRUGATED FIBREBOARD PACKAGING ON THE MARKET COULD SAFELY CONTAIN A THERMAL RUNAWAY EVENT. CURRENT TRANSPORT REGULATIONS ADDRESS THE REQUIREMENT FOR ENHANCED PACKAGING THAT SHALL CONTAIN AN INCIDENT FOR DAMAGED AND DEFECTIVE BATTERIES, BATTERIES CARRIED FOR DISPOSAL AND PROTOTYPES. THIS IS NOT ENFORCED FOR BATTERIES THAT ARE CLASSED AS SAFE FOR SHIPMENT.

For businesses and battery manufacturers, the risk of a potential incident and the brand damage this would cause, could be catastrophic.

Evidence based data collected from live cell destructive testing with the HSE, has enabled Tri-Wall UK to develop the first corrugated and timber packaging designed to contain, manage and extinguish a thermal runaway event, whatever state the battery is in. This is achieved from very specific design features and by incorporating a mitigating material that has an endothermic reaction to extinguish a lithium-battery fire by displacing the energy produced and restricting the oxygen generated by the cells. The designs are scalable and customisable based on the customers' requirements and are easily integrated into a production end of line packing facility.

Tri-Wall are proud of their part in this ground-breaking research and product innovation.

ACKNOWLEDGEMENTS:

MIKE VALENTINE:	PROJECTS LEAD
BEN OVEN:	HEAD OF TESTING SERVICES
NAOMI WILLIAMS-ROBERTS:	DESIGN MANAGER
LEWIS EVANS:	TECHNICAL PACKAGING ENGINEER

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KNOWLEDGE AND RESOURCE /

COMMON PHRASES

Cell
An electrochemical device composed of positive and negative plates and electrolyte, which can store electrical energy. It is the basic "building block" of a battery. Sub-component of the pack/module and/or the battery. This is the individual 18650 cell (or any other format) and the smallest component. As in the car battery, it is made up of six cells, each cell is ~2V-2.3V each. These cells are connected in series to give an ending result of 12V-13.8V.

Module
A module consists of multiple cells connected in series and/or parallel, encased in a mechanical structure. Sub-component of the battery, the battery is made of packs/modules. This is "optional"; the battery is not always divided in packs or modules.

Sometimes the word pack is also used for a battery (as in power pack).

Battery Pack
The completed product, a usable DC source for the intended application, made from several modules or cells, connected in series and/or in parallel. Such as a car battery. The unit is referred to as a battery.

Lithium-Ion Battery
A lithium-ion battery or Li-ion battery (abbreviated as LIB) is a type of rechargeable battery in which lithium ions move from the negative electrode to the positive electrode during discharge and back when charging.

BMS
A Battery Management System also referred to as simply BMS is an electronic system that controls the charging of rechargeable batteries. It serves as both a regulator and monitor and performs these functions through varied mechanisms.

CELL TYPES/SIZES

Cylindrical
Similar to an AA battery

18650, 21700, 26650
These are all common cell sizes. Roughly, an 18650 cell is 18mm in diameter and 650mm in length.

Pouch
This is the type of cell used in mobile phones and IPad etc. It has the same fundamental construction as a cylindrical cell but with the layers laid flat rather than rolled (Jellyroll) in a cylindrical type.

Prismatic Cell
Prismatic cells consist of many positive and negative electrodes that are flanked together making it possible for short circuit and inconsistency. Prismatic cells die faster because thermal management is less efficient and relatively sensitive to deformation in high-pressure situations

Cylindrical Advantages
Compared to prismatic cells, cylindrical cells can be produced much faster so more KWh per cell can be produced every day equalling lower $ per KWh. The electrodes in a cylindrical cell are wound tightly and encased in a metal casing. This minimises electrode material from breaking up from the mechanical vibrations, thermal cycling from charging and discharging and mechanical expansion of the current conductors inside from thermal cycling. Many cells are combined in series and in parallel to increase voltage and capacity of the battery pack. If one cell goes bad, the impact on the entire pack is low. With prismatic cells if one cell goes bad it can compromise the whole battery pack. Cylindrical cells radiate heat and control temperature more easily than prismatic cells.

Prismatic Disadvantages
Prismatic cells are made up of many positive and negative electrodes sandwiched together leaving more possibility for short circuit and inconsistency. The higher capacity makes it difficult for the BMS to protect each cell from over charging and dissipating heat. The larger cell size minimizes the possibility for automation leading to a lower degree of consistency. The internal electrodes can easily expand and contract causing deformation that can lead to an internal short circuit and are more prone to swelling like lead batteries.

COMPETENT AUTHORITY AND TRANSPORTATION REGULATIONS:

VCA
The Vehicle Certification Agency (Dangerous Goods Office) is the designated UK competent authority responsible for the certification of all UK packaging used for transporting dangerous goods.

ADR
Formally the European Agreement of 30 September 1957 concerning the International Carriage of Dangerous Goods by Road, is a 1957 United Nations treaty that governs transnational transport of hazardous materials. “ADR” is derived from the French name for the treaty: Accord européen relatif au transport international des marchandises Dangereuses par Route). From 1 January 2021, the treaty will be renamed Agreement concerning the International Carriage of Dangerous Goods by Road as the word “European” in the original name may give the impression that the treaty is only open for accession to European states.

IATA
The International Air Transport Association. It’s the global trade association for the world’s airlines and everything air transport related, representing some 290 carriers across 120 different countries and accounting for 82% of total air traffic.

IATA code of practice for shipping batteries: https://www.iata.org/contentassets/05e6d8742b0047259bf3a700bc9d42b9/lithium-battery-shipping-guidelines.pdf

WHAT IS THE UN 38.3 CERTIFICATION AND WHY IT MATTERS?

Since batteries are classified as dangerous goods by the United Nations, the transportation of lithium batteries is heavily regulated because they can pose a critical safety risk. When manufacturing batteries, companies must keep these regulations in mind. The UN has created several tests that batteries need to pass to receive the 38.3 certifications that ensure batteries are safe for transportation. These tests include environmental, mechanical, and electrical stresses to ensure that the lithium batteries are durable and reliable to be transported via air, sea, or road.

Altitude Simulation Test:
This test simulates low-pressure conditions such as airplanes or aircraft cabins at a 15,000-meter altitude after storing the batteries at 11.6kPa for at least 6 hours. To pass this test, there should be no mass loss, leaking, venting, disassembly, rupture of fire, and the end voltage must be at least 90% of the sample’s voltage measured before the test.

Thermal Test:
This test covers changes in temperature extremes from -40°C to 75°C and are stored for 6 hours (12 hours total), at each temperature for a total of 10 cycles. To pass this test, the sample must not leak, vent, disassemble, rupture, or ignite. The end voltage must be at least 90% of the sample’s voltage measured before the test.

Vibration Test:
This test simulates vibration during transportation. During the test, the battery is secured to a vibration machine and subjected to vibrations over a three-hour period. To pass this test, the sample must not leak, vent, disassemble, rupture, or ignite. The end voltage must be at least 90% of the sample’s voltage measured before the test.

Shock Test:
This test simulates possible impact during transportation. During the test, the battery is secured to a testing device and subjected to three shocks in both a positive and negative direction in three mounting positions, for a total of 18 shocks. To pass this test, the sample must not leak, vent, disassemble, rupture, or ignite. The end voltage must be at least 90% of the sample’s voltage measured before the test.

External Short Circuit Test:
This test simulates an external short to the terminals of the cell or battery. During the test, a battery is subjected to a short circuit condition for at least one hour and is observed for an additional six-hour period. To pass this test, the temperature of the sample must not exceed 170°C, and the sample must not disassemble, vent, or ignite during the test, or within the six-hour period following the test.

Impact Test:
This test determines if the battery can withstand an impact that may result in an internal short circuit. During the test, the battery is subjected to an impact from a mass dropped from a specified height. During the crush test, a sample is crushed between two flat surfaces until either the applied force reaches a calculated limit, the voltage of the cell drops by at least 100 mV, or the cell is deformed by 50%. To pass this test, the temperature of the battery must not exceed 170°C and must not disassemble, vent, or ignite during the test, or within the six-hour period following the test.

Overcharge Test:
The overcharge test evaluates the ability of a cell or battery to withstand an overcharge condition without adverse consequences. During the test, a sample is subjected to a current charge equal to twice that of the manufacturer’s maximum recommended continuous charge current at ambient temperature for a period of 24 hours. To pass this test, the sample must not disassemble or ignite during the test, or within the seven-day period following the test.

Forced Discharge Test:
The forced discharge test assesses the ability of a cell or battery to withstand a forced discharge condition. During the test, a sample is forced discharged at ambient temperature at an initial current equal to the maximum discharge current specified by the manufacturer and for a calculated time interval. To pass the test, the sample must not disassemble or ignite during the test, or within the seven-day period following the test.

The UN 38.3 Certification ensures that our batteries pass all testing and safety requirements under the UN Manual of Tests and Criteria. We do this to ensure that our batteries are not only safe for you, but for your customers as well. Before purchasing a battery, make sure it is UN 38.3 Certified to ensure the best quality possible.

GLOSSARY OF MAIN TECHNICAL BATTERY TERMINOLOGY /

The listed terms have been defined in a way that will be most useful and meaningful to the greatest number of readers, so apologies if you find any of the definitions too simplistic, incomplete or unclear.

Accumulator
A rechargeable battery or cell (see also Secondary battery).

Ampere or Amp
An Ampere or an Amp is a unit of measurement for an electrical current. One amp is the amount of current produced by an electromotive force of one volt acting through the resistance of one ohm. Named for the French physicist Andre Marie Ampere. The abbreviation for Amp is A but its mathematical symbol is “I”. Small currents are measured in milli-Amps or thousandths of an Amp.

Amp Hour or Ampere-Hour
A unit of measurement of a battery’s electrical storage capacity. Current multiplied by time in hours equals ampere-hours. One amp hour is equal to a current of one ampere flowing for one hour. Also, 1 amp hour is equal to 1,000 mAh

Ampere-Hour Capacity
The number of ampere-hours, which can be delivered by a battery on a single discharge.

Anode
During discharge, the negative electrode of the cell is the anode. During charge, that reverses, and the positive electrode of the cell is the anode. The anode gives up electrons to the load circuit and dissolves into the electrolyte.

Aqueous Batteries
Batteries with water-based electrolytes. The electrolyte may not appear to be liquid since it can be absorbed by the battery’s separator.

Actual Capacity or Available Capacity
The total battery capacity, usually expressed in ampere-hours or milliampere-hours, available to perform work. The actual capacity of a particular battery is determined by several factors, including the cut-off voltage, discharge rate, temperature, method of charge and the age and life history of the battery.

Battery
An electrochemical device used to store energy. The term is usually applied to a group of two or more electric cells connected electrically. In common usage, the term “battery” is also applied to a single cell, such as an AA battery.

Battery Capacity
The electric output of a cell or battery on a service test delivered before the cell reaches a specified final electrical condition and may be expressed in ampere-hours, watt- hours, or similar units. The capacity in watt-hours is equal to the capacity in ampere-hours multiplied by the battery voltage.

Battery Charger
A device capable of supplying electrical energy to a battery.

Battery-Charge Rate
The current expressed in amperes (A) or milli amps (mA) at which a battery is charged.

Cut-off Voltage, final
The prescribed lower-limit voltage at which battery discharge is considered complete. The cut-off or final voltage is usually chosen so that the maximum useful capacity of the battery is realized. The cut-off voltage varies with the type of battery and the kind of service in which the battery is used. When testing the capacity of a NiMH or NiCD battery a cut-off voltage of 1.0 V is normally used. 0.9V is normally used as the cut-off voltage of an alkaline cell. A device that is designed with too high a cut-off voltage may stop operating while the battery still has significant capacity remaining.

C
Used to signify a charge or discharge rate equal to the capacity of a battery divided by 1 hour. Thus, C for a 1600 mAh battery would be 1.6 A, C/5 for the same battery would be 320 mA and C/10 would be 160 mA. Because C is dependent on the capacity of a battery the C rate for batteries of different capacities must also be different.

Capacity
The capacity of a battery is a measure of the amount of energy that it can deliver in a single discharge. Battery capacity is normally listed as amp-hours (or milli amp-hours) or as watt-hours.

Cathode
Is an electrode that, in effect, oxidizes the anode or absorbs the electrons. During discharge, the positive electrode of a voltaic cell is the cathode. When charging, that reverses, and the negative electrode of the cell is the cathode.

Cell
An electrochemical device composed of positive and negative plates and electrolyte, which can store electrical energy. It is the basic "building block" of a battery.

Charge
The conversion of electric energy, provided in the form of a current, into chemical energy within the cell or battery.

Charge Rate
The amount of current applied to battery during the charging process. This rate is commonly expressed as a fraction of the capacity of the battery. For example, the C/2 or C/5.

Charging
The process of supplying electrical energy for conversion to stored chemical energy.

Constant-Current Charge
A charging process in which the current applied to the battery is maintained at a constant value.

Constant-Voltage Charge
A charging process in which the voltage applied to a battery is held at a constant value.

Cycle
One sequence of charge and discharge.

Deep Cycle
A cycle in which the discharge is continued until the battery reaches its cut-off voltage, usually 80% of discharge.

Shallow Cycling
Charge and discharge cycles, which do not allow the battery to approach its cut-off voltage. Shallow cycling of NiCad cells leads to "memory effect". Shallow cycling is not detrimental to NiMH cells and it is the most beneficial for lead acid batteries.

Cycle Life
For rechargeable batteries, the total number of charge/discharges cycles the cell can sustain before its capacity is significantly reduced. End of life is usually considered to be reached when the cell or battery delivers only 80% of rated ampere- hour capacity. NiMH batteries typically have a cycle life of 500 cycles; NiCad batteries can have a cycle life of over 1,000 cycles. The cycle of a battery is greatly influenced by the type of depth of the cycle (deep or shallow) and the method of recharging. Improper charge cycle cut-off can greatly reduce the cycle life of a battery.

Direct Current (DC)
The type of electrical current that a battery can supply. One terminal is always positive, and another is always negative.

Discharge
The conversion of the chemical energy of the battery into electric energy.

Depth of Discharge
The amount of energy that has been removed from a battery (or battery pack). Usually expressed as a percentage of the total capacity of the battery. For example, 50% depth of discharge means that half of the energy in the battery has been used. 80% DOD means that eighty percent of the energy has been discharged, so the battery now holds only 20% of its full charge.

Discharge, deep
Withdrawal of all electrical energy to the end-point voltage before the cell or battery is recharged.

Discharge, high-rate
Withdrawal of large currents for short intervals of time, usually at a rate that would completely discharge a cell or battery in less than one hour.

Discharge, low-rate
Withdrawal of small currents for long periods, usually longer than one hour.

Drain
Withdrawal of current from a cell.

Dry Cell
A primary cell in which the electrolyte is absorbed in a porous medium or is otherwise restrained from flowing. Common practice limits the term "dry cell" to the Leclanch, cell, which is the common commercial type.

Electrochemical Couple
The system of active materials within a cell that provides electrical energy storage through an electrochemical reaction.

Electrode
An electrical conductor through which an electric current enters or leaves a conducting medium, whether it be an electrolytic solution, solid, molten mass, gas, or vacuum. For electrolytic solutions, many solids, and molten masses, an electrode is an electrical conductor at the surface of which a change occurs from conduction by electrons to conduction by ions. For gases and vacuum, the electrodes merely serve to conduct electricity to and from the medium.

Electrolyte
A chemical compound, which, when fused or dissolved in certain solvents, usually water, will conduct an electric current. All electrolytes in the fused state or in solution give rise to ions, which conduct the electric current.

Electro positivity
The degree to which an element in a galvanic cell will function as the positive element of the cell. An element with a large electro positivity will oxidize faster than an element with a smaller electro positivity.

End-of-Discharge Voltage
The voltage of the battery at termination of a discharge.

Energy
Output Capability - expressed as capacity time's voltage, or watt-hours.

Energy Density
Ratio of cell energy to weight or volume (watt-hours per pound, or watt-hours per cubic inch).

Final Voltage
(see Cut-off voltage)

Float Charging
Method of recharging in which a secondary cell is continuously connected to a constant-voltage supply that maintains the cell in fully charged condition. Typically applied to lead acid batteries.

Galvanic Cell
A combination of electrodes, separated by electrolyte, that can produce electrical energy by electrochemical action.

Gassing
The evolution of gas from one or both of the electrodes in a cell. Gassing commonly results from self-discharge or from the electrolysis of water in the electrolyte during charging.

Memory Effect
A phenomenon in which a cell, operated in successive cycles to less than full, depth of discharge, temporarily loses the remainder of its capacity at normal voltage levels (usually applies only to Ni-Cd cells). Note, memory effect can be induced in NiCad cells even if the level of discharge is not the same during each cycle. Memory effect is reversible.

Negative Terminal
The terminal of a battery from which electrons flow in the external circuit when the cell discharges. See Positive Terminal.

Nonaqueous Batteries
Cells that do not contain water, such as those with molten salts or organic electrolytes.

Ohm's Law
The formula that describes the amount of current flowing through a circuit. Ohm's Law - In each electrical circuit, the amount of current in amperes (I) is equal to the pressure in volts (V) divided by the resistance, in ohms (R). Ohm's law can be shown by three different formulas:

- To find Current I = V/R
- To find Voltage V = I x R
- To find Resistance R = V/I

Open Circuit
Condition of a battery, which neither is on charge nor on discharge (i.e., disconnected from a circuit).

Open-Circuit Voltage
The difference in potential between the terminals of a cell when the circuit is open (i.e., a no-load condition).

Oxidation
A chemical reaction that results in the release of electrons by an electrode's active material.

Parallel Connection
The arrangement of cells in a battery made by connecting all positive terminals together and all negative terminals together. The voltage of the group remains the same as the voltage of the individual cell. The capacity is increased in proportion to the number of cells.

Polarity
Refers to the charges residing at the terminals of a battery.

Positive Terminal
The terminal of a battery toward which electrons flow through the external circuit when the cell discharges. See Negative Terminal.

Primary Battery
A battery made up of primary cells. See Primary Cell.

Primary Cell
A cell designed to produce electric current through an electrochemical reaction that is not efficiently reversible. The cell, when discharged, cannot be efficiently recharged by an electric current. Alkaline, lithium, and zinc air are common types of primary cells.

Rated Capacity
The number of ampere-hours a cell can deliver under specific conditions (rate of discharge, end voltage, temperature), usually the manufacturer's rating.

Rechargeable
Capable of being recharged; refers to secondary cells or batteries.

Recombination
State in which the gases normally formed within the battery cell during its operation, are recombined to form water.

Reduction
A chemical process that results in the acceptance of electrons by an electrode's active material.

Seal
The structural part of a galvanic cell that restricts the escape of solvent or electrolyte from the cell and limits the ingress of air into the cell (the air may dry out the electrolyte or interfere with the chemical reactions).

Secondary Battery
A battery made up of secondary cells. See Storage Battery, Storage Cell.

Self-Discharge
Discharge that takes place while the battery is in an open-circuit condition.

Separator
The permeable membrane that allows the passage of ions but prevents electrical contact between the anode and the cathode.

Series Connection
The arrangement of cells in a battery configured by connecting the positive terminal of each successive cell to the negative terminal of the next adjacent cell so that their voltages are cumulative. See Parallel Connection.

Shelf Life
For a dry cell, the period (measured from date of manufacture), at a storage temperature of 21 degrees C (69 degrees F), after which the cell retains a specified percentage (usually 90%) of its original energy content.

Short-Circuit
A condition that occurs when a short electrical path is unintentionally created. Batteries can supply hundreds of amps if short-circuited, potentially melting the terminals and creating sparks.

Short-Circuit Current
That current delivered when a cell is short-circuited (i.e., the positive and negative terminals are directly connected with a low-resistance conductor).

Starting-Lighting-Ignition (SLI) Battery
A battery designed to start internal combustion engines and to power the electrical systems in automobiles when the engine is not running. SLI batteries can be used in emergency lighting situations.

Stationary Battery
A secondary battery designed for use in a fixed location.

Storage Battery
An assembly of identical cells in which the electrochemical action is reversible so that the battery may be recharged by passing a current through the cells in the opposite direction to that of discharge. While many non-storage batteries have a reversible process, only those that are economically rechargeable are classified as storage batteries. Synonym: Accumulator; Secondary Battery. See Secondary Cell.

Storage Cell
An electrolytic cell for the generation of electric energy in which the cell after being discharged may be restored to a charged condition by an electric current flowing in a direction opposite the flow of current when the cell discharges. Synonym: Secondary Cell. See Storage Battery.

Taper Charge
A charge regime delivering moderately high-rate charging current when the battery is at a low state of charge and tapering the current to lower rates as the battery becomes more fully charged.

Terminals
The parts of a battery to which the external electric circuit is connected.

Thermal Runaway
A condition whereby a cell on charge or discharge will destroy itself through internal heat generation caused by high overcharge or high rate of discharge or other abusive conditions.

Trickle Charging
A method of recharging in which a secondary cell is either continuously or intermittently connected to a constant-current supply that maintains the cell in fully charged condition.

Vent
A normally sealed mechanism that allows for the controlled escape of gases from within a cell.

Volt
The unit of measurement of electromotive force, or difference of potential, which will cause a current of one ampere to flow through a resistance of one ohm. Named for Italian physicist Alessandro Volta (1745-1827).

Voltage, cut-off
Voltage at the end of useful discharge. (See Voltage, endpoint.)

Voltage, end-point
Cell voltage below which the connected equipment will not operate, or below which operation is not recommended.

Voltage, nominal
Voltage of a fully charged cell when delivering rated current.

Watt
A measurement of total power. It is amperes multiplied by volts. 120 volt @ 1 amp = 12 volts @ 10 amps.

Wet Cell
A cell, the electrolyte of which is in liquid form and free to flow and move.

THANK YOU

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