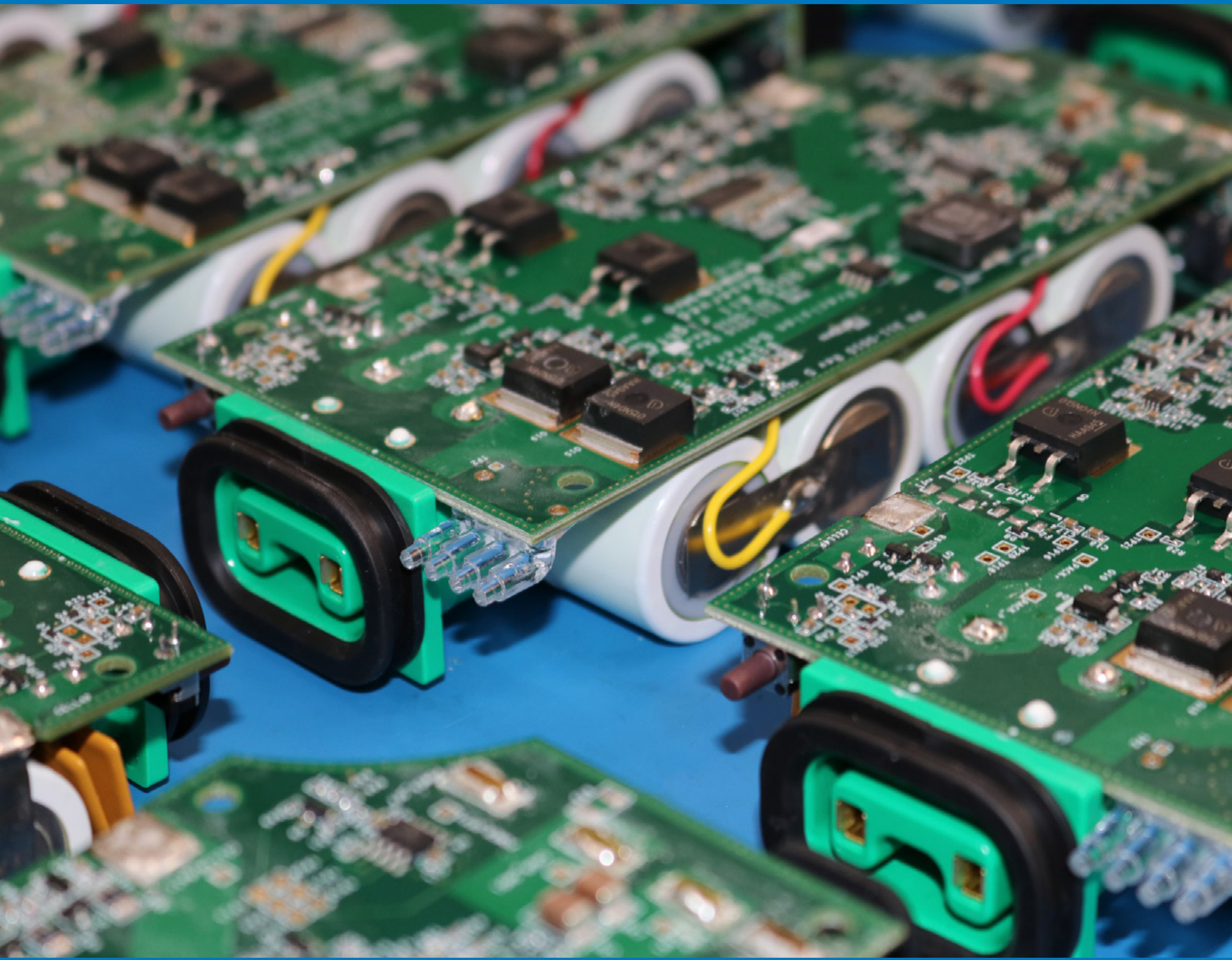
www.epectec.com

# CUSTOM BATTERY PACKS

## Technical Engineering Guide



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# DELIVERING QUALITY SINCE 1952

Epec Engineered Technologies designs and manufactures customized, build-to-print, performance-critical products for all sectors of the electronics industry.

At Epec, we have a powerful story to tell – a history of great achievements, world-class talent, and innovative breakthroughs, but most importantly, a story of helping our customers deliver their high-quality products to market, faster.

Epec has a more than 65-year history of reliability, on-time delivery, and financial stability. Our continuous investment in people, technology, and new ideas are making it easier for our customers to do great work.

We have built the industry's leading supply chain platform and technology team with Epec UL certified manufacturing operations in Shenzhen, Taipei, and North America to seamlessly manage the needs of our customers' product life cycles.

With more than 100 dedicated employees throughout North America and Asia, Epec Engineered Technologies has become one of the fastest growing companies in the industry.

# TECHNOLOGY OVERVIEW

Epec has built one of the Industry's leading global supply chain and engineering platforms.

As one of North America's leading PCB and build-to-print engineered product companies, Epec's annual capital expenditures are consistently among the highest in the industry.

Our investments are focused on world-class engineering design systems, such as EpecDFx™ and on continually improving our global technology platform to accelerate our customer's time to market.

# ENGINEERING OVERVIEW

Epec's technical engineering and manufacturing solutions have helped thousands of leading companies reduce their time to market.

With 24/7 North American engineering support, we provide our customers the most in-depth feedback, with exact accuracy, eliminating delays, and quality problems.

Epec can provide complete engineering and design services on all our engineered products from concept through production in a quick and efficient time frame.

With more than 65 years of experience and knowledge across diverse industries, Epec has the ability to think outside the box and create innovative designs and solid manufacturing solutions.

Our technical staff will work with you to generate material specifications, product renderings, complete documentation, and prototypes.

# OVERVIEW OF BATTERY PACKS

Battery packs are used to provide power to devices that need to be portable or need to be powered, but are in a location too removed from other power source options. Cells, the basic building block of a battery, come in fixed voltages, which are defined by the chemistry. The voltages don't vary much within a chemistry family. The capacities do vary, however, since they are defined by the physical size of the cell. In order to meet your portable-power requirements, a battery pack can be designed using various combinations of cells to obtain the voltage and capacity requirements of the application.

The type of battery required is determined by the requirements of the device being powered: device voltage, load-current, and recharge time requirements; environmental considerations; physical space available; weight constraints; and regulatory and transportation requirements. The battery pack can be designed to meet these requirements by selecting the appropriate chemistry and configuring the cells to meet the voltage, current, and capacity requirements. The number of cells, the size of the cell, and how the cells are assembled defines the shape and weight of the pack, as a battery pack consists of multiple components in the electromechanical, thermodynamic, mechanical, control, and regulatory fields.

## How Much Voltage Do I Need?

The voltage of any cell varies depending on its state of charge. So, a 10-cell pack of NiMH cells would have 14 volts when fully charged and run down to 10 volts when fully discharged. Your system must be able to tolerate this voltage range, or request that Epec design and embed an output voltage regulator into the battery so the output voltage is constant. Furthermore, if you want to be able to charge while your system is running, the system must be able to accept the charging voltage, which is always higher than the nominal or the fully charged voltage.

## How Many Amp Hours Do I Need?

Cell capacity is rated in amp-hours or milliamp hours. The symbol for capacity is C or It, current X time. This is amps times hours. Divide by hours, and you get amps. Divide by amps, and you get hours. For example, a 5Ahr (amp hour) battery is the same as a 5,000 milliamp hour battery. If you want to discharge in 10 hours, you can get a current of 5/10 = 0.5 amps. If you need 100 milliamps current, then you can run for 5000/100 = 50 hours. Often a discharge or charge rate is given proportional to C. So, a discharge rate of C/5 means C/(5 hours) or the constant current to fully discharge the battery in 5 hours. The calculation of run time versus current is a rough estimate, but is accurate under the right environmental and electrical conditions. The faster you discharge or the lower the temperature, the lower the capacity of a battery.

This trade-off depends on the battery chemistry and construction. Usually, the capacity of a battery is specified at a C/20 discharge rate at ambient temperature, so a 12Ahr-sealed-lead-acid battery will actually put out a steady 0.6 amps for 20 hours. However, if you discharge the same battery at a much higher 12-amp discharge rate, you would expect to run an hour, but you will only get about half of that due to the losses in the chemical exchange and internal impedance within the cell. Cells specifically designed for high-discharge rates are available, which minimizes these losses. As a tested expert in design, assembly, and integration with a diverse portfolio of cells in various sizes, temperature ranges, and rate capabilities, our team can produce a custom battery pack that meets the unique needs of your application. This guide provides information that may be useful and is organized to provide an outline of what needs to be understood and considered to design and then produce custom battery packs for your application.

## SMART BATTERY PACKS

A smart battery pack provides the device with information so that it can manage its own charging, report errors, inform the device of low-charge conditions, predict remaining run-time, provide temperature, voltage, and current information, continuously self-correct to maintain prediction accuracy, and maintain its power status so that the device can conserve power intelligently. Smart battery packs can include many additional features and functionality, such as fuel gauge integration, communication protocol (I2C, SMBus, RS485, RS232 or CANBUS), cell balancing, and protection circuitry.

As all different types of equipment are becoming smaller and lighter, a custom lithium battery have the advantage of having high energy density, being lightweight, wide operating temperature range, and the flexibility to use software and firmware to design the proper battery management systems (BMS) for every application.

One of the most critical parts of designing a custom battery pack is cell selection. Various chemistries are made in a wide variety of sizes, and custom battery packs offer the ability to dial in the performance of a specific cell chemistry to exactly match the performance that a device requires. A key thing to remember is that a smaller, lighter battery with the same energy density will usually cost more to produce and develop than a larger, heavier battery, which is why it is usually wise to work with an experienced custom battery pack designer before picking a specific cell technology.

The communication protocol architecture provides a means for keeping hardware costs low while also providing flexible functionality in a modular way. SMBus is a protocol that allows multiple nodes to respond to unique addresses. Details and specifications for SMBus can be found at www.smbus.org.

As battery technologies continue to increase every day, today's batteries can now be viewed more as power systems/power supplies than normal batteries. Smart battery packs can offer embedded electronics, which improves the safety, reliability, cycle life, and functionality of the battery while giving the end-product system engineer more options to make the end product more reliable and user friendly. Smart battery packs can be designed using a BMS with features that include features that prevent charging in high temperatures or discharging in low temperatures, which can damage lithium batteries, encryption, backup power design, wide temperature demands (-20 to 50 degrees C), shock-vibration durability, and battery status monitoring, which can be stored in memory or accessed remotely.

How a battery pack becomes qualified as "smart" is, quite simply, because of software. The Smart Battery System (SBS) forum defines a smart battery as a battery pack where some level of communication occurs between the battery, the equipment, and the user.

For further details, see these additional resources:

- What Makes a Smart Battery Pack ... Smart?
- Added Value Electronics Can Turn Normal Batteries into Smart Battery Packs

# LITHIUM CHEMISTRY VS. NiMH

Do I really need the expense and the product risk of a lithium chemistry custom battery pack? Custom rechargeable battery packs using lithium cells can provide both high voltage and excellent capacity, resulting in an extraordinary high-energy density. Many applications, such as cell phones, medical devices, electric vehicles, and others require such a high-energy density that only lithium chemistry will do. However, for many of the applications that we see, custom nickel metal hydride (NiMH) battery packs are more cost-effective to design and manufacture and do not come with all the potential hazards associated with lithium products.

NiMH batteries have been around since the early 1970s. The technology has been driven by its high-energy density (vs. NiCd and lead acid), being environmentally friendly, good cycle life performance, and with having a good safety and reliability record. While NiMH battery packs don't need the complex battery management system (BMS) essential with lithium batteries, we do design and manufacture BMS systems for NiMH packs that help the battery pack last long and communicate with the customer's device in order to provide the same information as a complex lithium pack.

## What are the Best Applications for NiMH Battery Packs?

Most applications where there is a high-energy consumption and demand is where NiMH battery packs excel. They are also suitable in applications as backup power source, where the NiMH batteries have a BMS in order to control the charging and discharging to improve the lifetime of the battery pack.

## Don't NiMH Batteries Self-Discharge and are Prone to the Memory Effect?

Yes, NiMH batteries will self-discharge 1% per day if used in a low-energy consummation or stand-by device and the chemistry has been known to succumb to the memory effect. However, using very cost-effective BMS technology from manufacturers such as Texas Instruments, Analog Devices, and On Semiconductor, we can develop a system that trickle charges (charge rate of less than 0.025 C (C/40) ) the battery in order to ensure that the pack is always at its maximum capacity and reduce the negative effects of overcharging.

## Will NiMH Batteries Last as Long as a Lithium Battery?

If a NiMH battery is repeatedly overcharged, small crystals form on the electrodes, inhibiting their ability to fully charge, and as a result, the battery's voltage drops. Undercharging can cause low service where overcharging can cause loss of cycle life. The way to address this is using our cost-effective BMS that manages the charging process so that there will 100% never be a chance that the battery can be overcharged and damaged.

Most low-end chargers use rudimentary timers rather than actively monitoring the voltage to determine when to cut off the charge current. Typically, a moderate rate (2- to 3-hour) smart charger is preferred for NiMH batteries. Extremely fast charging (less than 1 hour) can impact battery cycle life and should be limited to an as needed basis.

## Does an Enclosure for NiMH Custom Battery Packs Need Venting Similar to Lithium Chemistry?

The primary gases emitted from the NiMH battery when subjected to excessive overcharge or over-discharge is hydrogen and oxygen. Battery enclosure should not be airtight and should be strategically vented. Isolation of the battery from heat-generating components and ventilation around the battery will also reduce thermal stress on the battery and ease design of appropriate charging systems.

## Do I Really Need a BMS for NiMH Battery Packs?

No, you do not. However, NiMH battery packs are amongst the hardest batteries to charge accurately, and because the BMS solutions are very cost-effective, we recommend having one in your design. The charging for NiMH batteries is based on forcing current through the battery whereas with lithium-ion and lead acid batteries, you can control overcharge by just setting a maximum charge voltage. Therefore, having an electronic safety in place will increase the overall life of the battery.

## What is the Difference in NiMH vs. Lithium Overall Cost and Battery Pack Size?

This is where the two big differences are when it comes to these two chemistries.

- **Cost:** NiMH is less than 50% of a lithium battery in terms of the final battery pack production price, and it is less than 75% of a lithium battery in terms of the development of the product. While NiMH has some regulatory and other development steps, it is still significantly less than lithium.

- **Size:** Lithium cells are lighter and smaller than NiMH cells, however lithium cells only have an average of 1500mAh compared to the 2200 mAH average of NiMH cells.

# DESIGN AND DEVELOPMENT STAGES

The earliest stage of development comes when a customer knows what they want the battery for their product to do but aren't quite sure how they want to build and develop it, further discussion is required.

Our engineering and technical teams need to truly understand the customer's requirements to create a scope of work that can be used as a starting point for the developments.

The biggest challenge with this type of development is that there tends to be many changes that are requested as the development process occurs, and this can extend the timeline, increase development costs, and create a higher higher-priced product. The first step is to work with the customer to help them finalize what their operating parameters and specifications are, which in turn will help us develop a scope of work for the entire project.

**The most important things for a customer to know at this point in their process, besides their technical requirements, include:**

- What they have in a budget for the development cost.
- When they need to go to market.
- What their piece price needs to be in order to make their product viable in the marketplace.

Too often on applications, the required functionality and the retail sale price of the product are not practical together. However, in most instances, we can operate within our customer's parameters by using either our domestic facility or low-cost Asian manufacturing capabilities.

# ESTABLISHED SPECIFICATION BATTERY PACK DESIGN

For a design that uses custom housings (soft pack, low pressure molding, plastic housings) a very detailed specification outline with answers from our two questionnaire documents makes the quotation for the development process and manufacturing price very accurate.

To reach this stage means the customer has spent a significant amount of time on the specifics of their application. Having established design details will dramatically reduce the development timeline, setting a very clear direction to production.

The process then moves to us developing all drawings, schematics, software, firmware, BMS, and all additional components of the battery pack. The reason we ask for our questionnaires to be filled out prior to starting the process is to minimize any additional work required in the future if one of the requirements that isn't listed at the beginning requires changes in other parts of the design.

## This Development Considers Many of the Following:

- **Hardware Development:** Manufacturer independent selection of the optimum cell chemistry to fulfill all customer requirements, battery management system (i.e. PCB, protective circuits, communication) to fit sophisticated applications, including charging technology, fuel gauging interface.

- **Software Development:** Host and user interface parameters (SMBUS, PMBUS, 1-Wire, I²C, etc.) specific configuration algorithms for safety mechanisms and charging parameters.

- **Mechanical Development:** Custom housings (soft pack, low pressure molding, plastic housings). Custom connectors if required.

- **Environmental Requirements:** State-of-the-art laboratories for all relevant environmental tests, such as climate, EMC, shock and vibration, etc.

- **Certification Management:** UL, CE, IEC, ITL, UN 38.3.

- Quality Management: Managing our production through our ISO9001:2015 standard and with our proven NPI process to make sure that we seamlessly get from prototype to production.

- **Testing and Programming:** Part of our process is to design and develop all fixtures and programs needed to fully program and test each battery pack in house.

The objective for any design is to keep the costs down and the timeline tight, and our experience has demonstrated that the only way to do that is to get an agreed upon specification developed prior to starting development. Our engineering team is here to work with you to help finalize and review the specification to make sure that we can meet all your requirements.

## BATTERY PACK DESIGN/BUILD FOR CERTIFICATION

At this stage, the customer has a very specific idea of what they want electrically and mechanically. They may even have a rough drawing of what they need and/or previous experience designing batteries. This allows us to move quickly through the entire process and into production as much of the upfront work has been completed. It will also dramatically reduce the development costs and provide customers with different production pricing options.

Here are a few common examples of customer service expectations at this stage of development. Those looking to have the protection circuity or other standard Battery Management System (BMS) components added to the design.

### Need the Design Completed and Certified for IEC, UL, or UN 38.3?

We can manage the entire processing of all certification submittals as we have long-standing professional relationships with agencies that allows us to quickly navigate to an approval. This includes understanding how many and what type of samples need to be submitted for the specific battery type.

### Customers Looking to Upgrade an Existing Product That Has Been in Service for Many Years

Some companies don’t have the resources to ship lithium batteries as it requires all individuals responsible to be certified by a recognized organization. Our service ensures that all your certifications are actively managed. This includes managing yearly renewals, ensuring your product can meet the new and yearly requirements, and minimizing your liability by making sure that your labeling, packaging, and shipping methods are always in compliance with DOT regulations. Even NiMH must be registered if they are manufactured in Asia and shipped via air freight to the U.S. In all instances the customer has completed a significant amount of the upfront work required so we are able to quickly create scope of work to finish the project and move into development and production.

**Most of these cases involve the customer having already documented the following:**

- Fully-completed questionnaire. All boxes are filled out, which indicates that you fully understand what you need the pack to do and it will quickly allow us to check your requests against the parameters.
- Have determined which cell chemistry that they would like to use. We can determine which brand is used based upon pricing budget and operating parameters.
- At a minimum: 2D drawings of an enclosure exterior (if applicable); 3D drawings would be even better. This must include specifications on color, finish, and material.
- Understanding and documenting of how they plan on connecting to the pack and how they want to charge the pack if rechargeable.

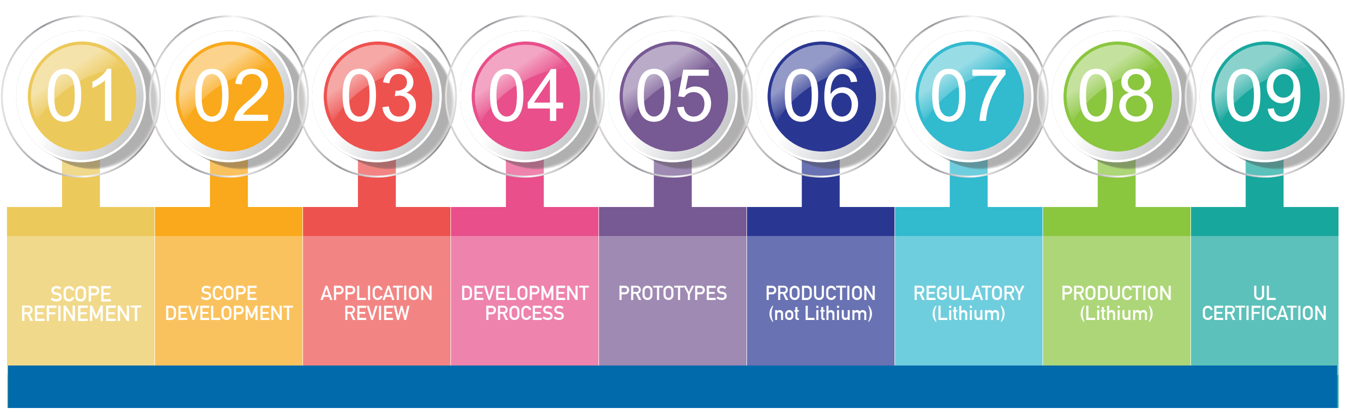
## BATTERY PACK DEVELOPMENT TIMELINE

Even the most experienced and talented engineers may not be familiar with all of the potential pitfalls and new developments when creating a specification for their batteries. The number one issue that we see with battery pack development is “scope creep” or when the customers change the specification in the middle of the development.

Because the development itself can take up to 14 weeks (and then the certifications another 16-20 weeks) it is important that we work with customers to ensure that we have a solid specification that can be met using the most available technologies and parts in order to quickly get these projects from concept to production.

We have developed many different resources on custom battery pack development timelines:

- Battery Pack Development Timeline
- Top 3 Reasons Why Battery Pack Development is Delayed
- Design Factors for Lithium Batteries Used in Portable Devices Webinar Q&A
- 5 Methods to Improve Battery Pack Time to Market



# BATTERY CHEMISTRY AND CELL TECHNOLOGY

Older batteries were mostly based on rechargeable lead-acid or non-rechargeable alkaline chemistries, with nominal voltages in increments of 2.10 - 2.13 and 1.5 volts, respectively, each representing one individual electrochemical cell. New special battery chemistries have strained older naming conventions. Rechargeable NiCd (nickel cadmium) and NiMH (nickel metal hydride) typically output 1.25 V per cell. Some devices may not operate properly with these cells, given the 16% reduction in voltage, but most modern ones handle them well. Conversely, lithium-ion rechargeable batteries output 3.7 V per cell, 23% higher than a pair of alkaline cells (3 V), which they are often designed to replace.

Batteries perform differently due to the diverse processes used by various manufacturers. Even another model cell from the same manufacturer will perform differently depending on what they are optimized for. You should also take into consideration the actual application in which the battery is being used. This can dramatically affect a battery's performance, so there are many factors to consider when choosing a battery cell for your product.

For more information, see our blog post on [how to select the type of cell to use in your battery pack].

## Comparison of Energy Density in Battery Cells

This battery comparison chart illustrates the volumetric and gravimetric energy densities based on bare battery cells.

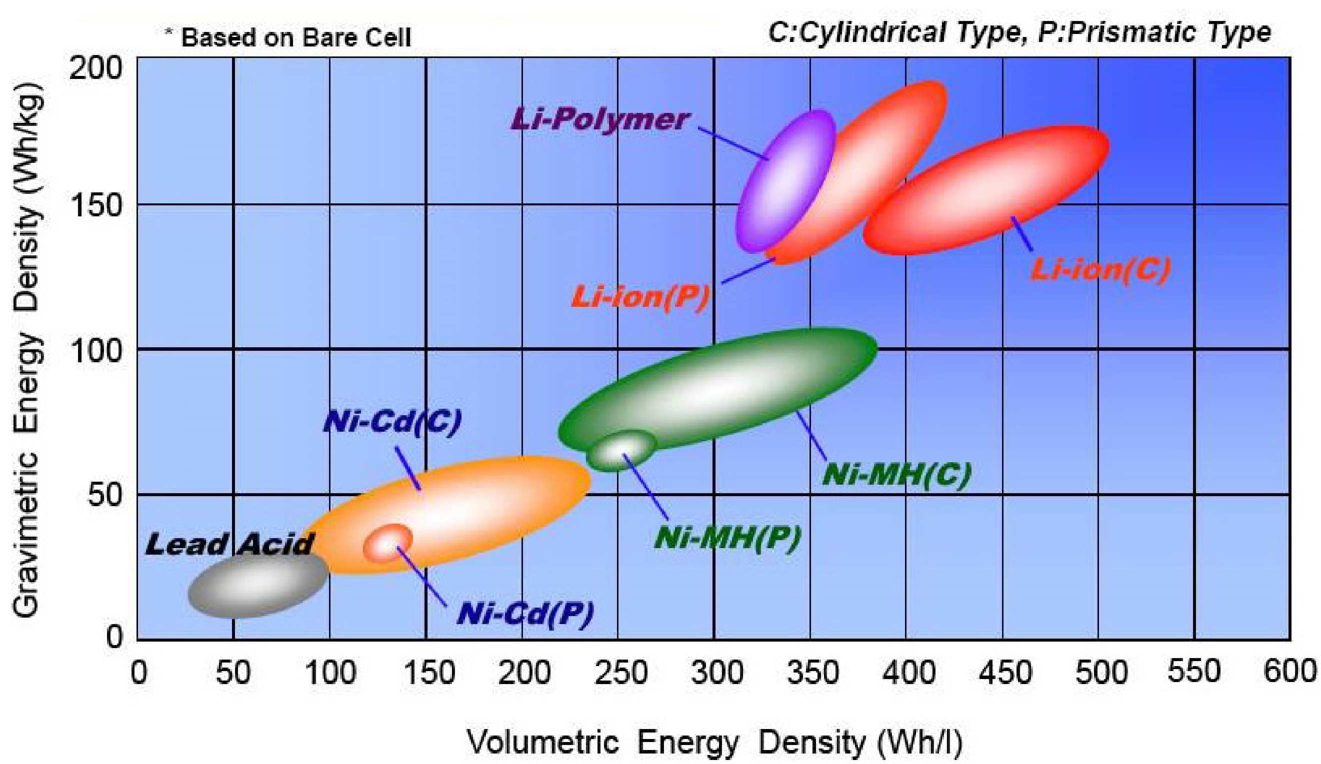
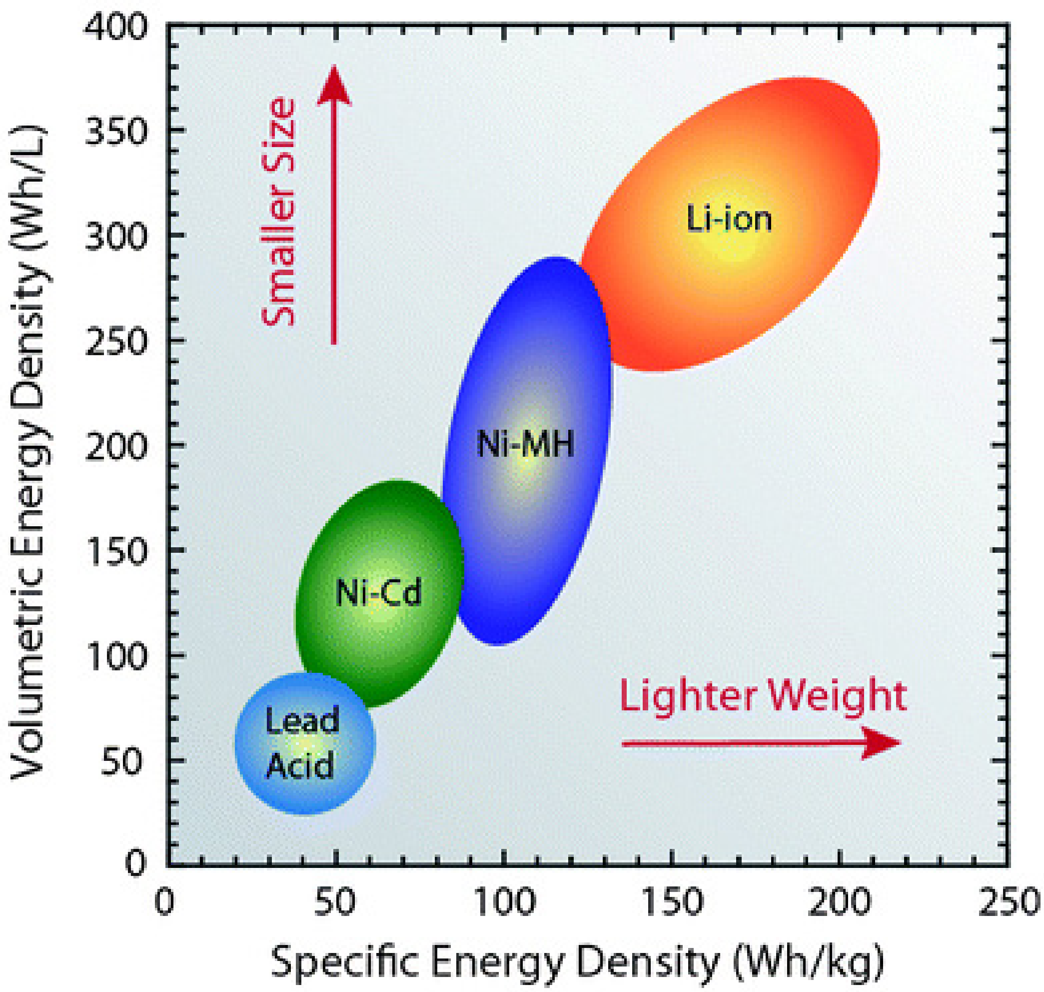



*Photo Credit: NASA - National Aeronautics and Space Administration*

## Energy Density Comparison of Size & Weight

The below battery comparison chart illustrates the volumetric and specific energy densities showing smaller sizes and lighter weight cells.




## Specifications by Battery Chemistry

<table>
<tr><th rowspan="2">Specifications</th><th rowspan="2">Lead Acid</th><th rowspan="2">NiCd</th><th rowspan="2">NiMH</th><th colspan="3">Li-ion</th></tr>
<tr><th>Cobalt</th><th>Manganese</th><th>Phosphate</th></tr>
<tr><td>Specific Energy Density (Wh/kg)</td><td>30-50</td><td>45-80</td><td>60-120</td><td>150-190</td><td>100-135</td><td>90-120</td></tr>
<tr><td>Internal Resistance (mΩ)</td><td><100<br>12V pack</td><td>100-200<br>6V pack</td><td>200-300<br>6V pack</td><td>150-300<br>7.2V</td><td>25-75<br>per cell</td><td>25-50<br>per cell</td></tr>
<tr><td>Life Cycle<br>(80% discharge)</td><td>200-300</td><td>1,000</td><td>300-500</td><td>500-1,000</td><td>500-1,000</td><td>1,000-2,000</td></tr>
<tr><td>Fast-Charge Time</td><td>8-16h</td><td>1h typical</td><td>2-4h</td><td>2-4h</td><td>1h or less</td><td>1h or less</td></tr>
<tr><td>Overcharge Tolerance</td><td>High</td><td>Moderate</td><td>Low</td><td colspan="3">Low<br>(cannot tolerate trickle charge)</td></tr>
<tr><td>Self-Discharge/ Month (room temp)</td><td>5%</td><td>20%</td><td>30%</td><td colspan="3"><10%</td></tr>
<tr><td>Cell Voltage (nominal)</td><td>2V</td><td>1.2V</td><td>1.2V</td><td>3.6V</td><td>3.8V</td><td>3.3V</td></tr>
<tr><td>Charge Cutoff Voltage (V/cell)</td><td>2.40<br>Float 2.25</td><td colspan="2">Full charge detection by voltage signature</td><td colspan="2">4.20</td><td>3.60</td></tr>
<tr><td>Discharge Cutoff Voltage (V/cell, 1C)</td><td>1.75</td><td colspan="2">1.00</td><td colspan="2">2.5-3.0</td><td>2.80</td></tr>
<tr><td>Peak Load Current<br>Best Result</td><td>5C<br>0.2C</td><td>20C<br>1C</td><td>5C<br>0.5C</td><td>>3C<br><1C</td><td>>30C<br><10C</td><td>>30C<br><10C</td></tr>
<tr><td>Charge Temperature</td><td>-20 to 50°C<br>-4 to 122°F</td><td colspan="2">0 to 45°C<br>32 to 113°F</td><td colspan="3">0 to 45°C<br>32 to 113°F</td></tr>
<tr><td>Discharge Temperature</td><td>-20 to 50°C<br>-4 to 122°F</td><td colspan="2">-20 to 65°C<br>-4 to 149°F</td><td colspan="3">-20 to 60°C<br>-4 to 140°F</td></tr>
<tr><td>Maintenance Requirement</td><td>3-6 months<br>(topping charge)</td><td>30-60 days<br>(discharge)</td><td>60-90 days<br>(discharge)</td><td colspan="3">Not required</td></tr>
<tr><td>Safety Requirements</td><td>Thermally Stable</td><td colspan="2">Thermally stable, fuse protection common</td><td colspan="3">Protection Circuit Mandatory</td></tr>
<tr><td>In Use Since</td><td>Late 1800s</td><td>1950</td><td>1990</td><td>1991</td><td>1996</td><td>1999</td></tr>
<tr><td>Toxicity</td><td>Very High</td><td>Very High</td><td>Low</td><td colspan="3">Low</td></tr>
</table>

# BATTERY MANAGEMENT SYSTEMS

Battery management systems (BMS) mean different things to different people. At Epec BMS is simply constant monitoring of key operational parameters during charging and discharging using outputs from sensors which give the actual status of voltages, currents, and temperatures within the battery as well as the state of charge.

Since we have developed our own unique battery management system we don't have to rely on 3rd parties for battery management system design as a lot of other companies do.

Our state of the art BMS integrates a precise battery gauge, cell balancing, protection circuitry, system control firmware and other safety features like temperature protections that will not allow charging outside of a specified temperature range.

## Battery Pack with Integrated Management System

This is done by utilizing a microcontroller to manage information from the sensing circuitry and then make decisions with the received information using application specific algorithms that are digitally encoded into the microcontroller. Working closely with some of the key integrated circuit (IC) manufactures in the industry such as Texas Instruments (TI), Linear Technologies and Sieko, we safely and cost effectively build some of the most creative designs in the industry.

## How We Customize a BMS for Each Application

In order to control battery performance and safety it is necessary for an in-depth understanding of the fundamental application requirements that the battery needs to meet. From there we can move into putting all of the building blocks in place.

## BMS Critical Components

Every BMS performs 3 critical functions for every application, provides protection for the cells, the battery pack and the pieces of equipment that it is powering as a thermal runaway in a battery pack can cause significant damage, extends the life of the battery by managing how and when it is used which minimizes the number or charge/discharge cycles, and keeps the battery in a state so that it is constantly prepared to power the application the moment it becomes necessary.

## Additional BMS Functions that can be Incorporated

**Cell Protection:** Lithium-ion cells have two critical design issues. If you overcharge them, you can damage them and cause overheating and even explosion or flame, so it is important to have a battery management system to provide over-voltage protection. They can also be damaged if they're discharged below a certain threshold, approximately 5 percent of total capacity. If the cells are discharged below this threshold, their capacity can become permanently reduced.

**Charge Control:** All batteries have a useful number of charge/recharge cycles so managing this function efficiently is critical to the life of the battery back. Along with that, overcharging is the most harmful thing that can happen to any battery.

**Demand Management:** The objective of any battery pack design is to minimize the current drain on the battery to lengthen the battery life by implementing power saving techniques into the BMS circuitry. This requires many years of design experience and a library of designs to pick and choose the right tools.

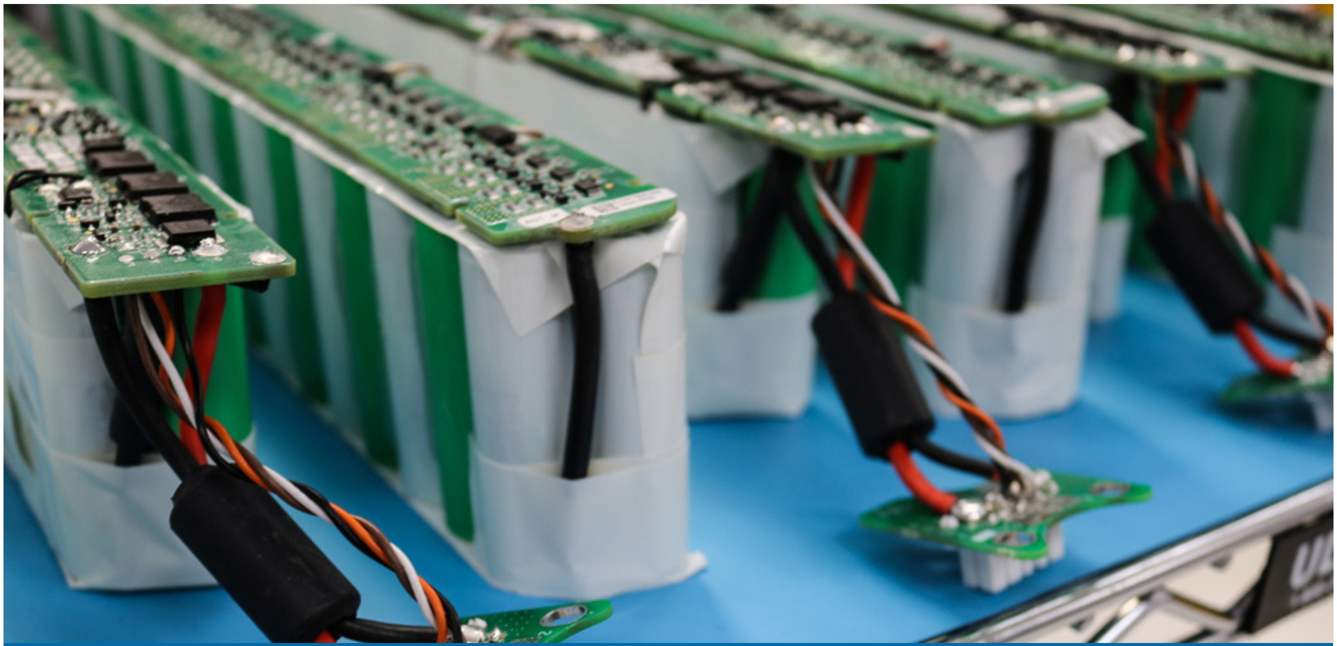
**SOC Determination:** Many applications require knowledge of the state of charge (SOC) of the battery or of the individual cells in the battery chain. This may simply be for providing the user with an indication of the capacity left in the battery, or it could be needed in a control circuit to ensure optimum control of the charging process. In many applications, this is the first reading to the control board as a device may have a minimum SOC for effective use.

**SOH Determination:** An important aspect of battery diagnostics is the battery state of health (SOH) determination, which is a qualitative measure of the battery's ability to store energy and deliver power. Battery diagnostics track the degradation of battery's performance to estimate battery SOH.

**Cell Balancing:** A battery pack usually consists of several individual cells that work together in combination. Ideally, all the cells in a battery pack should be kept at the same state of charge. If the cells go out of balance, individual cells can get stressed and lead to premature charge termination and a reduction in the overall cycle life of the battery. The cell balancing function extends the life of the battery by preventing this imbalance of charge in individual cells from occurring. While this functionality is not necessary in every application as it adds cost, we make it standard in all of our designs.

**History - (Log Book Function):** Being able to write data about the performance of the battery pack is another possible function of the BMS. This is an important tool in determining state of health (SOH) of the battery, usage data for next generation designs, and in assessing warranty claims.

**Authentication and Identification:** Being able to write information to the battery pack hardware allows OEMs to serialize, lot number control, and provide any other traceability that an application requires.



# PROTECTION CIRCUIT MODULES

Safety protection from overheating is a critical component of every lithium battery pack. While it is true that UL has very specific regulations concerning the safety of lithium battery packs, there is no substitute for significant experience in deploying electronics and other physical protections to assure safe operation of your end product.

## Primary Safety Circuits

The primary safety circuits manage all the basic safety functions: over-voltage, under-voltage, over-current, and sometimes over- and under-temperature. Additionally, most of the world-class designs that we produce also include a secondary safety circuit which is there to protect the cell from charge in the event the primary safety circuit fails.

## Protection Circuits

The protection circuits are contained in what is commonly referred to as the protection circuit module (PCM). While there are many off-the-shelf PCMs that you can buy, each individual application requires unique parameters are maintained, so it is not recommended that these off-the-shelf modules are used for anything other than lab prototypes. The PCM is a part of the battery management system (BMS), which manages the electronics of a rechargeable battery pack by monitoring its state, reporting that data, balancing the cells along with protecting the battery, and controlling its environment.

Battery protection circuits for the most demanding applications are operated mostly by integrated circuits (ICs) typically using MOSFETs to switch lithium cells in and out of circuit. The over-current protection is normally provided when the IC detects the upper current limit of the battery being reached and then interrupts the circuit.

## Fail Safe Environments

Many of these protections are resettable, but in fail safe environments they can be designed so that they are not. The two key manufacturers of these ICs are Texas Instruments (TI) and Sieko, both ICs require system programming based upon the functionality of the specific battery packs. This is why it is critical to work with an experienced company who has a history of these designs, and this will include a library of the software and firmware that can be transitioned to any application.

## Importance of Protection Circuit Modules

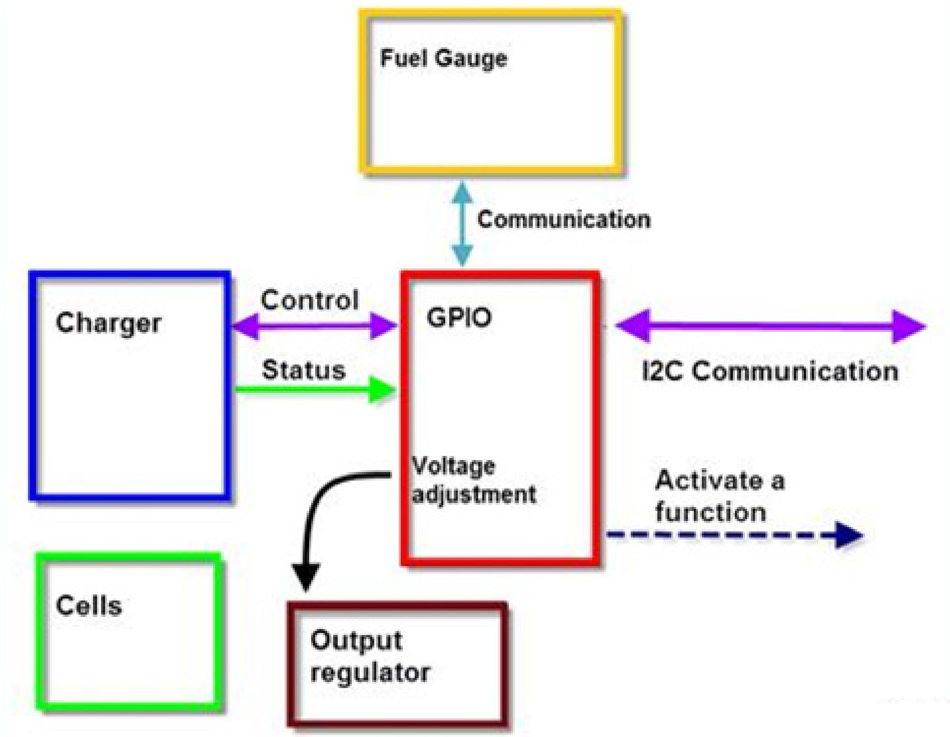
As many of the largest battery cell manufacturer’s move away from smaller applications to focus on the electric vehicle market, a lot of the newer and smaller companies are now providing cells for critical applications. This is why PCMs using primary and secondary safety mechanism is of the utmost importance for any company that wants to make their device portable and safe to use.

# GPIO OPTIONS

General Purpose Input/Outputs (GPIO) can be added to almost any custom battery pack and can be used to control any battery subsystem or control end-product functions using a simple two-wire interface, I2C.

## When to Use GPIO in Your Application

The addition of GPIO can be useful when the end system needs additional logic support that was not originally built into the product or if the logic supports changes based on different end product SKU levels. It can serve as the "glue logic" that links various subsystems together (see diagram).




It can be particularly useful when a single battery must support different products with widely varying parameters. An example of this is when different products require different regulated voltages. The GPIO can be used to adjust the battery's output regulator depending on the software commands from each system, allowing one battery pack to support many different products.

**Examples of GPIO Options:**

- Adjust battery charger current
- Turn LED indicators on and off
- Automated production BIT
- Read internal hardware status indicators
- Voltage monitoring
- Activate or switchover multiple battery banks
- Adjust on-board voltage regulators as needed by the fuel gauge or end product
- Self-destruct to protect IP (for military applications)

# FUEL GAUGES FOR BATTERY PACKS

Determining the cost of a battery pack with fuel gauge technology will vary depending on the accuracy of the battery fuel gauge required. The overall size of the battery pack will also have an effect on the final cost. For example, if a high-accuracy gauge is required on a small multi-cell battery, it could potentially double the cost. The good news is that the cost of battery cells become relatively small when factoring in the added value received from implementing a fuel gauge.

If your application does not require a fuel gauge with the highest accuracy, depending on by the size of the battery, it may only add an additional 10% to the price because the overall cost goes into the actual cells and the energy density of the battery. Each application will differentiate; if cost is a deciding factor, we can offer trade-offs to find the best solution based on your specifications.

## What is a Battery Fuel Gauge?

A battery fuel gauge informs the user how much power (battery life) is left in relation to total battery charging capacities. We actually use products with fuel gauges every day in electronics that run on battery power. Portable electronic devices, like your cell phone, are the most widely used example. There are a couple different ways in which fuel gauging can be achieved within your custom battery pack design. One way is through voltage lookup, which is the state of charge that can be determined by measuring battery voltage and comparing it with an internal lookup table. Another method is through coulomb counting. This is the total amount of energy entering and leaving the battery measured. Last is by using a combination of both voltage lookup and coulomb counting. This method offers the advantage of having each method balance any inaccuracies between the two types of readings.

Additionally, the Texas Instruments' impedance tracking fuel gauge technology offers further solution to issues with inaccurate readings due to aging and battery temperature. Using impedance tracking, the battery pack fuel gauge may be programmed to be accurate within 1% for the life of the battery. Accurate fuel gauges allow batteries to be discharged to almost empty confidence; hence, batteries do not need to be oversized making them smaller, lighter, and more dependable. A battery fuel gauge is much more complex that a fuel gauge in car for example. In a car, the gas tank always remains the same size regardless of temperature, the age of the car, or how fast the gas is being consumed. The tank size always remains the same and the float gauge is always accurate. In a battery, the capacity "size of the tank" is always changing with temperature, aging, and at the rate of energy consumption, and even the type of chemistry used. In order to be able to calculate the remaining capacity in a battery, all of these factors must be accounted for. If any variable is ignored, the gauge becomes less accurate.

# SYSTEM OUTPUT POWER

All lithium-ion (Li-ion) batteries require a battery management system (BMS). This is due to the fact that all Li-ion batteries will fail if overcharged, completely discharged, or operated outside their safe temperature window. Each Li-ion cell type has its own safe operating area, which makes it necessary to program the BMS accordingly.

In low-cost systems, there might be some differences in the requirements or functions for the BMS, especially for a low number of cells in series (e.g. 12 V systems with four cells in series), some battery system manufacturers propose a simple external under-voltage shutoff circuit and a charger with controlled end-of-charge voltage. For larger and more complex systems, the BMS guarantees the protection of highly expensive components and adds to the system functionality.

## Difference Between Battery, Module, and Cell

To begin with, it is important to understand the difference between the terms “battery,” “module,” and “cell.” Basically, a battery is the completely assembled pack with electrical, mechanical, and communication signal interfaces. The battery pack may consist of several modules that are wired in series and/or (less often) parallel. A module can be described as a part of the battery and is normally contained in the battery housing, although with very large batteries the modules can also be connected separately through cables.

In each module, single cells are connected in series or parallel. If the modules are connected in parallel, then it is possible to obtain higher currents and a series connection leads to a higher voltage. In a module, every cell has to be monitored to guarantee a proper function in the desired operating range (voltage, current, and temperature). The control of these modules is realized with a module control unit (MCU).

In a battery pack, several of these MCUs are connected directly or through a communication bus with a supervisory circuit or battery control unit (BCU) that, based on the input of the MCU, calculates historical values and incorporates any measures needed to protect the battery and maintain the performance of the pack. Some of these additional functions can be described as follows:

- Protect the cells from being operated outside the threshold condition.
- Balance the charge in the individual cells to maintain symmetry between the cells or to enhance overall available capacity.
- Disconnect the battery during emergency conditions in a safe way.
- Communicate relevant data for the driver displays and alarm functions.

## Optional System Output Power Design

Custom circuitry can be added to your battery pack BMS to make it behave more like a power supply or UPS system rather than a typical battery. These types of battery pack power systems are useful in applications that:

- Need instant UPS power in the event of input power failure.
- Need more power than can be provide by the input power source.
- Are sensitive to power fluctuations.

### How Does it Work?

A typical typology of a battery that offers system power that is derived from either the input power source or the battery. A typical arrangement capable of providing power from an external source to the system power input while charging the battery if needed. In the event input power fails, system power receives energy from the battery via the ideal diode shown in blue.

If a high-power demand accrues that is greater than the capability of the input power supply, the input current limit resistor shown in red above can be sized to allow supplemental power to be supplied by the battery. This is convenient when occasional surges are expected, but are not sufficient enough or long enough to justify a larger input power source. Output regulators can also be added to provide a regulated output power source. Adding this type of capability varies with every system due to the number of power variables and operating environments.

## BATTERY CHARGING METHODS AND DESIGN

In order to provide our customers with a full power management solution we have the experience and expertise to develop and configure a battery charger that fits your needs. Proper charging of a battery pack is essential to ensure safe and optimal operation of portable electronic devices. By optimizing both the battery pack and charger during the design phase, manufacturers can take into account all relevant considerations for their portable power source, including charge rate, accurate determination of full charge and charge termination. We have extensive experience offering customers customized charging solutions, utilizing products from Texas Instruments, Microchip, Analog Devices, Seiko, and others that significantly improve the battery charging dynamics. It provides greater efficiency and reduced charging time while improving battery cycle life.

### Charging Methods

**Constant Voltage:** A constant voltage charger is basically a DC power supply, which in its simplest form may consist of a step down transformer from the mains with a rectifier to provide the DC voltage to charge the battery. Such simple designs are often found in cheap car battery chargers. The lead-acid cells used for cars and backup power systems typically use constant voltage chargers. In addition, lithium-ion cells often use constant voltage systems, although these usually are more complex with added circuitry to protect both the batteries and the user safety.

The Li-ion charger is a voltage-limiting device that is similar to the lead acid system. The difference lies in a higher voltage per cell, tighter voltage tolerance, and the absence of trickle or float charge at full charge. While lead acid offers some flexibility in terms of voltage cut off, manufacturers of Li-ion cells are very strict on the correct setting because Li-ion cannot accept overcharge.

**Constant Current:** Constant current chargers vary the voltage they apply to the battery to maintain a constant current flow, switching off when the voltage reaches the level of a full charge. This design is usually used for nickel-cadmium and nickel-metal hydride cells or batteries.

**Taper Current:** This is charging from a crude unregulated constant voltage source. It is not a controlled charge as in V Taper. The current diminishes as the cell voltage (back emf) builds up. There is a serious danger of damaging the cells through overcharging. To avoid this the charging rate and duration should be limited (suitable for sealed lead acid batteries only).

**Pulsed Charge:** Pulsed chargers feed the charge current to the battery in pulses. The charging rate (based on the average current) can be precisely controlled by varying the width of the pulses, typically about one second. During the charging process, short rest periods of 20 to 30 milliseconds between pulses allow the chemical actions in the battery to stabilize by equalizing the reaction throughout the bulk of the electrode before recommencing the charge. This enables the chemical reaction to keep pace with the rate of inputting the electrical energy. It is also claimed that this method can reduce unwanted chemical reactions at the electrode surface such as gas formation, crystal growth, and passivation. If required, it is also possible to sample the open circuit voltage of the battery during the rest period.

**Burp Charging:** Also called reflex or negative pulse charging used in conjunction with pulse charging, it applies a very short discharge pulse, typically 2 to 3 times the charging current for 5 milliseconds, during the charging rest period to depolarize the cell. These pulses dislodge any gas bubbles that have built up on the electrodes during fast charging, speeding up the stabilization process and hence the overall charging process. The release and diffusion of the gas bubbles is known as “burping.” Controversial claims have been made for the improvements in both the charge rate and the battery lifetime as well as for the removal of dendrites made possible by this technique. The least that can be said is that “it does not damage the battery.”

**IUI Charging:** This is a recently developed charging profile used for fast charging standard flooded lead acid batteries from particular manufacturers. It is not suitable for all lead acid batteries. Initially, the battery is charged at a constant (**I**) rate until the cell voltage reaches a preset value, normally a voltage near to where gassing occurs.

This first part of the charging cycle is known as the bulk charge phase. When the preset voltage has been reached, the charger switches into the constant voltage (U) phase, and the current drawn by the battery will gradually drop until it reaches another preset level. This second part of the cycle completes the normal charging of the battery at a slowly diminishing rate. Finally, the charger switches again into the constant current mode (**I**), and the voltage continues to rise up to a new higher preset limit when the charger is switched off. This last phase is used to equalize the charge on the individual cells in the battery to maximize battery life.

**Trickle Charge:** Trickle charging is designed to compensate for the self discharge of the battery. Continuous charge. Long term constant current charging for standby use. The charge rate varies according to the frequency of discharge. Not suitable for some battery chemistries (e.g. NiMH and lithium) that are susceptible to damage from overcharging. In some applications, the charger is designed to switch to trickle charging when the battery is fully charged.

**Float Charge:** The battery and the load are permanently connected in parallel across the DC charging source and held at a constant voltage below the battery’s upper voltage limit. Used for emergency power backup systems. Mainly used with lead acid batteries.

**Random Charging:** All of the above applications involve controlled charge of the battery, however there are many applications where the energy to charge the battery is only available or delivered in some random, uncontrolled way. This applies to automotive applications where the energy depends on the engine speed, which is continuously changing. The problem is more acute in EV and HEV applications that use regenerative braking since this generates large power spikes during braking, which the battery must absorb. More benign applications are in solar panel installations that can only be charged when the sun is shining. These all require special techniques to limit the charging current or voltage to levels the battery can tolerate. You can get more information here.

## Battery Charger Design

Rechargeable batteries need to be recharged. This can be accomplished in a number of different ways depending on the chemistry and application. Simple batteries can use a simple off-the-shelf battery charger where the cells can be removed from the product and placed in a charger designed for charging the cells. This is common for rechargeable NiCd and NiMH type batteries.

Larger, more complex batteries can use a similar method using a less universal type of battery charger. This type of charging is commonly found in the power tool market where the larger battery is removed from the tool and placed into an external battery charger.

Other common charging methods are to use an external charger that plugs into the product or an external power supply that supplies power to the internal charger in the product. These are common methods used in the cell phone and laptop markets, respectively.

Custom manufactured Lithium-Ion battery chargers provide safe and reliable charging support for our lithium battery packs whether they are embedded in the battery pack or a stand-alone charger.

**Some specific design features that we support include:**

- Linear power supply
- Fault detection
- Embedded charge design
- Pack circuitry integration
- Custom molded or fabricated enclosures
- Synched battery pack & charger encryption
- Multiple intelligent design functionalities

More information on different charging options:

- Embedded Battery Chargers
- Wireless Charging Technologies
- Limitations of Inductive Charging
- What to Know to Successfully Charge Your Batteries

# ENCLOSURE AND MECHANICAL CONSIDERATIONS

A well-designed battery pack provides mechanical protection, thermal stability, electrical protection, and the safety features for the end user. The electrical interconnections, mechanical supports, external enclosures, and thermodynamic systems are all essential elements of the battery packs structural design.

## Enclosures

Some battery packs are installed inside the product, and only require a shrink-wrap enclosure. In other cases, battery packs are mounted externally and may serve a mechanical function, such as a handle or base for the product. At the same time the case must also protect the cells and the electronics from the harsh operating environments of temperature extremes, water ingress, humidity and vibration in which these batteries work.

## Injection Molded Plastic

Enclosures made from injection molded plastics are most commonly used for battery packs. For these enclosed pack designs, two or more plastic parts are molded and then assembled with the pack and accompanied circuitry. They can be sealed using glue, mechanical fasteners (screws) or ultrasonic welding. The product cost can be reduced by using insert moldings in which the interconnection strips and the terminals are molded into the plastic parts to eliminate both materials and assembly costs. In some designs, the battery pack can form part of the outer case of the end product and usually requires a mechanical latch to hold the battery in place. This latch as well as the terminals must interface with plastic parts from the device itself so high precision and tight tolerances are essential.

## Shrink Wrap of Vacuum Formed Plastic

The simplest and least expensive packaging for small batteries is shrink wrap or vacuum formed plastic. These solutions are only possible if the battery is intended to be completely enclosed by the finished product. In other cases, battery packs are mounted externally and may serve a mechanical function, such as a handle or base for the product. Our extensive experience in designing battery enclosures of all types allow us to enhance the functional design of the product while assuring that the battery passes any shock, vibration and environmental testing required for your application.

## Other Considerations

Thermal effects need to be taken into account and, tolerances must allow for potential swelling of the cells. Some Lithium pouch cells may swell as much as 10% or more over the lifetime of the cell. For this reason, enclosures may be designed with vent holes to dissipate generated heat or exhaust vented gases from cells. Multiple vent holes may be used to increase airflow in and out of the pack.

## Intrinsically Safe Batteries

Intrinsically safe batteries will not initiate and explosion should the electronic device malfunction while operating in areas that contain explosive gases or high dust concentration.

For these applications, specific materials are selected for battery pack enclosure and many times potting material is used in the battery pack enclosure to eliminate any air gaps.

While seeming like a quick design development, the enclosure can raise costs to the point where the battery pack price is outside your budget. Off-the-shelf solutions can keep the price within a customer's means. In addition, enclosures that are inside the product that will not be seen by consumers can also have simple designs. However, there are certain occasions where a custom enclosure design will help market and sell the product. Both the battery enclosure and the tooling will need to be created, which can increase project timelines.

## Potting and Encapsulation

By utilizing potting and encapsulation compounds in your battery pack design, we can optimize the performance of your end product. You can get more information on these capabilities here.

## IP Rating

The IP rating goes hand in hand with the battery enclosure development. IP stands for Ingress (or Internal) Protection mark. This rating involves how watertight, dust resistant, and dirt resistant that the battery enclosure will be. Different industries will require specific IP ratings for battery pack enclosures in products.

Some customers will think that by seeking out the highest IP rating will be best for their battery pack enclosure to meet all certification levels. However, the more that is added to the battery pack will drastically increase the costs, along with the weight of the battery pack. Also, the type of product that is being created may not need to reach such high certification levels.

# CERTIFICATIONS - WHAT IS NEEDED?

Lithium battery safety is at the top of the list for anyone who manufactures custom battery packs. The battery pack certifications listed here are near universal standard industry practice for leading companies in the electronic industry. Product safety is important to all product stakeholders and passing safety certifications are an independent means of assuring products are safe. The practice of testing to UL, IEC, and IEEC, is routine for companies with years of experience and with in-house resources to manage the process. Below you will find a chart that outlines some general guidelines for costs and timing of these certifications.

| | CE | IEC | UL | UN38.3 |
|---|---|---|---|---|
| **Packs Required** | 0 | 21 | 33 sealed, 11 open | 16 |
| **Est Cost** | $500 | $5 – 10,000 | $15 – 20,000 | $5 - 7,000 |
| **Test Timing** | 3 weeks | 6-8 weeks | 10 - 12 weeks | 4 – 6 weeks |

All of the costs and the lead times of these tests will vary depending on the battery construction, capacity, pack size, and cycle requirements. In our initial proposal we will provide you with the specifics for each based on your design.

- IEC testing includes CB certification.
- IEC and UL testing must be done after the transportation certification is complete.

## UN/DOT

In order to ship ANY lithium batteries products via air freight, the UN 38.3 test must be passed by the battery packs. New regulations were passed in 2016 that tighten requirements for shipments of lithium products and that forbid lithium batteries to be shipped on passenger aircraft. It is been projected by some that shipping lithium by air freight all together may eventually become forbidden. So currently, unless a company intends to be extremely restricted in its options for transporting their lithium batteries (ground transport as Class 9 Hazardous Goods), they will need to certify that their batteries have passed UN/DOT 38.3. The UN (United Nations) issues recommendations for the transport of dangerous goods worldwide.

The U.S. DOT (United States Department of Transportation) defines shipping regulations for the U.S. under 49 CFR, Sections 100 - 185. Section 173.185 specifically addresses specifications and exceptions and packaging for lithium batteries; section 172.101 covers shipping. Together, the UN and DOT guidelines define test requirements for the safe packaging and shipment of lithium metal and lithium ion batteries. Safety test criteria are defined in the “Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, Part III, Section 38.3.” UN/DOT 38.3 (also known as the T1-T8 Tests and UN ST/SG/AC.10/11/Rev. 5). Covers transportation safety testing for all lithium metal and lithium ion cells and batteries.

The test criteria span 8 different tests (T1 - T8) and are all are focused on hazards associated with transportation. See our United Nations Testing for more information.

## IATA (International Air Transport Association)

To assist in understanding the complete requirements related to the transport of lithium batteries, including packing instructions, IATA has developed guidance for shippers, freight forwarders, ground handlers, airlines, and passengers. The 58th (2017) Edition of the IATA Dangerous Goods Regulations (DGR) provides the definitions, classifications, exceptions, and prohibitions for shipping lithium batteries. While you don't need to submit product to get certification from IATA, any employee who will be responsible for shipping lithium batteries must pass a test to become certified to do so. It also requires that this person re-certify this qualification on a yearly basis.

## Underwriters Laboratories (UL)

UL is an independent product safety certification organization which, in conjunction with other organizations and industry experts, publishes consensus-based safety standards. For lithium batteries, key standards are:

- UL 1642 (lithium batteries) – This standard is used for testing lithium cells. Battery pack level tests are covered by UL 2054.
- UL2054 (requirements cover portable primary (no rechargeable) and secondary (rechargeable) batteries for use as power sources in products. These batteries consist of either a single electrochemical cell or two or more cells connected in series, parallel, or both, that convert chemical energy into electrical energy by chemical reaction).
- UL 2580 (batteries for use in electric vehicles)

## The International Electrotechnical Commission (IEC)

IEC is a non-profit standards organization that writes International Standards for all electrical, electronic, and related technologies. IEC standards address general, safety, and transportation specifications. For lithium batteries, key standards are:

- 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 60086-4 - Specifies tests and requirements for primary lithium batteries to ensure their safe operation under intended use and reasonably foreseeable misuse.
- IEC 61960 - Secondary Cells and Batteries containing Alkaline or other Non-Acid Electrolytes – Secondary Lithium Cells and Batteries for Portable Applications.
- IEC 62281 - Requirements for primary and secondary (rechargeable) lithium cells and batteries to ensure their safety during transport other than for recycling or disposal.

## CE Marking

The European Union's CE Marking requirements help to ensure that all safety requirements are met. CE Marking is a self-declaration made by the manufacturer to acknowledge that a product meets requirements for EU product safety. The CE Mark does not apply to products sold in the U.S.

### The American National Standards Institute (ANSI)

ANSI is a private nonprofit organization that develops consensus-based standards. The ANSI C18 Standard specifies tests and requirements for portable primary lithium cells and batteries, both the chemical systems and the types covered in ANSI C18.3M, Part 1, to ensure their safe operation under normal use and reasonably foreseeable misuse.

ANSI's safety standards for primary and rechargeable lithium and lithium-ion cells and batteries are:

- ANSI C18.2M, Part 2 (Portable Rechargeable Cells and Batteries - Safety Standard)
- ANSI C18.3M, Part 2 (Portable Lithium Primary Cells and Batteries - Safety Standard)

### The Institute of Electrical and Electronics Engineers (IEEE)

IEEE is an international non-profit organization covering technologies related to electricity, and develops safety standards for industry, including batteries. For lithium batteries, key standards that are design guidelines, not pass/fail safety standards are:

- IEEE 1725 (Rechargeable Batteries for Cellular Telephones) Design analysis criteria for qualification, quality, and reliability of rechargeable lithium ion and lithium ion polymer batteries for any device that utilize cellular phone capabilities it's operation. Also included in the standard are: battery pack electrical and mechanical construction, packaging technologies, and pack and cell level charge and discharge controls and overall system considerations.
- IEEE 1625 (Rechargeable Batteries for Multi-Cell Mobile Computing Devices) this standard establishes criteria for design analysis for qualification, quality, and reliability of rechargeable battery systems for portable computing.

### SAE International

Society of Automotive & Aerospace Engineers is a professional organization for the aerospace, automotive, and commercial vehicle industries. With hybrid and full electric vehicles now entering the marketplace in large numbers, the need for battery standards is getting greater attention, and the SAE has created standards for these products that are very specific to that industry and the few large companies that manufacture batteries for vehicles.

## SHIPMENT & TRANSPORTATION OF BATTERY PACKS

Lithium batteries are considered hazardous materials and are subject to various regulations. When offering for transport, different rules will apply depending on the power requirements of the design, whether they are rechargeable or not, and on how they are transported (land, air, ocean). By law, the shipper carries all the responsibility when offering lithium batteries for transport.

International shipments by air are regulated by the International Civil Aviation Organization (ICAO) Technical Instructions and International Air Transport Association (IATA). For shipments by ocean, the International Maritime Dangerous Goods (IMDG) code is used.

Shipments in the U.S. are regulated by Title 49 of the Code of Federal regulations (49 CFR). The ICAO and IMDG codes are updated every two years, while 49 CFR and IATA are updated annually. Anyone who is directly responsible for the shipment of hazardous materials must be trained in their specific function (49 CFR, §172.702(b)).

Companies should also consider the logistics when it comes to battery pack development, prototypes, transportation testing, certifications, and production. Some manufacturers will pass off part of the process to other companies as they may not design or build certain aspects of the battery pack components. Finding out which parts of the development and production that will be performed in-house with the manufacturer, and which components will be passed off to other shops, will help a company understand what additional costs and lead times will be needed.

Some companies will handle all the design, development, prototyping, and manufacturing of the battery packs, then send the prototypes off to be tested and signed off before starting the production line. This process allows them to better control lead times and provide any required design changes that may be necessary so that the battery pack manufacturing process will be feasible for the product.

Battery technology is driven by the need to increase energy storage density, which lithium helps achieve. Today, there are two types of lithium battery: non-rechargeable dry cells, sometimes called lithium-metal, and rechargeable Lithium-ion or Li-ion. Dry cell lithium batteries – the type used in flashlights and portable radios – don’t pose the same challenges as Li-ion batteries. They are, however, still hazardous owing to the use of lithium, a metal that burns readily in air and at a temperature above the melting point of aluminum.

The potential hazards of Li-ion have led domestic and international safety agencies to implement a range of restrictions on battery transportation. The most onerous are those on movement by air, although rules also apply to sea, road, and rail transport. (Anyone who flies regularly will know airlines want rechargeable batteries kept with their owners/passengers and not in the hold).

Note that there are differences between the rules for batteries shipped contained in or packed with equipment and those shipped without equipment. There are also different limits for very small batteries. “Contained in” means the battery is shipped in the device it will power. For example, the battery in a cordless drill may be shipped either “contained in equipment” or “packed with equipment,” while batteries going to the U.S. for assembly into electrical devices are “without equipment.” The differences in shipping regulations relate principally to the number of batteries that may be placed in a package.

To assist shippers in understanding the complete requirements related to the transport of lithium batteries, including packing instructions, IATA has prepared the updated Lithium Battery Guidance Document (pdf). This 2020 guidance document includes updated and additional FAQs for shippers to learn how to comply with the 61st (2020) Edition of the IATA Dangerous Goods Regulations (DGR) on definitions, classifications, exceptions, and prohibitions.

You can get more detailed information on shipping lithium batteries see our blog post on What to Know Before Shipping Lithium Batteries.

# UNITED NATIONS TESTING

The UN Publication "Recommendations on the Transport Of Dangerous Goods Model Regulations" and its counterpart "Recommendations on the Transport Of Dangerous Goods Manual of Tests and Criteria" are the internationally recognized authority for the testing, packaging, and shipping of dangerous goods.

Epec follows these documents and provides our customers with safe, tested battery assemblies that can weather the rigors of transport. New battery assemblies requiring testing are certified for transport against a series of tests as applicable.

### T.1 Altitude

This test simulates air transport under low-pressure conditions.

### T.2 Thermal

This test assesses cell and battery seal integrity and internal electrical connections. The test is conducted using rapid and extreme temperature changes.

### T.3 Vibration

This test simulates vibration during transport.

### T.4 Shock

This test simulates possible impacts during transport.

### T.5 External Short Circuit

This test simulates an external short circuit.

### T.6 Impact

This test simulates an impact (cell only).

### T.7 Overcharge

This test evaluates the ability of a rechargeable battery to withstand an overcharge condition.

### T.8 Forced Discharge

This test evaluates the ability of a primary or a rechargeable cell to withstand a forced discharge condition.

# UN REGULATIONS

Please visit http://www.iata.org/ and http://live.unece.org/ for more information regarding the UN Regulations and Testing.

IATA UNECE

# GLOSSARY OF TERMS

**Anode:** The negative electrode of a cell.

**Button Cell:** A small round or elliptical cell whose diameter is greater than its height.

**Capacity:** Capacity is the product of the discharge current Amps (A) or milli Amp (mA) and the discharge time (h) at a given load and is expressed in Amp-Hours (Ah) or milli Amp-Hours (mAh).

**Cathode:** The positive electrode of a cell.

**Cell:** A single encased electrochemical unit (one positive and one negative electrode) which exhibits a voltage differential across its two terminals. Under the Model Regulations of Tests and Criteria (See UN38.3 Tests), to the extent the encased electromechanical unit meets the definition of a “cell” herein, is a “cell”, not a “battery”, regardless of whether the unit is termed a “battery” or a “single cell battery” outside of the Model regulations. The CE mark (Abbreviation of Conformité Européenne) is a mandatory conformity mark for products placed on the market in the European Community. With the CE mark on the product, the manufacturer ensures that the product conforms to the requirements of the applicable EC directive.

**Chemistry:** Refers to the basic material of the negative electrode. Example: Zinc, Lithium, Nickel.

**Closed Circuit Voltage - CCV:** Voltage across the terminals of a battery under load when there is external current flowing.

**Coin cells:** A small cell whose diameter is greater than its height. Coin cells are typically lithium chemistry.

**Cycle:** One sequence of fully charging and fully discharging a rechargeable cell or battery.

**Discharge:** Operation during which a battery delivers current to an external circuit or load.

**Discharge Characteristics - Discharge Curve:** Graphical representation of the change in output voltage over time under various loads and/or ambient temperature.

**Electrolyte:** Medium in a battery which causes ions to move to create an electrochemical reaction. Either water or non-aqueous solution is used as solvent. The latter is called non-aqueous electrolyte solution, either organic or inorganic.

**End-point Voltage:** Specified closed circuit voltage at which a cell is terminated. Also referred to as “cutoff” or “final” voltage.

**Energy Density:** Available energy of a battery per unit volume or unit weight.

**IATA:** The International Air Transport Association (IATA) is an international trade group comprised of some 240 airlines and is headquartered in Montreal Quebec, Canada. IATA’s stated mission is to represent, lead and serve the airline industry. The main aim of IATA is to provide safe and secure transportation to its passengers. IATA annually publishes the IATA Dangerous Goods Regulations (DGR), which are modeled after the ICAO Technical

Instructions. (The 54th Edition became effective on 1-1-2013.) Working closely with governments in the development of the regulations, including ICAO and other national authorities, IATA ensures that the rules and regulations governing dangerous goods transport are both effective and efficient. The U.S. Department of Transportation (DOT) does not officially recognize or enforce the IATA Dangerous Goods Regulations. Instead, the DOT has the authority to enforce the ICAO Technical Instructions.

**Internal Impedance:** Internal impedance of a cell that increases as the cell ages or is discharged. This is measured by a 1000Hz Bridge, also called internal resistance. Typical internal impedance of a cell is <100μOhms.

**Leakage:** The escape of material from a cell or battery. The most common leakage is electrolyte, which is either very flammable or very corrosive.

**Lithium Content:** The mass, in grams, of lithium metal contained within the anode of lithium metal or lithium alloy cell. These are, for the most part, primary cells. The lithium content of a lithium battery is the sum of the lithium mass of the anodes of all the cells in the battery.

**Load:** External device or method through which a battery is discharged.

**Nominal Voltage:** Approximate midpoint voltage, during discharge, of a fully charged battery cell. This varies by chemistry with common examples below:

- Alkaline manganese primary - 1.5V
- Zinc Carbon Primary - 1.5V
- Lithium manganese dioxide primary - 3.0V
- Lithium thionyl chloride primary - 3.6V
- Nickel cadmium rechargeable battery - 1.2V
- Nickel metal-hydride rechargeable - 1.2V
- Nickel Zinc rechargeable - 1.6V
- Lithium-ion rechargeable - 3.7V
- Lithium-prismatic rechargeable - 3.7V
- Lithium-polymer rechargeable - 3.7V
- Silver Oxide Primary - 1.55V
- Zinc Air Primary - 1.45V

**Open Circuit Voltage - OCV:** Voltage across the terminals of a battery when no external current is flowing and not under load. The OCV is typically higher than a battery's nominal voltage.

**Over Discharge:** To discharge a cell to a voltage below its end-point voltage.

**Packing Instructions:** The ICAO Technical Instructions and the IATA Dangerous Goods Regulations require compliance to specific Packing Instructions (PIs) in order to offer lithium-metal primary cells and batteries and lithium-ion rechargeable batteries for transport in passenger and cargo aircraft.

- PI 965: UN3090 Lithium-metal primary cells and batteries.
- PI 966: UN3091 Lithium-metal primary cells and batteries shipped with equipment.
- PI 967: UN3091 Lithium-metal primary cells and batteries installed in equipment.
- PI 968: UN3480 Lithium-ion rechargeable cells and batteries.
- PI 969: UN3481 Lithium-ion rechargeable batteries shipped with equipment.
- PI 970: UN3481 Lithium-ion rechargeable batteries installed in equipment.

**Protection Circuit Module - PCM:** The safety circuit installed in all lithium-ion and lithium-polymer rechargeable battery packs to control over-charge, over-discharge and short circuit of the cells within the pack. This circuit is mandated by the UN Manual of Tests and Criteria, paragraph 38.3, Rev. 5.

**Protective Devices:** Devices, such as fuses, diodes, and current limiters which interrupt the current flow, block the current flow in one direction or limit the current flow in an electrical circuit.

**Primary:** A cell or battery which is not designed to be charged and discharged.

**Rated Capacity:** The capacity, in ampere-hours (Ah) of a cell or battery as measured by subjecting it to a load, temperature and cut-off voltage point specified by the manufacturer.

**Self-discharge:** Decreasing capacity during storage without load, caused by chemical reaction in a battery. The higher the temperature during battery storage, the greater the rate of self-discharge.

**SMBus:** System Management Bus, as defined by the Intel Corporation in 1995. It is used in personal computers and servers for system management communications, including battery charge status.

**UN3090, UN3091, UN3480 & UN3481:** The IATA Dangerous Goods Regulations and the U.S. Code of Federal Regulations (49CFR Part 172(c)(1)) classify lithium-metal primary and lithium-ion rechargeable cells and batteries as Dangerous Goods; and must be shipped in passenger and cargo aircraft in accordance with specific packing instructions. (See Packing Instructions)

- UN3090: Lithium-metal primary cells and batteries.
- UN3091: Lithium-metal primary cells and batteries shipped with or in equipment.
- UN3480: Lithium-ion rechargeable cells and batteries.
- UN3484: Lithium-ion rechargeable cells and batteries shipped with or in equipment.

UN 38.3 Tests: In order to offer for transport in passenger and cargo aircraft, lithium-metal primary cells and batteries and lithium-ion rechargeable cells and batteries must comply with Packing Instructions 965 through 970 (as applicable) in The ICAO Technical Instructions “Recommendations on the Transport of Dangerous Goods Manual of Tests and Criteria”. This packing instruction includes mandatory provisions for the testing of lithium metal and lithium-ion cells and batteries (Sub-section 38.3).

**Vent:** A safety device built into almost all cells designed to release internal pressure in the case of overcharge, over temperature and other abuses. The vent will preclude rupture or disassembly.

**Venting:** The release of excessive internal pressure from a cell or battery in a manner intended by design to preclude rupture or disassembly. Venting may also release electrolyte.

**Watt-hours:** A cell or battery’s nominal voltage multiplied by its rated capacity in amp-hours.

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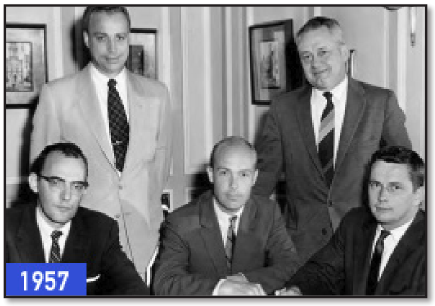



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