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LITHIUM BATTERIES 101

HISTORY | CHEMISTRY | VARIATION | TECHNOLOGY | APPLICATIONS

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Lithium 101

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What you need to know when connecting and charging lithium batteries in series, parallel and series parallel banks.

Introduction

A brief history and overview of advanced battery chemistry:

Gaston Planté (22 April 1834 – 21 May 1889) was a French physicist who invented the first advanced battery chemistry; the lead-acid battery in 1859. Lead-acid rechargeable batteries have continued to evolve and today are used in a variety of starting, lighting and ignition applications as is the most widely used rechargeable cell chemistry.

Modern-day non-rechargeable (primary cell) alkaline batteries were invented by Canadian engineer Lewis Urry in the late 1950s while working for Union Carbide's Eveready battery division in Cleveland Ohio. Rechargeable (secondary cell) alkaline manganese batteries followed in the 1970s from Union Carbide in conjunction with Mallory.

First developed in 1899 by Swedish inventor Walderman Jungner, Nickel-cadmium (Ni-Cd) cell chemistry continued to be improved and have been commercially available for many decades. Battery packs using small Ni-Cd cells became very popular in the late 1980s as the battery of choice for portable devices. Large format Ni-Cd battery packs using large Ni-Cd cells have proven to be rugged, forgiving batteries and have a loyal following in the rail and airline industries.

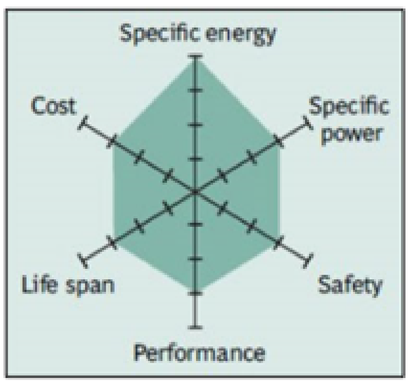
After decades of development that began in 1967, nickel-metal hydride (NiMH) cells have become a popular alternative to rechargeable alkaline cells. While potentially difficult to charge and discharge, control protocols evolved that allows NiMH cells to become one of the most readily available cell chemistries for consumer-grade rechargeable batteries. NiMH cells have a limited service life when compared to Ni-CD. NiMH batteries are negatively affected by deep discharges and require tightly controlled charge algorithms. However, NiMH cells have a higher capacity than equivalent Ni-CD cells and are less prone to memory effects.

The first lithium-ion battery prototype

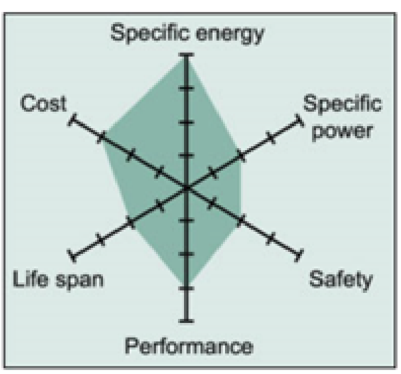
was made by Asahi Chemical of Japan in 1985, and a stable consumer version was brought to market by Sony in 1991. Lithium-ion cells have evolved with a number of widely used lithium-ion chemistries in the market today. We expect this trend to continue as the search for the ultimate battery continues.

Popular lithium (ion) cell types:

- Lithium Nickel Manganese Cobalt Oxide - $LiNiMnCoO_2$ (NMC). A cost-reducing technology that is popular for power tools, e-bikes and electric vehicles.



- Lithium Cobalt oxide battery - $LiCoO_2$ (LCO). A popular choice for consumer electronics that is slowly being replaced by NMC



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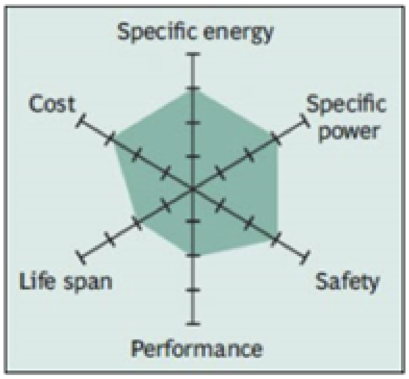
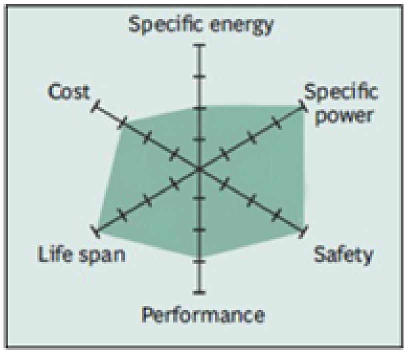
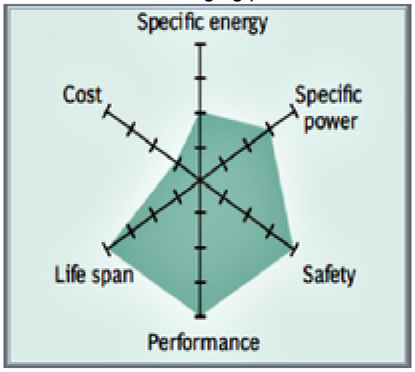
- Lithium Manganese Oxide battery - $LiMn_2O_4$ (LMO). Fast Charging and popular in hybrid electric vehicles, power tools and medical devices



- Lithium Iron Phosphate battery - $LiFePO_4$ (LFP). Does not use any speculative materials like Nickel or cobalt helping to make this one of the safest and price-stable technologies. The use of phosphate also avoids cobalt's environmental concerns. LFP is a long-life, robust, deep-cycle technology with a particular application in the energy storage market as well as a deep-cycle lead-acid battery replacement.



- Lithium Titanate and Nano-Titanate battery – Li_2TiO_3 / $Li_4Ti_5O_{12}$ (LTO). Excellent safety and life span for use in extreme cold or hot temperatures and/or high cost to serve installations. Combined with Ultra-fast charge and discharge characteristics, LTO cell chemistry has wide-ranging potential in mission-critical applications.



Thanks to Boston Scientific for the above 5 images

What are batteries made of?

What are lead-acid batteries made of?

The **(+)** and **(-)** grids in a lead-acid battery cell are made from a lead alloy. Pure lead is too soft and would not support itself, so small quantities of other metals are added to get improved mechanical strength and electrical properties. The grids are pasted with a lead-oxide paste that includes various additives. The paste is applied at various densities depending upon battery type and application. The pasted grids are now referred to as finished plates. A separator is included between the pasted **(+)** and **(-)** plates to prevent them from coming into contact with each other. The most popular automotive battery separator uses a PE material formed into an envelop that then surrounds either all of the negative plates or all of the positive plates (but not both) depending upon battery design. Then the plates are immersed in an electrolyte of sulphuric acid and water.

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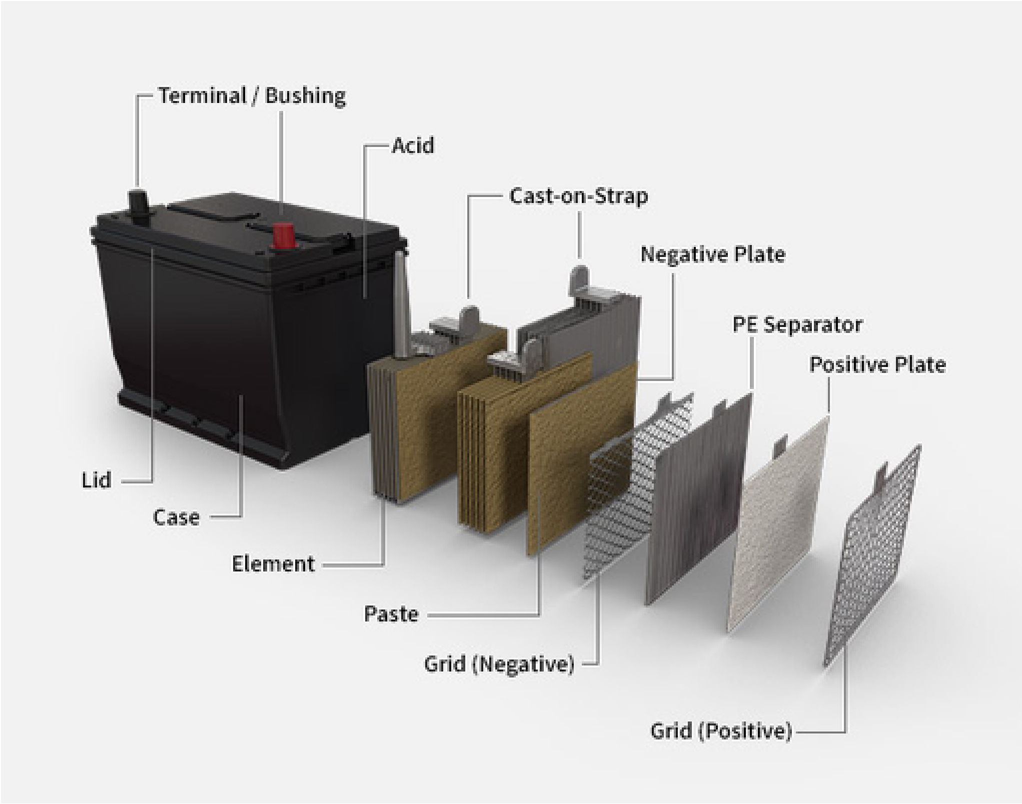

Lead-acid battery building blocks

Lead-Acid Battery	Cathode(+) Grid	Cathode Active Material Paste	Separator	Anode(-) Grid	Anode Active Material Paste	Electrolyte
Material	Lead Metal Alloy	Lead dioxide PbO_2	Typically PE or PVC. Sometimes include Glass fiber mats	Lead Metal Alloy	Pb lead Oxide	Sulfuric Acid (H_2SO_4)
When Charged	Lead Metal Alloy Grid provides current pathway	Lead dioxide PbO_2		Lead Metal Alloy Grid provides current Pathway	Lead Pb	High Specific Gravity H_2SO_4
When Discharged	Lead Metal Alloy Grid provides current Pathway	Lead Sulfate $PbSO_4$		Lead Metal Alloy Grid provides current Pathway	Lead Sulfate $PbSO_4$	Low Specific Gravity H_2O

How do lead-acid batteries work? What is the electro-chemical process?

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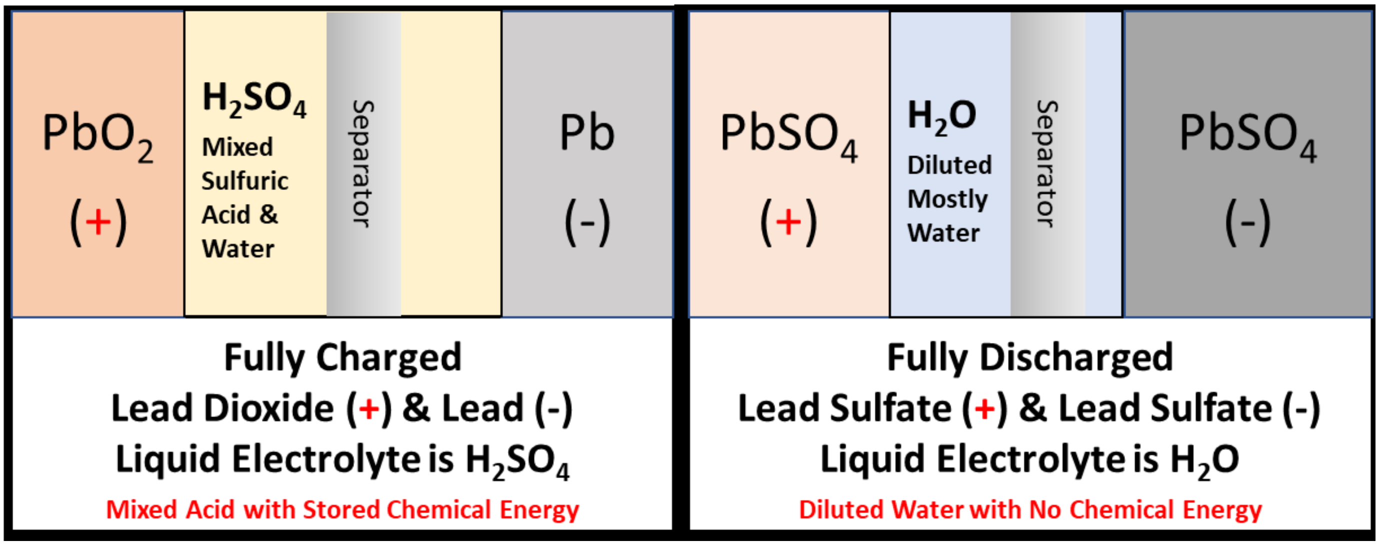

What are lithium (ion) batteries made of?

Most Li-ion batteries share a similar cell design involving 4 components.

1. The positive electrode is typically made of a metal oxide active material layer pasted onto an aluminum current collector positive**(+)** electrode (cathode),

2. Generally, the negative electrode of conventional lithium cells is made from a carbon/graphite active material layer pasted onto a copper current collector negative**(-)** electrode (anode),

3. A separator that prevents the positive plate from coming in contact with the negative plate but porous enough to allow lithium ions to pass through as they migrate back and forth through the electrolyte solution during the charge and discharge process.

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4. The electrolyte is made of lithium salts dissolved in an organic carbonate solvent. Electrolyte plays a key role in transporting the positive lithium ions (Li+) between the cathode and anode.

Lithium (ion) battery building blocks

Lithium Battery	Cathode(+) Sheet	Cathode Active Material	Separator	Anode(-) Sheet	Anode Active Material	Electrolyte
Material	Aluminum	Metal Cobalt, Nickel, Manganese, Iron, Titanate oxides	Typically Polyethylene or Polypropylene Can be proprietary	Copper	Carbon Based (can be a nanotechnology oxide in highly designed products)	Lithium salts diluted in an organic carbonate solvent Typically $LiPF_6$ The diluted lithium salts become Lithium Ions
When Charged	Provide current Pathways	Electrons are lost		Provide current Pathways	Electrons are gained	
When Discharged	Provide current Pathways	Cathode gains electrons		Provide current Pathways	Electrons are lost. Anode oxidizes to mainly Carbon	

How much lithium is in a typical Lithium battery?

The Lithium content in a high capacity Lithium battery is actually quite small.

For example the Lithium content by weight makes up about 7% of the total cathode material in a $LiCoO_2$ cell. The cathode material itself makes up between 25% and 35% of the total cell weight so the Lithium content within the electrodes amounts to about 2% of the cell weight. In addition the electrolyte which accounts for about 10% of the cell weight also contains smaller amounts of dissolved Lithium raising the total Lithium content in a high energy battery to approximately 3% by weight. High-energy Lithium batteries weigh about 7 Kg per KWh so that the Lithium content is about 0.2 Kg per kWh.

The capacity of high-power cells is typically 10%-20% less than the capacity of the same dimension high-energy cell and the corresponding weight of Lithium used is 10%-20% less.

A typical electric vehicle may use high-energy batteries with capacities between 30KWh and 50KWh. The lithium content will therefore be about 6 Kg to 10 Kg per vehicle.

Thus 1 million EVs would consume less than 10,000 metric tons of Lithium.

Lithium battery raw materials

Lithium is the 31st most abundant element in the Earth's crust with an abundance of 20 ppm. This compares with Lead (14 ppm), Tin (2.3 ppm), Cobalt (25 ppm) and Nickel (84 ppm). It is found in small amounts in nearly all igneous rocks and mineral springs with particularly large deposits in China, North America, Brazil, Chile, Argentina, Russia, Spain, and parts of Africa.

The current estimate of useable reserves (apart from recovery from seawater) is estimated as 28.4 million tons. In addition the earth's 1.4×10^{21} kilograms of seawater contain a relatively high 0.17 ppm of Lithium which means that there are over 200 billion tons of Lithium in the world's oceans.

The US Geological Survey reported the world production of Lithium in 2006 was 333,000 metric tons, slightly down on the previous year with new production growing at between 40,000 and 50,000 tons per year.

Considering the available supply of Lithium (and not considering recycling potentials) there is more than enough Lithium available to satisfy the world demand for high-energy and high-power lithium batteries.

Is lithium toxic?

In case you wondered whether there were any toxic effects associated with Lithium, it is claimed that Lithium on the contrary has therapeutic benefits. The soft drink "7Up" started life in 1929, two months before the Wall Street Crash, with the catchy name "Bib Label Lithiated Lemon-Lime Soda". "7Up" contained Lithium Citrate until 1950 when it was reformulated, some say because of Lithium's association with mental illness. Since the 1940s, Lithium in the form of Lithium Carbonate has been used successfully in the treatment of mental disorder particularly manic depression. As with most chemicals however, small doses may be safe or therapeutic, but too much can be fatal.

How does a lithium (ion) battery work?

During charge, an oxidation reaction occurs at the cathode, meaning that it loses negatively charged electrons **(e^-)**. To maintain the charge balance in the cathode, an equal number of some of the positively charged lithium ions (Li+) are pushed out and dissolved into the electrolyte solution. The Li+ travels over to the anode, where they are absorbed (intercalated) within the active material in time to bind with the arriving electrons **(e^-)**. The current in the charge circuit moves in the opposite direction of the electrons **(e^-)** and Li+.

During discharge, the Lithium ions (Li+) are pushed out (de-intercalated) from the anode, dissolved, and then travel back through the electrolyte to the cathode. This releases the electrons **(e^-)** from the anode active material to flow through the external electrical system (discharge load) to provide the electric current needed to do work in the circuit. The current in the load circuit moves in the opposite direction of the electrons **(e^-)** and Li+.

It's the connection of an external load that closes the electric circuit (the circuit is no longer open). The external load enables or promotes the discharge reaction to proceed. When a circuit is closed, electrons **(e^-)** are freed to travel through the circuit and the positively charged Li+ are freed to move through the electrolyte back to the cathode to balance the movement of the negatively charged electrons **(e^-).**

When the cathode becomes full of Li+, the reaction stops and the battery is has reached theoretical 100% Depth of Discharge (DoD) and is fully discharged. To recharge the battery, we need to apply an external electric charge voltage into the circuit that pushes the Li+ out of the cathode, releasing the electrons **(e^-)** to once again, travel back to bind with the Li+ arriving in the active material of the anode during the charge process.

When a Li+ enters a grain of active material, a reduction reaction occurs as an electron **(e^-)** also enters the grain from the electrode. To help understand:

During charge:

- **Anode**: The anode is where the **reduction** reaction takes place. In other words, this is where the copper metal gains electrons **(e^-)**.
- **Cathode**: The cathode is where the **oxidation** reaction takes place. This is where the metal electrode loses electrons **(e^-)**

During discharge:

- **Anode**: The anode is where the **oxidation** reaction takes place. In other words, this is where the copper metal loses electrons **(e^-)**.
- **Cathode**: The cathode is where the **reduction** reaction takes place. This is where the metal electrode gains electrons **(e^-)**.

it can all be a little confusing so, when it comes to these redox reactions, it is important to understand what it means for a metal to be "oxidized" or "reduced". An easy way to do this is to remember the phrase "OIL RIG".

OIL = **O**xidization **i**s **L**oss (of electrons **e^-**)

RIG = **R**eduction **i**s **G**ain (of electrons **e^-**)

The role of the Li+ is to shuttle back and forth between the anode**(-)** and the cathode**(+)** during charging and discharging. The Li+ travels between the anode and cathode by diffusion through a liquid electrolyte. The most popular electrolyte in use is composed of Lithium Hexafluorophosphate ($LiPF_6$) dissolved in an organic aqueous solvent carbonate mixture.

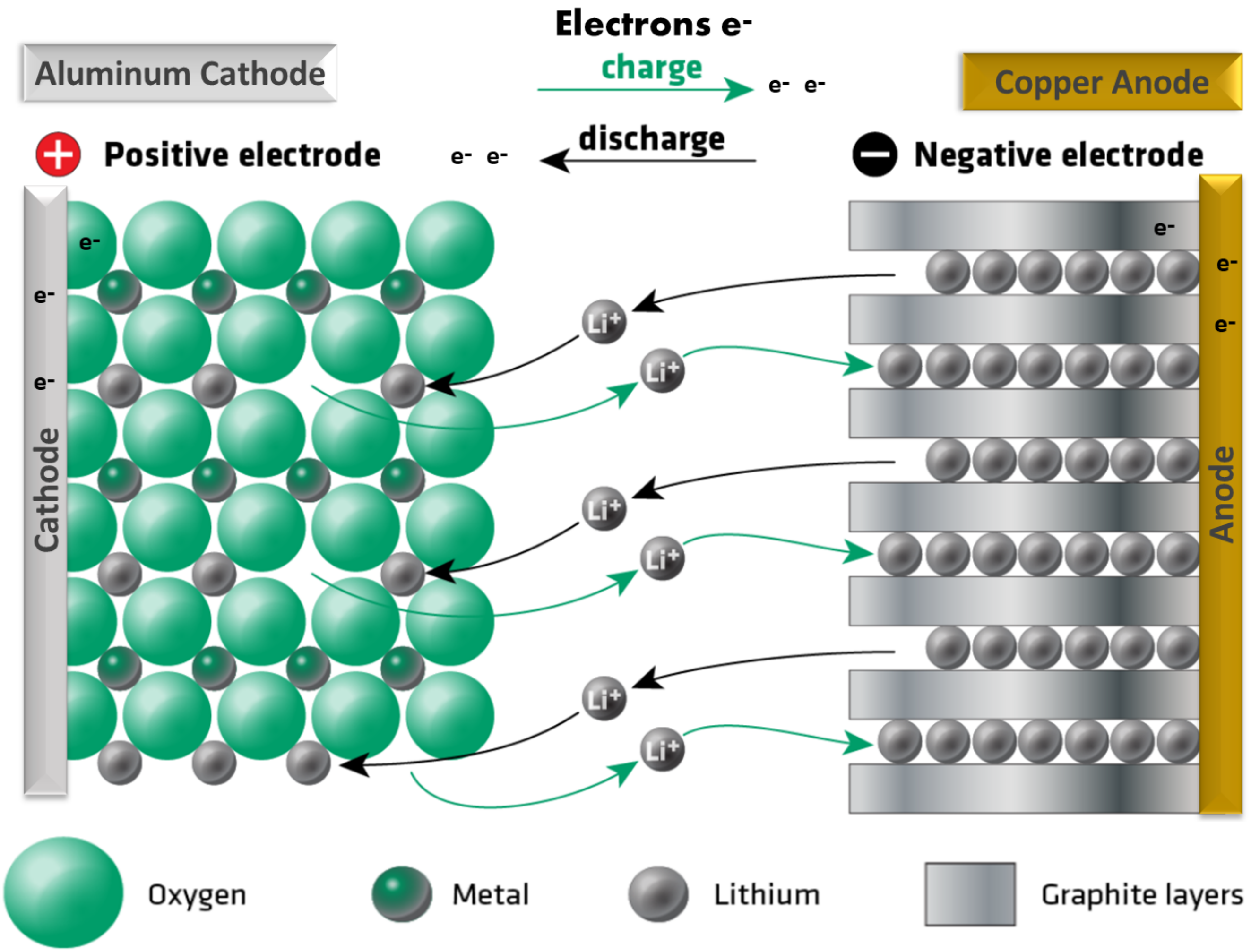
All Li+ batteries work in **broadly the same way**. When the battery is charging up, the lithium positive electrode gives up its Li+, which move through the electrolyte to the negative electrode to bind with the arriving electrons and remain there until the process is reversed. The battery takes in and stores energy during this process.

How does the lithium (ion) battery electro-chemical process work?

The structure or granule size of the active materials on the anode and cathode are very small and very porous and are measured in micrometers or even nanometers. The small multi-sided grain structure is necessary for the adequate performance of the battery because the smaller the grains, the greater the sum total of the total surface area of the active material. It is in this microscopic level that the Lithium ions (Li+) enter the layered structure of graphite active materials on the anode and/or cathode to bind with an electron during the electrochemical process, as the cell is charged and discharged. Inside the cell, the Li+ is found in three places. (1) as part of the cathode active material, (2) as Li+ salt in the electrolyte and (3) in the anode where the Li+ is found between the carbon layers in the graphite.

This pasted material layer must be electrically conductive/active to allow electrons **(e^-)** to move into and out of the copper**(-)** or the aluminum**(+)** electrodes to bind with the Li+ within the pasted active material powders.

"This is why we call it active material… there is a lot of activity happening within the active material. As the battery ages, capacity loss and eventual battery failure can often be attributed to the break down of the active material in this area"



What is the difference between a lithium battery and a lithium ion battery?

Lithium batteries are often called lithium-metal cells/batteries. Lithium-metal batteries are primarily disposable and not rechargeable. Lithium metal has a low coulombic efficiency (high internal resistance against charging activity) which makes it increasingly difficult and potentially unsafe to recharge in an uncontrolled fashion. Lithium-metal cells/batteries have a long shelf life and have higher energy densities so they pack a lot of long-lasting energy into small sizes making them excellent for smoke detectors, computers motherboards and pacemakers. The ultimate difference between Lithium batteries and Lithium-ion (Li+) batteries is:

- As a general rule lithium-metal batteries are not rechargeable and Li+ batteries are.
- Lithium-metal Batteries use lithium in its pure metallic form.
- Li+ batteries use lithium compounds which are much more stable than the elemental lithium used in lithium-metal batteries.

How are batteries different?

Lead-acid, Alkaline, and Lithium batteries can "generally" be compared and contrasted by:

1. Are they rechargeable or disposable/non-rechargeable?
2. What are their operating voltage differences?
3. What are the relative differences in their energy and power densities?
4. What is the difference in their useable capacities versus rated capacities?

Battery technologies are either "primary" non-rechargeable or "secondary" and rechargeable!

What is a Primary Battery?

Primary cells or batteries are not rechargeable and are most commonly used in devices that have a low current drain. Disposable primary cells cannot be reliably recharged since the chemical reactions are not easily reversible and the active materials may not return to their original forms. In general, primary cells have higher energy densities compared to secondary rechargeable batteries.

What is a Secondary Battery?

Secondary batteries, also known as *secondary cells* or *rechargeable batteries,* are made using active materials that can be returned to their original form during a (re)charge process by applying electric current, which reverses the chemical reactions that occur during discharge/use.

- Lead-acid batteries are made with rechargeable secondary cell technology
- Alkaline cells are generally made using primary cell technology, and are disposable and not rechargeable. Over the years attempts have been made to develop rechargeable alkaline batteries, but as of 2020 alkaline battery sales are nearly 100% primary.
- Lithium-ion cells/batteries are made using secondary rechargeable technology.
- Lithium-metal cells/batteries are “primary cells” and primarily disposable and not rechargeable. Lithium metal cells/batteries have a long shelf life and have higher energy densities so they pack a lot of long-lasting energy into small sizes making them excellent for smoke detectors, computers motherboards and pacemakers. Lithium metal has a low coulombic efficiency (high internal resistance against charging activity) which makes it increasingly difficult and potentially unsafe to recharge in a controlled fashion.

Batteries have different Operating Voltages.

Lead-acid, Alkaline, and Lithium cells (pretty much all battery types) have large differences in their nominal working voltage under load, and their open-circuit voltage when charged and at rest (OCV)

What is nominal voltage?

Nominal voltage is the “average” close circuit voltage (CCV) at which the cell or battery performs most of its work (operates at) when a load is applied. The circuit is closed when current is passing through the terminals.

What is open circuit voltage?

Open circuit voltage (OCV) is the terminal voltage of a cell or battery at rest after a period of discharge or at rest 12 to 24 hours after a full charge when there is no load applied. The circuit is open when no current is passing through the terminals.

The nominal voltage for a lead-acid cell is 2.0 volts per cell.

Lead-acid batteries have an upper and lower operating (CCV) between 2.12 and 1.9 (80% DoD) volts per cell. A 12-volt lead-acid battery is made with 6 x 2-volt cells connected in series to achieve a 12-volt nominal (12Vn) rating. After a full charge (and rest period) a 12Vn lead-acid battery will have a typical OCV voltage of between 12.70 to 12.80 volts. While lead-acid cells can be discharged below 1.9vpc there is very little useable energy available and the voltage drops quickly to 1.75vpc (100% DOD) after passing through 1.90-1.85vpc during discharge..

Alkaline cells have a nominal voltage of 1.5 volts per cell.

Because they are non-rechargeable we do not typically consider OCV for alkaline cells.

Lithium metal cells can have nominal voltages from 1.50V/cell to 3.70V/cell.

Because they are non-rechargeable we do not typically consider OCV.

Lithium (ion) cells come in a variety of chemistries and have various nominal voltages.

The average nominal (CCV) and low - high OCV voltage range of various lithium-ion cell chemistry are:

- NMC =had a nominal CCV of 3.6Vn/cell and an open circuit voltage range of 3.0-4.2V/cell
- LCO =had a nominal CCV of 3.6Vn/cell and an open circuit voltage range of 3.0-4.2V/cell
- LMO =had a nominal CCV of 3.7Vn/cell and an open circuit voltage range of 3.0-4.2V/cell
- LFP =had a nominal CCV of 3.2-3.3Vn/cell and an open circuit voltage range of 2.5-3.65V/cell
- LTO =had a nominal CCV of 2.4-2.5Vn/cell and an open circuit voltage range of 1.65-2.85V/cell

NiCD (Nickel Cadmium) and NiMH (Nickel Metal Hydride) cells typically output 1.20 - 1.25 V/cell nominal.

Nickel based cell OCV varies little from nominal Voltage because the specific gravity of the potassium hydroxide electrolyte does not change with state of charge.

What is Current? What is Power? What are Amps? What is Voltage? What is Resistance?

What is Current?

During charge and discharge, an electric circuit is formed when a conductive path is created to allow an electric charge in amps to continuously move through the circuit. This continuous movement of electric charge through the conductors of a circuit is called a ***current*** and is often referred to in terms of current flow in amps.

Just like how the rate that water flows downhill is determined by the steepness of the hill and the debris and grade changes in its way, ***current*** flow intensity in a circuit is influenced by the voltage potential in the circuit and the resistance in the circuit.

What is Power?

Electric ***power*** is defined as the rate at which electrical energy is transferred or consumed in an electrical circuit. ***Power*** is time based and represents the rate at which work is being done. The SI unit of power is the watt, (Amps x volts = watts) which is one joule per second. Voltage potential (pressure) forces current in amps through a circuit that includes resistance such as a heating element or motor. These forms of resistance consume watts over time to work.

What are Amps?

Amps are the basic SI unit of measure for electrical current. Just as we can think of the rate of water flowing in a river as the river's current, we can think of the rate of the flow of ***amps*** through electrical circuit conductors (wires or cables) as the electrical current.

What is Voltage?

The force or pressure creating the flow of power in a circuit is called ***voltage.*** Voltage is a measure of the potential energy differential that must always exist between two points if there is to be any flow between the high voltage (pressure) and low voltage (pressure) points. Without potential, there is no voltage. Voltage is pressure. The pressure between the top of the hill and the bottom is greater, depending on the steepness of the grade. The steeper the grade the greater the potential ***voltage*** difference there is between the top of the hill and the bottom. The greater the potential, the greater the pressure and because pressure equals voltage, the greater the power flow rate!

What is Resistance?

Ohms () are the basic SI unit of measure for ***resistance*** in an electrical circuit. Current flow moves from one point to another through various points of friction. This friction or opposition to motion is called ***resistance.*** The intensity (flow amount) of current in a circuit depends on the amount of voltage (downhill pressure) and the amount of ***resistance*** against that pressure in the circuit to oppose or resist the current flow. Resistance is a quantity relative between two points or the sum total amount of all of the ***resistance*** points in the circuit. For this reason, the combined quantities of resistance works against the voltage potential in the electrical circuit and is often spoken of as being “the voltage-drop” between two points or “the total ***resistance*** between two points” in an electrical circuit.

Just as running water will continue to flow downhill until the source of the water and the destination is level with each other, current will continue to flow from the highest voltage potential to the lowest voltage potential until that potential is virtually zero.

To speak to the charge and discharge process in an electrical system we need to be able to make meaningful statements about the quantities of voltage, current and resistance in the charge and discharge circuits so we need to be able to describe them:

Unit of Measure	Symbol	Units	Abbreviation(s)
Volts (Potential or Flow Pressure)	V or U or E	Volt	V (U)
Current (Flow intensity)	I	Ampere (Amps)	A
Resistance (resistance to flow)	R	Ohms or (Milliohms)	(m)

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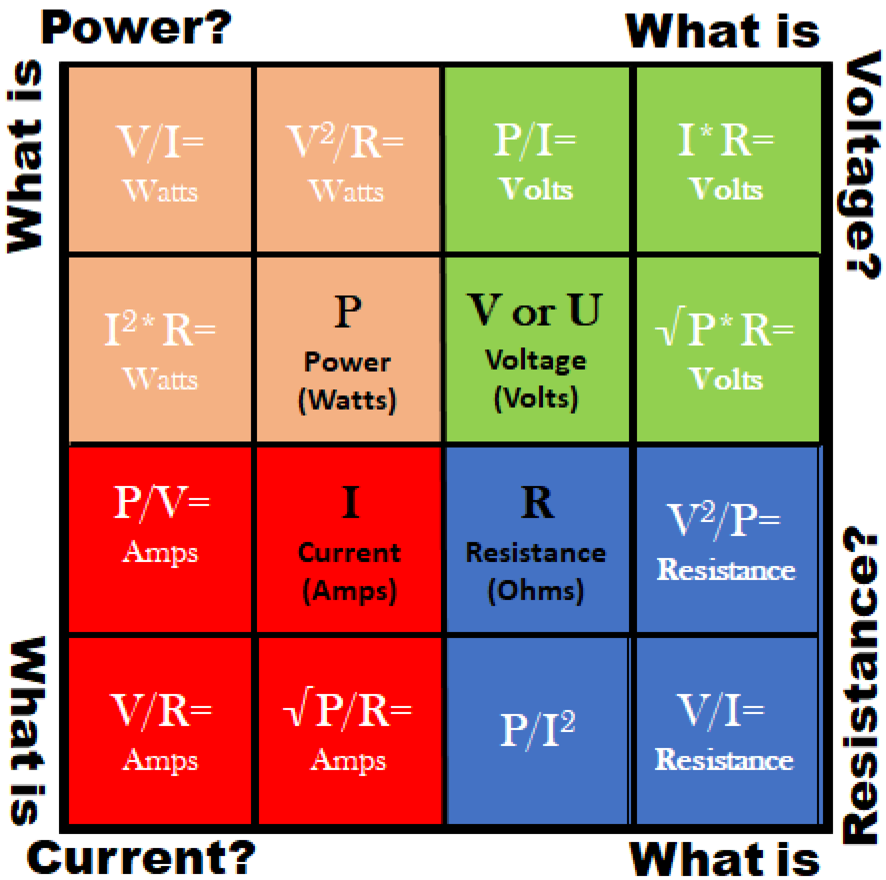


Ohms Law: States the relationships between current (amps), resistance (ohms) and voltage.

Watts Law: States the relationships between power (watts), current (amps) and voltage.

Batteries have different power and energy density?

What is power?

The simplest definition of power is "the rate at which the work is done".

It takes **power** to push the energy into your home to power your stove, or light bulb.

What is power density?

The simplest definition of power density is "the amount of power in a unit of volume" or "the rate in time that energy can transfer".

Common references to power density are: horsepower per cubic inch, watts per square meter and watts per kilogram. Power density is the amount of power (time rate of energy transfer) per unit volume.

Power density describes how quickly the device can deliver energy. It is equivalent to the maximum energy or current you can draw from a battery of a given mass/volume.

Batteries have a higher *energy* density than capacitors, but a capacitor has a higher *power* density than a battery. Said differently, capacitors generally offer very high power density but low energy density. They are good for short bursts of very high power current. On the other hand, batteries are good at providing lower currents for extended periods of time.

A battery's energy density is a measure of the amount of energy per unit weight or per unit volume which can be stored in a battery. Thus if equal in weight or volume, a higher energy density cell will store more energy than a high power cell or alternatively a higher energy density cell can be smaller and lighter and still provide the same energy as a high power cell. The chart below shows some typical examples.

What is energy?

The simplest definition of energy is "the ability to do work" "or the water in your tank".

It takes **energy** to cook food, to drive to school, to power a light bulb or to power a dam.

What is energy density?

The simplest definition of energy density is: "the amount of energy in a given mass, volume or space".

Energy density describes how much energy a particular battery size or energy storage container can store. This will vary depending upon the battery technology being measured. Therefore a device with a higher energy density can supply an electric load for longer than one with a low energy density and the same mass/volume.

Energy density is explained in two ways.

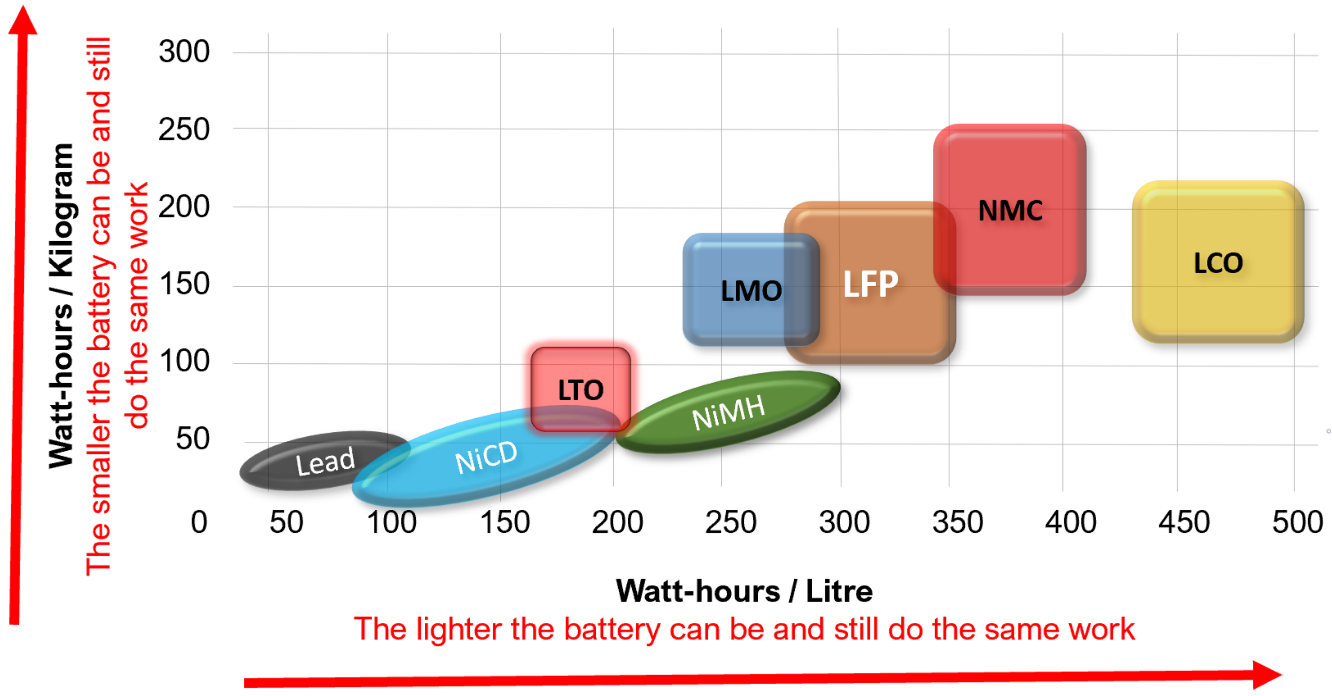
What is gravimetric energy density?

Gravimetric Energy density or specific energy is a measure of how much energy a battery contains in comparison to its weight and is generally expressed in ***Watt-hours per kilogram***. The higher the watt-hours per kilogram the smaller the battery can be and still do the same amount of work.

What is volumetric energy density?

Volumetric energy density or the energy density of a battery is a measure of how much energy - or potential to do work - a battery contains in comparison to its volume and is generally expressed in ***Watt-hours per liter.*** The higher the watt-hours per liter, the lighter the battery can be and still do the same amount of work.

Lithium (ion) has a better **gravimetric density** compared to **lead-acid**. The implication of this is that devices powered by a Li+ battery can be made much lighter without sacrificing run time or, they can have extended run times while keeping their weight virtually unchanged. Because of this equipment ergonomics and design can be liberated and/or the productivity of existing equipment can be enhanced.



What is useful or useable energy?

While it is important to know the available energy density of potential energy sources, it is equally important to understand the useful or use-able energy available.

As of 2020, the best battery energy densities are still 100 times less than the energy density of gasoline. You need 100 kilograms of battery to do as much work as 1 kilogram of gasoline. (100 lbs. of battery to do the work of 1 Lb. of gasoline).

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Just as there is always a little reserve amount of gasoline in your tank when your fuel gauge reads “E”mpty to protect you from immediately running out of gas and having to suffer the consequences, you cannot use all of the *available* energy from any particular battery chemistry without negative consequences. For you and your car, the consequences are that you may need to call a tow truck or walk. For your battery-powered device or equipment, it might mean premature battery failure and early replacement.

How is useable energy different than available energy?

High-quality lead-acid deep cycle battery manufacturers recommend you use 50% to 80% of the batteries available energy during system design to represent “E” on the state of charge gauge or a limit of 50%-80% depth of discharge (DOD). They strongly suggest that regularly exceeding these limits will cause premature battery failure.

For daily cyclic applications such as in solar or renewable energy systems, most lead-acid battery manufacturers recommend no more than 30% DOD (with an occasional 50% DOD) be useable to represent “E” during system design.

All batteries and all battery chemistries have recommended *useable* versus *available* capacity recommendations.

Lithium, Ni-Cd and NiMH technologies should be *responsibly* sized to a maximum depth of discharge of </=80%-90% DOD.

Just as most storage devices (gas tanks or batteries) have recommended safe low pressure “E” limits, they also have recommended high pressure or “F”ull on your fuel gauge recommendations or limits after which liquid or gas vapors may gush or spill out of the tank filler spout or battery vents.

For batteries, these upper-pressure limits that indicate when the battery is “**F**”ull or the vents might expel gas and lower pressure limits that indicate when the vessel is “**E**”mpty or beyond which it may become over discharged, are expressed in voltage. As described earlier, all battery types have recommended High and Low voltage (pressure) operating limits that should be followed if you don't want to damage the battery.

In general higher energy densities are obtained by using more reactive chemicals and metals. These higher energy densities operate at a higher pressure and therefore have higher operating voltage potentials.

Just like when you operate your car it is always best to follow the manufacturer's recommended “**E**”mpty and “**F**”ull voltage settings when working with batteries to avoid negative consequences and premature battery failure.

How does Temperature effect lithium batteries?

HEAT KILLS all Batteries!

It's the “law”! Lead or Lithium, no matter the battery technology, heat Kills all Batteries! Arrhenius’ Law outlines how for every 10° increase in temperature above 77°F /25°C the chemical reaction inside a batteries cells approximately doubles cutting battery life in half *. Eliminating or mitigating the high-temperature environments of battery compartments will reduce the related electrochemical reactions that accelerate premature capacity loss and early battery failure. This same Law explains why as temperatures drop your battery’s available capacity drops along with it as the chemical reaction inside your battery decreases. Keeping batteries cool will work to reduce the electrochemical reactions that accelerate premature capacity loss and battery failure.

***Arrhenius’ Law**

For ease of understanding temperature effects on lithium batteries we need to break down how temperature affects:

- How does temperatures affect lithium battery electrochemical reactions?
- How does temperature affect lithium battery components or building blocks?
- How does temperature affect lithium battery state of charge?
- How does temperature affect lithium battery self-discharge processes?
- How does temperature affect lithium battery power electronics or BMS?

How does temperature affect lithium battery electrochemical reactions?

The role of the Li+ is to shuttle back and forth between the anode**(-)** and the cathode**(+)** during charge and discharge. The Li+ travels between the anode and cathode of the cell by diffusion through a liquid electrolyte. This electrochemical process is dependent on temperature. At above freezing temperatures, the Li+ easily enter the anode active material (*the active material door is open*) however, as temperatures drop the Li+ find it progressively more difficult to enter the anode as the active material porosity falls and the door begins to close eventually stacking up at the entrance (*the active material door is closed*) in a process called *lithium plating*. Think of water turning to slush and finally freezing solid.

The electro-chemical process diffuses progressively faster as temperature rises and slower as temperature falls. At temperatures below 5°C/41°F charge currents need to be reduced for most Li+ technologies to prevent damage to the cell. At temperatures below 0°C/32°F the Li+ does not diffuse fast enough at the anode interface for the safe or adequate operation to continue in most Li+ types.

All of the reactions taking place in the electrochemical process are related to the relationship between the speed or rate of the charge or discharge activity and the temperature before, during and at the end of the charge or discharge process.

Suffice it to say that a change in temperature will change the viscosity of the electrolyte and porosity of the active materials and accordingly the chemical reaction speed and efficiency of the Li+ movement is impacted as they shuttle back and forth through the electrolyte and into the active materials of the cathode**(+)** or anode**(-)** during the discharge and charge process.

Temperatures decrease in the high latitudes above the Tropic of Cancer and below the Tropic of Capricorn. As you move further north of the Tropic of Cancer or further south of the Tropic of Capricorn batteries will increasingly be exposed to temperatures below 5°C/41°F. At these lower temperatures, the electrolyte viscosity increases and the active material porosity decreases. This, in turn, reduces the ionic conductivity of the electrolyte with the active material layer on the anode. The combination of these activities causes a rise in impedance within the cell against the migration of Li+ which leads to increases in the overall Internal resistance within the cell.

The internal resistance of all types of batteries rises when cold, prolonging charge times and reducing available discharge capacity.

Many battery users are unaware that their consumer-grade Li+ batteries cannot be charged below 0°C/32°F. Although the battery may appear to be charging normally, plating of metallic lithium is certainly occurring on the anode if the battery is being charged at freezing temperatures. The severity of the damage is directly proportional to the charge rate. While this negative process is *somewhat* reversible for negative plate sulfation or plating in a lead-acid battery, Li+ plating is not reversible and cannot be repaired by cycling or conditioning. Once developed, Li+ batteries with lithium plating are more vulnerable to catastrophic failure if exposed to vibration or other stressful conditions.

To solve the problem of cold temperature charging cell and battery manufacturers incorporate expensive electrolyte doping and Nano-structured active material upgrades of the negative active material. Discover deploys proprietary BMS controlled self-heating algorithms and/or advanced active material and electrolyte doping in Discover's purpose-built Lithium AES, PRO and EXTREME series batteries. In addition, Discover's proprietary computer-controlled battery management system (BMS) is programmed to temperature adjust and manage all charge and load currents within preset safe operating parameters.

How does temperature affect lithium battery components or building blocks?

Temperature affects the strength, pliability, malleability, and vitality of all materials used to produce a battery.

Consider how all objects prevalent in our daily lives are affected by temperature. Solids like copper, aluminum and plastics and liquids like gels, oils and water all transform and behave differently as temperature changes. At temperature extremes, these substances change completely. i.e. water becomes solid ice, and copper, aluminum and plastic melt becoming liquids.

Remember that the electrochemical reaction diffuses progressively faster as temperatures rise. While this accelerating process produces improved performance and more capacity, it is guaranteed to lead to shortened life if repeated. Since high-temperature storage and operation is arguably the #1 cause of premature battery failure, the effects of high-temperature operation are wider and much more complex than those at low temperatures.

Remember that all of the reactions taking place in the battery are related to the relationship between the speed or rate of the charge or discharge activity and the temperature before, during and at the end of the charge or discharge process.

While low temperature slows or restricts the vitality of the batteries active materials by making them more rigid and inflexible against the electrochemical process resulting in reduced capacity, high-temperature operation and the additional heat generated *inside* the cells from the much more energetic electrochemical process ultimately thermally stresses and breaks down these active materials and the batteries other components. The increased thermal activity within the cell can cause the cells to both be over-discharged and overcharged. The resulting active material breakdown caused by continued over-discharge and overcharge activity leads to venting, permanent capacity loss and to the extent that the separator breaks down, failure from short circuits. Understanding heat generation and management are critical to minimizing high-temperature effects on Li+ batteries.

To solve the problem of high-temperature operation Discover purpose builds proprietary BMS controlled temperature-related algorithms in all of its Lithium AES, PRO and BLUE series battery solutions and further deploys innovative advanced active material doping solutions in Discover's EXTREME series batteries. Discover's proprietary computer-controlled battery management system (BMS) is programmed to temperature adjust and manage all charge and load currents within preset safe operating parameters.

How does temperature affect a lithium battery state of charge?

Temperature affects a battery's state of charge and the potential to do work. The temperature effect on a battery's state of charge is defined as the ratio of available capacity at different temperatures compared to the overall potential capacity at a fixed reference temperature. (usually the 20-hour or 5-hour capacity at 20°C/68°F or 25°C/77°F).

Remember that all of the reactions taking place in the battery are related to the relationship between the speed or rate of the discharge currents and the temperature before, during and at the end of the discharge.

The speed or rate of the discharge current also affects the totality of the temperature-related impact on the batteries' state of charge or ability to do work. Due to the Peukert effect, the higher the discharge current above the reference rate (20 Hour rate or 5 Hour rate), the lower the total available capacity will be at any temperature above or below the reference temperature (usually 20°C/68°F or 25°C/77°F). While the Peukert effect is far less impactful on lithium batteries than lead-acid batteries it still does affect lithium cell technologies with some technologies being more affected than others.

It is a simple fact that every battery technology is affected by temperature. The only way to change this reality is thru the use of mechanical countermeasures (usually heating or cooling) or through electrochemical doping of the active materials and electrolytes. While doping can be a practical solution for space restrained, extreme temperature and mission-critical applications, it is often not cost-effective for most systems where it is much easier to simply parallel in more capacity to cover the expected capacity losses that will arise when temperatures drop or to use additional mechanical heating or cooling components.

As all drivers in cold countries know, a warm battery cranks the car engine better than a cold one. Cold temperature increases the internal resistance and lowers the capacity. A battery that provides 100 percent capacity at 27°C (80°F) will typically deliver only 50% of that capacity at –18°C (0°F). The capacity-decrease differs amongst the various battery chemistries/technologies

Remember, its the law* that for every 10° increase in temperature above 25°C/77°F the chemical reaction inside your battery will approximately double cutting battery life in half *. Eliminating or mitigating the high-temperature environments of battery compartments will reduce the related electrochemical reactions that accelerate premature capacity loss and battery failure. Lead or Lithium, no matter the battery technology, Heat Kills all Batteries!

This same Law explains why as temperatures drop your battery's available capacity drops along with it as the chemical reaction inside your battery decreases. Keeping batteries cool will work to reduce the related electrochemical reactions that accelerate premature capacity loss and battery failure.

*Arrhenius' Law

How does Temperature affect lithium batteries self-discharge process?

All batteries have an inherent self-discharge process that is calculated at room temperature. But as we have outline throughout this section on how temperature affects lithium batteries, the internal electro-chemical process diffuses progressively faster as temperature rises and slower as temperature falls. As temperatures rise the molecules become much more active and are moving around within the cell much more aggressively. This activity raises the internal self-discharge rate of the battery.

Moving faster tires you out faster… It is as simple as that! Store your batteries in cool temperatures (not freezing) to slow the self-discharge rate.

How does temperature affect lithium battery power electronics or BMS?

While advanced cell technology such as is used in Discover's EXTREME mission critical series can allow for operation at very extreme temperatures versus conventional lithium technology, special care must be taken to chose power electronics components for the Battery Management and controls circuitry to ensure they are also hardened against extreme temperatures. Circuit boards, computer chips, fuses and the like all must be tested and verified for capabilities at temperatures that exceed the operating parameters of the cell technology. If the power electronics (BMS and protection circuitry) can't handle extreme temperatures there is no point in paring them with advanced cell chemistries for use in extreme environments.

Are Lithium batteries more efficient & faster charging versus lead-acid?

New Lead-acid batteries typically have coulombic efficiencies (charge acceptance efficiency) of 80%-85% and round trip energy efficiencies in the order of 60% to 70% when they are charged and discharged at moderate rates. Lead-acid battery coulombic and energy efficiency decline at higher charge and discharge rates as voltage rises and internal resistance grows, and as batteries age.

All lead-acid batteries suffer from acid stratification. Acid stratification causes a lead-acid battery's dynamic charge acceptance to decline with age. Depending upon battery type and the application, a lead-acid battery's dynamic charge acceptance can decline by as much as 50% within the first year of its life.

High power and high energy Lithium batteries do not suffer the effects of acid stratification and maintain a high level of charge efficiency throughout their life. At 20°C/68°F to 25°C/77°F high-power and high-energy Lithium batteries typically have coulombic efficiencies (charge acceptance) of >99% of the available charging current when charged at rates below .5C (their 2 hour rate). High power lithium battery charge efficiency will drop to around 97%-98% at room temperature when charge rates are maintained at a 1C (1 hour) rate.

Depending upon Li+ cell technology, as temperatures drop to under 10°C/50°F charge rates must be reduced to avoid Li+ plating and permanent damage. The role of the Li+ is to shuttle back and forth between the anode**(-)** and the cathode**(+)** during charge and discharge. The Li+ travels between the anode and cathode of the cell by diffusion through a liquid electrolyte. This electrochemical process is dependent on temperature. At warm temperatures, the Li+ easily enters the anode active material during charge (*the active material door is open*) however, as temperatures drop the Li+ find it progressively more difficult to enter the anode as the active material porosity falls and the door begins to close and the Li+ eventually stack up at the entrance (*the active material door is closed*) in a process called *lithium plating*. Think of water turning to slush and finally freezing solid.

Many battery users are unaware that their consumer-grade Li+ batteries cannot be charged below 0°C/32°F. Although the battery may appear to be charging normally, plating of metallic lithium is certainly occurring on the anode if the battery is being charged at freezing temperatures. The severity of the damage is directly proportional to the charge rate.

While these negative processes are *somewhat* reversible for negative plate sulfation in a lead-acid battery, Li+ plating is not reversible and cannot be repaired by cycling or conditioning a Li+ battery. Once developed, Li+ batteries with lithium plating are more vulnerable to catastrophic failure if exposed to vibration or other stressful conditions.

Suffice it to say that a change in temperature will change the viscosity of the electrolyte and porosity of the active materials and accordingly the reaction speed and efficiency of the electrochemical process in both Lead-acid and Li+ batteries. Movement is impacted as ions shuttle back and forth through the electrolyte and into the active materials of the cathode**(+)** or anode**(-)** during the discharge and charge process.

Li+ batteries are faster charging than lead-acid batteries at any temperature above 0°C/32°F. Li+ batteries are faster charging at warmer temperatures than at cool temperatures as the electro-chemical process diffuses progressively faster as temperature rises and slower as temperature falls. At temperatures below 0°C/32°F the Li+ does not diffuse fast enough at the anode interface for safe charging to continue in most Li+ battery types. For charging at cold temperatures below 0°C/32°F heating appliances or different purpose-built Li+ cell technology must be used that allows for charging at below zero temperatures.

All of the reactions taking place in the electrochemical process are related to the relationship between the speed or rate of the charge or discharge activity and the temperature before, during and at the end of the charge or discharge process.

Because of their low charge efficiency, and depending upon charge rate and battery design, lead-acid batteries require an overcharge of between 105% and 125% of the previously discharged capacity to return to a fully charged state. Compared to lead-acid batteries that can spend 40% to 60% of their total charge time in low current charge rate saturation or absorption phases, most lithium technologies spend less than 5%-10% of their total charge times in lower current saturation/absorption or finishing charge phases because they absorb charge current so efficiently.

Also, while lithium batteries will last exponentially longer if constantly operated in a partial state of charge between 10%-20% SOC and 80%-90% SOC, lead-acid batteries will permanently loose capacity and fail prematurely if they are constantly maintained in a partial state of charge condition.

Just as high-quality lead-acid deep cycle batteries need to be equalized and balanced, high-quality lithium batteries with integrated BMS should periodically be allowed to stretch their legs and fully charge as this allows the batteries balancing circuits to work which will bring all of the batteries cells into balance. Balancing circuits in high-quality $LiFePO_4$ batteries will initiate at 3.35-3.40 Vpc.

At high discharge and charge rates above ..33C (3-hour rates), there is little point in comparing the efficiency or productivity potential of lead versus any lithium battery technology. Lead simply does not compare!

When lithium batteries are paired with fast charges they can deliver up to 400% increases in productivity for multi-shift operations versus lead-acid batteries.

Some advanced and modified HIGH-ENERGY deep-cycle lithium-ion cell technologies that incorporate active material nanotechnology and electrolyte additives can easily be charged and discharged at much higher 10C (6 minute) rates as well as cold weather charging down -40°C/-40°F.

How fast can you charge a lithium battery?

Theoretically you can charge any battery - lead-acid or lithium - at any rate equal to or less than the total discharged capacity prior to the battery being put back on charge. If 100Ah was removed from the battery prior to charge you could theoretically charge the battery at an initial charge current of 100 amps! The key is to make sure the charge rate (current) is reduced once the maximum (V Max) switching voltage (or lead-acid gassing voltage) is reached.

Consider that charging a battery cell is like filling your gas tank. You can fill your gas tank pretty much as fast as you want but eventually pressure will build up and gas and air will attempt to rush out of the filler tube before the tank is full and you will have to stop or cut back the fill rate. ***(this represents the V Max switching voltage point when charging a battery)****. Alternatively if you fill your tank at a slower rate less pressure will build up in the tank and you will be able to completely fill the tank without experiencing the pressure buildup and spillage. It is common knowledge that you can fill your gas tank at a very high rate up to a certain point at which you need to reduce the flow rate to complete the fill and sometimes you will squeeze the nozzle in spirts at the end to "really" top up the tank.* ***The principles for Charging a battery are the same!***

More realistically, as it relates to Li+ cells or batteries, the manufacturers recommended maximum constant current charge rate should never be exceeded. With any high-quality Li+ battery the maximum current limits will be dictated and controlled by the batteries Battery Management System (BMS). **It should be understood that even if the cell technology can handle a higher current the maximum current cannot exceed the BMS design limits.**

At 20°C/68°F to 25°C/77°F most commercially available large format high-energy (not consumer products like phones or laptops) Li+ batteries can begin their charge at a constant current (CC) rate equal to 50% of the batteries rated capacity. *(A 100Ah rated battery can be safely charged at an initial constant current of 50 amps.).*

Li+ batteries with higher-quality BMS designs can be spotted if they offer continuous charge ratings of 1C or greater (*A 100Ah rated battery can be safely charged at an constant current of 100 amps or more).*

Unlike lead-acid batteries, lithium battery charge voltage will remain low and the battery will continue to draw full current until the battery is nearly 90% full. Finishing currents should be limited to 2%-3% of the batteries rated AH capacity (2-3A for a 100AH battery).

CAUTION: Very few chargers have the sophisticated control circuitry capable of measuring and controlling finishing currents (charging amps) below 2 amps. Most use a % of the initial BULK charge current algorithm to determine charge termination rates and others may use pulse phases at near the end of charge to mask this inability. This is the reason for wild variations in charge current termination recommendations across the various chargers available for purchase in the market. Therefore, it is prudent to set (if you can) or purchase a charger capable of setting (if you are in the market for a new charger) a charge current termination point equal to 2% - 3% of the battery capacity (2A - 3A per 100 Ah battery). Don't worry if your charger cannot be set to precisely measure the current at these lower levels. A setting of 10% or 15% will simply mean that the battery may only charge to 98% or 99% SOC before the charger turns off. If the battery has a float or maintenance mode, the battery will eventually be fully topped up and maintained at 100% SOC.

Remember Li+ batteries are not like lead-acid batteries and will not suffer negative consequences constantly operating in a partial state of charge condition. Fast charging can be utilized effectively to quickly return Li+ batteries to service by fast charging them to 80% to 90% at a high constant current rate and bypassing the constant voltage phase completely.

Fast charging lithium batteries has a trade-off

Fast charging lithium batteries comes with a trade-off. The faster the charge rate (the higher the initial charge current), the lower the recharged capacity will be before the battery reaches its V Max limit requiring the charger to switch to the constant voltage or absorption phase of the charging profile. Because the internal pressure (internal resistance) of the batteries cells rises faster when the battery is being charged at higher rates, the constant voltage (V Max) limit is reached faster and the charge rate must correspondingly be reduced. The inconvenient truth is fast charging - without dynamic closed-loop charger controls - may not be as fast as the math predicts. Doubling the charge rate does not guarantee 1 /2 the charge time because the battery will spend more time in the constant voltage absorption phase..

Consider that charging a battery cell is like filling your gas tank. If you fill your gas tank very fast, pressure will build up and gas and air will attempt to rush out of the filler tube long before the tank is full ***(this represents the V Max switching voltage point when charging a battery)****. Alternatively if you fill your tank at a slower rate less pressure will build up in the tank and you will be able to completely fill the tank without experiencing the pressure buildup and spillage. It is common knowledge that you can fill your gas tank at a very high rate up to a certain point at which you need to reduce the flow rate to complete the fill and sometimes you will squeeze the nozzle in spirts at the end to "really" top up the tank.* ***The principles for Charging a battery are the same!***

For example, charging at 1C (100% of the batteries rated capacity) may result in a charged capacity of 70% before the switching voltage (V Max) is reached and the constant absorption voltage stage begins. Alternatively, charging at 0.5C or 50% of the batteries rated capacity may result in a charged capacity of 90% before the switching voltage is reached and the constant voltage stage begins.

It should be understood that even if the cell technology can handle a higher current the maximum current must not exceed the BMS maximum current design limits. Also note that there is no industry-accepted definition of a "fast or quick charge" for a Li+ batteries. These terms are generally applied to any charge that accelerates charging compared to a "typical" 0.5 C charge rate.

Depending upon your charger output (fast charging rates or slower charging rates), you should set your charge profiles differently by raising the Voltage Max setting for fast charging and lowering it for slower charging. It would seem that increasing the charging current would decrease the recharge time. This is true, but only to a certain degree. Firstly, ions have a finite mobility, so increasing the charging current past a certain threshold doesn't shift them any quicker. Instead, the energy is actually dissipated as heat, raising the battery's internal temperature and risking permanent damage. Secondly, unrestricted charging at a high current eventually causes so many ions to embed into the negative electrode that the electrode disintegrates and the battery is ruined.

Fast Charging Technology

New Li+ nanotechnology features higher Li+ mobility so faster charging without the risk of overheating is possible. To keep pace some charger manufacturers are utilizing advanced computer chip technologies to simplify the design of chargers and are developing faster charging ability but with tighter silicon controlled limits during the constant-current phase.

Fast Charge Carefully

Li+ battery charging follows a profile designed by the cells manufacturer to ensure safety and long life without compromising performance. High-quality Li+ batteries always have built in protection circuitry that prevents the battery from being operated outside of its preset safety limits. Avoid purchasing any Li+ battery that does not "clearly" pronounce maximum current and voltage operating limits.

How to charge lithium LiFePO4 (LFP) batteries

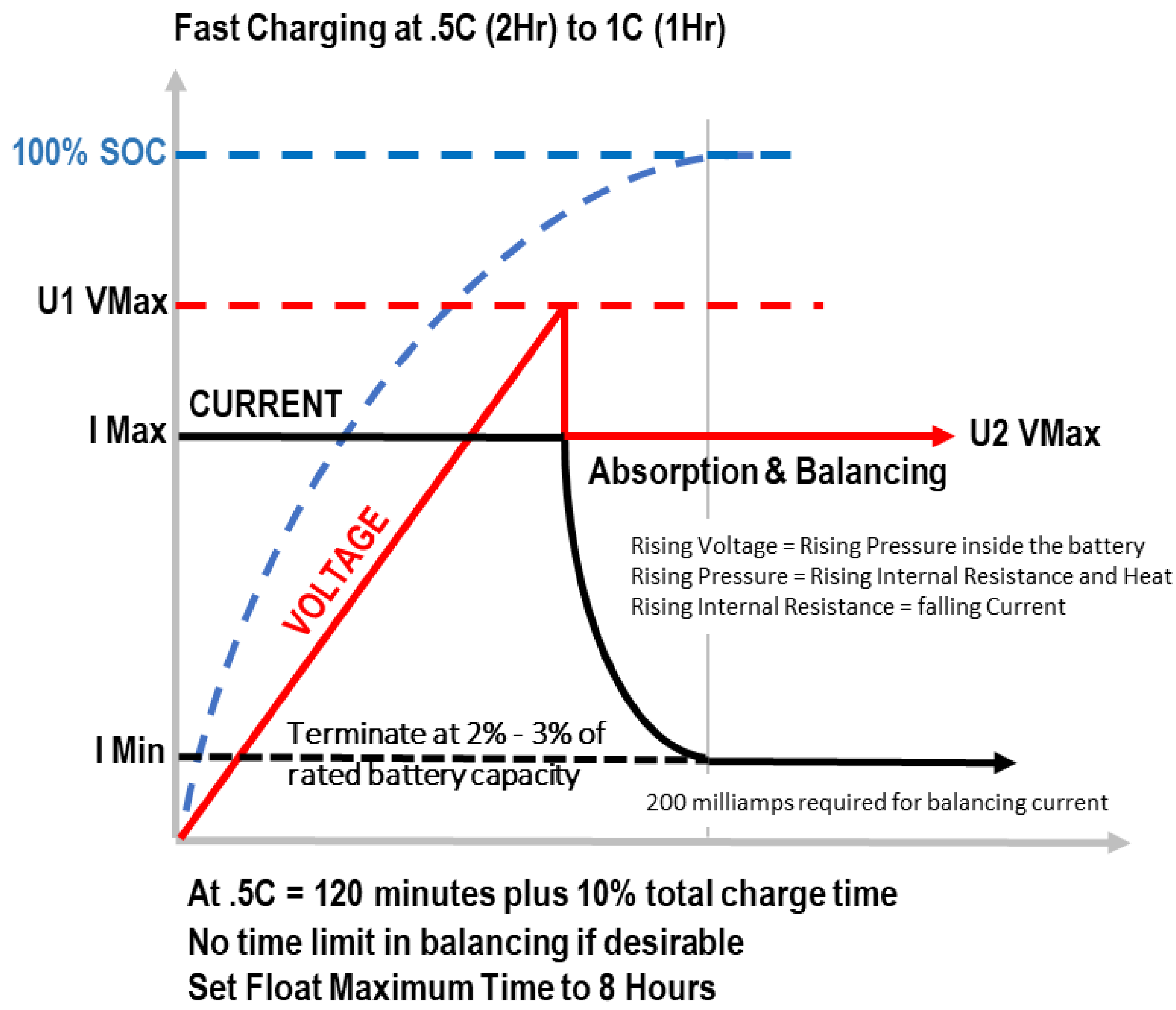
To achieve the best lifetime results for your lithium iron phosphate battery and depending upon your charger output (fast charging or standard charging rates), you should set your charge profiles differently by raising the Voltage Max setting for fast charging and lowering it for slower charging.

Discover $LiFePO_4$ Lithium Iron Phosphate	Fast Charging - Above 50% of Rated battery Capacity at 20°C/68°F to 25°C/77°F	Standard Charging - 20% to 50% of Rated Battery Capacity at 20°C/68°F to 25°C/77°F
U1 / Voltage Maximum	3.55Vpc (14.2V for a 12V battery)	3.4Vpc - 3.45Vpc (13.6V - 13.8V for a 12V battery)
U2 / Absorption Voltage	CV - 3.4Vpc constant voltage	CV - 3.4Vpc constant voltage
I Max Constant Current Amps	Up to 100% (1C) of Rated AH Capacity	Up to 50% (0.5C) of Rated AH Capacity
Balancing Begins	3.35Vpc (13.4V for a 12V battery)	3.35Vpc (13.4V for a 12V battery)
Charge Termination (I Min)	When current tapers to 2%-3% of rated battery capacity	When current tapers to 2%-3% of rated battery capacity
Float Voltage if Utilized		

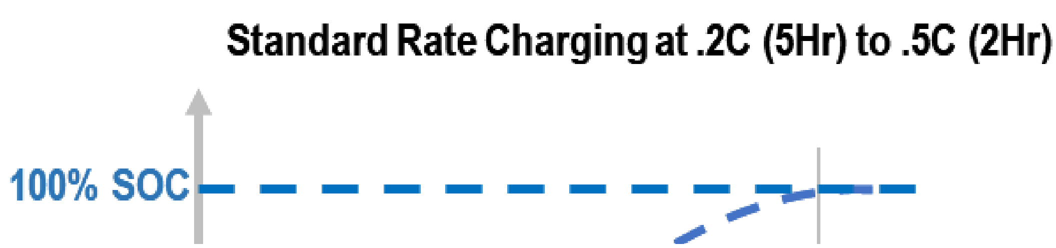
	3.4Vpc (13.6V for a 12V battery). Balancing continues permanently until charge is terminate	3.4Vpc (13.6V for a 12V battery). Balancing continues permanently until charge is terminated
Time in Float	Set Maximum time to 8 hours	Set Maximum time to 8 hours

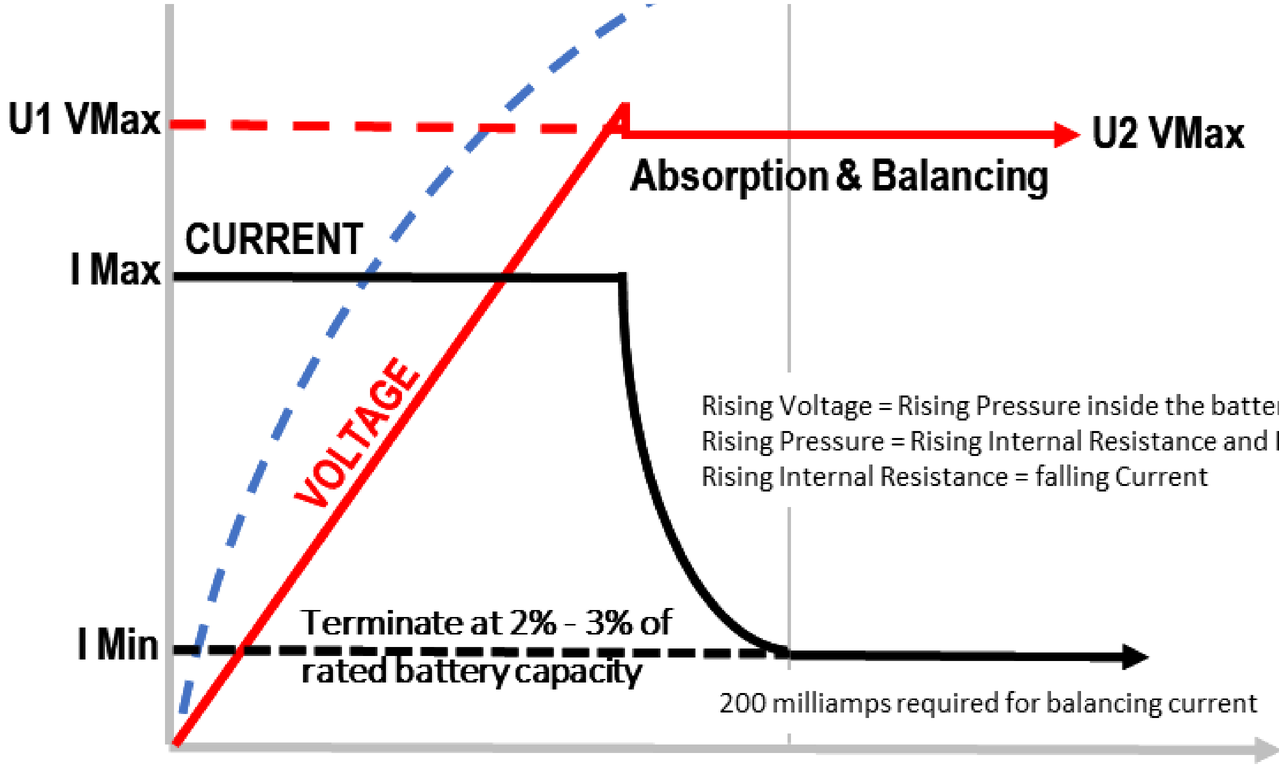
Closed-loop Dynamic Charging and Balancing should be used when operators want to take serious advantage of the fast charging ability of Li+ batteries. Closed-loop Dynamic Charging and Balancing occurs when the battery has the "SMART" ability to communicate with the charger and dynamically control the charge process as apposed to standard open-loop charging where the charger and battery cannot communicate and the charge process is left to the chargers basic pre-set variables.

How to fast charge lithium LiFePO4 (LFP) batteries?



How to charge lithium LiFePO4 (LFP) batteries?

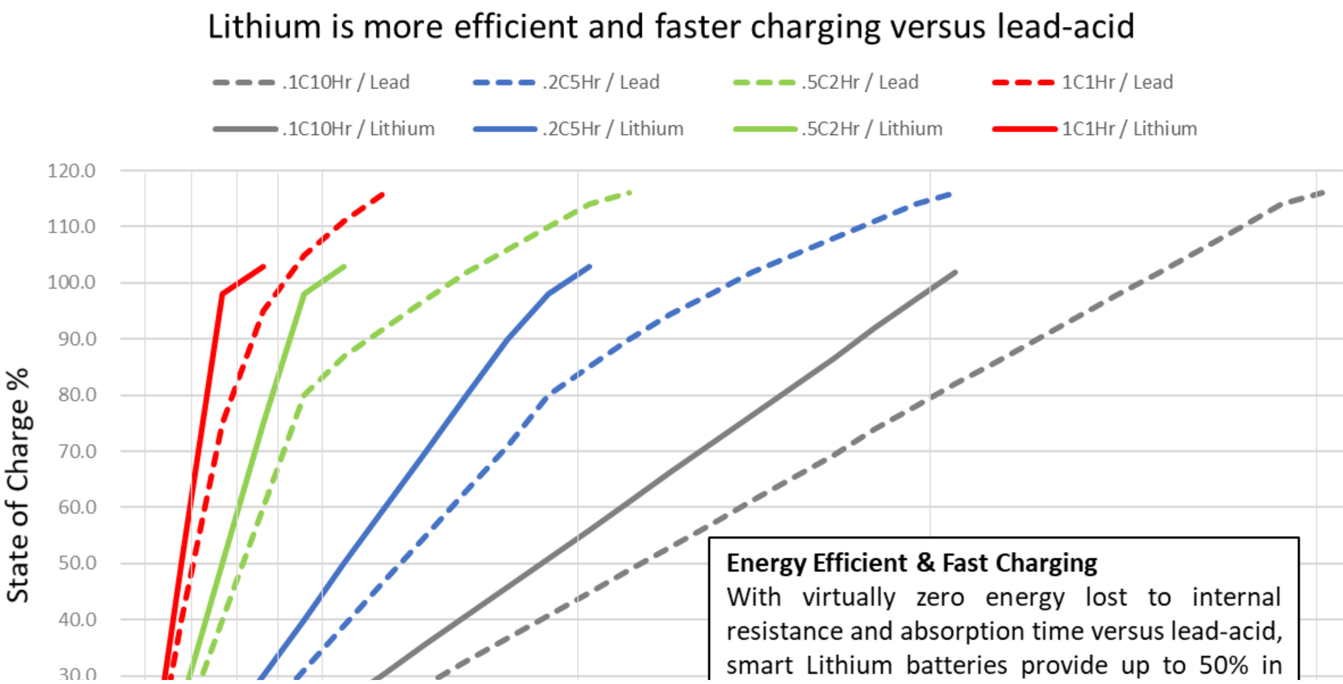


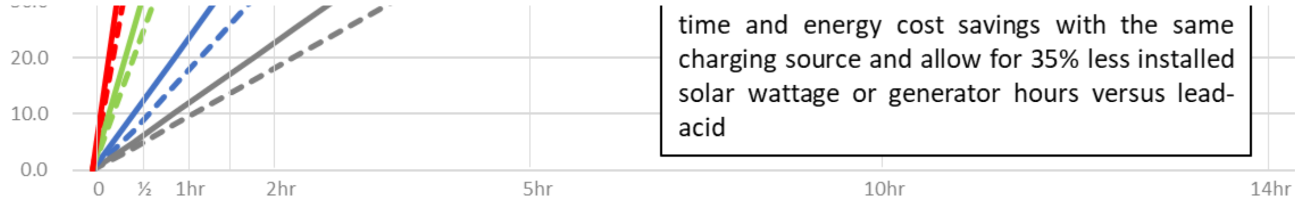


At .2C = 315 minutes total charge time
No time limit in balancing if desirable
Set Float Maximum Time to 8 Hours

Discover lithium LiFePO4 (LFP) batteries are fast charging.

Discover has a complete range of purpose-built *High-Energy* Lithium Solutions. Discover's Advanced Energy Systems (AES), PRO Series and the BLUE Series models incorporate BMS controlled Lithium Iron Phosphate cell technology ($LiFePO_4$) and are designed to be continuously charged at high rates up to 1C.





Lithium will charge to 98% SOC in the initial bulk charge stage and require short absorption time.
Most Lead-acid will charge to 80% SOC in the initial bulk charge stage and require long absorption time.

Discover's DLX Lithium Titanate (LTO) batteries are very fast charging.

Discover's Mission Critical Lithium EXTREME (DLX) series batteries are purpose-built with unique lithium Electrolyte additives and with Nano-technology applied to the development of an improved 3D crystal structure in the cells active materials. This advancement works to Increase the surface area of the anode active material by more than 33 times which dramatically decreases internal resistance and increases charge and discharge performance and efficiency throughout a wider temperature range versus other lithium technologies.

At 20°C/68°F to 25°C/77°F with voltage control Discover DLX batteries can be safely charged from 0% to 90% in as little as 6 minutes (10C) while still maintaining a coulombic efficiency of >98%. Without tight voltage control and AH counting Discover recommends up to 4C (15 minute) charging. Discover's DLX batteries with Nano-materials represent a major breakthrough for mission-critical and/or extreme environments with difficult or high cost to serve applications.

How to charge Discover DLX Lithium Titanate (LTO) batteries

Depending upon your charger output (fast charging rates or low or medium charging rates), you should set your charge profiles differently by raising the Voltage Max setting for fast charging and lowering it for slower charging.

Discover Lithium Extreme DLX Lithium Titanate	**Fast Charging - 100% to >400% of Rated battery Capacity at 20°C/68°F to 25°C/77°F**	**Standard Charging - 20% to 100% of Rated Battery Capacity at 20°C/68°F to 25°C/77°F**
U1 / Voltage Maximum	2.80Vpc (14.0V for a 12V battery)	2.72Vpc - 2.76Vpc (13.6V - 13.8V for a 12V battery)
U2 / Absorption Voltage	CV - 2.65Vpc constant voltage	CV - 2.65Vpc constant voltage
I Max Constant Current Amps	Up to 400% (4C) of Rated AH Capacity	Up to 100% (1C) of Rated Ah Capacity
Balancing Begins	2.0Vpc (10V for a 12V battery) and -30°C/70°C (-22°F/158°F) and 50mV cell deviation	2.0Vpc (10V for a 12V battery) and -30°C/70°C (-22°F/158°F) and 50mV cell deviation
Charge Termination	When current tapers to 2%-3% of rated battery capacity	When current tapers to 2%-3% of rated battery capacity
Float Voltage if utilized	2.56Vpc (12.8V for a 12V battery) Balancing continues permanently until charge is terminate	2.56Vpc (12.8V for a 12V battery) Balancing continues permanently until charge is terminate
Float Time	Set Maximum time to 8 hours	Set Maximum time in to 8 hours

Lithium Iron Phosphate ($LiFePO_4$) battery advantages

Lithium iron phosphate batteries (LiFePO4 or LFP) offer lots of benefits compared to lead-acid batteries and other lithium battery chemistries including the Longest life (other than LTO), no maintenance, extreme safety, non-toxic and environmentally friendly, ease of recycling, lightweight, and improved discharge and charge efficiency, LFP is the technology of choice where safety is paramount. LFP has excellent thermal and chemical stability and stays cooler when operating in higher temperatures. LFP is incombustible when it is mishandled during rapid charges and discharges or when there are short circuit events. Under normal operating conditions Lithium iron phosphate does not experience thermal runaway as the cathodes iron phosphate active material will not burn or explode during overcharging or overheating. LFP batteries are not the cheapest in the market, but due to their safe and long life span and near zero maintenance requirement, LFP batteries offer serious Total Cost of Ownership advantages (TCO).

Lithium Iron Phosphate batteries (LFP) are SAFE!

LFP batteries are safe because they are made with more stable active materials and they operate at a lower voltage (lower pressure) than NMC /LCO or LMO batteries. We guarantee the safety and reliability of our LFP batteries by incorporating purpose-built and proprietary internal Battery Management Systems (BMS) and OEM grade mechanical designs.

For two major and one minor reason Lithium Iron Phosphate $LiFePO_4$ (LFP) is a more stable and far safer lithium technology than the more popular (but lower cost) Lithium Nickel Manganese Cobalt Oxide - $LiNiMnCoO_2$ (NMC), Lithium Cobalt oxide battery - $LiCoO_2$ (LCO) and Lithium Manganese Oxide battery - $LiMn_2O_4$ (LMO) technologies.

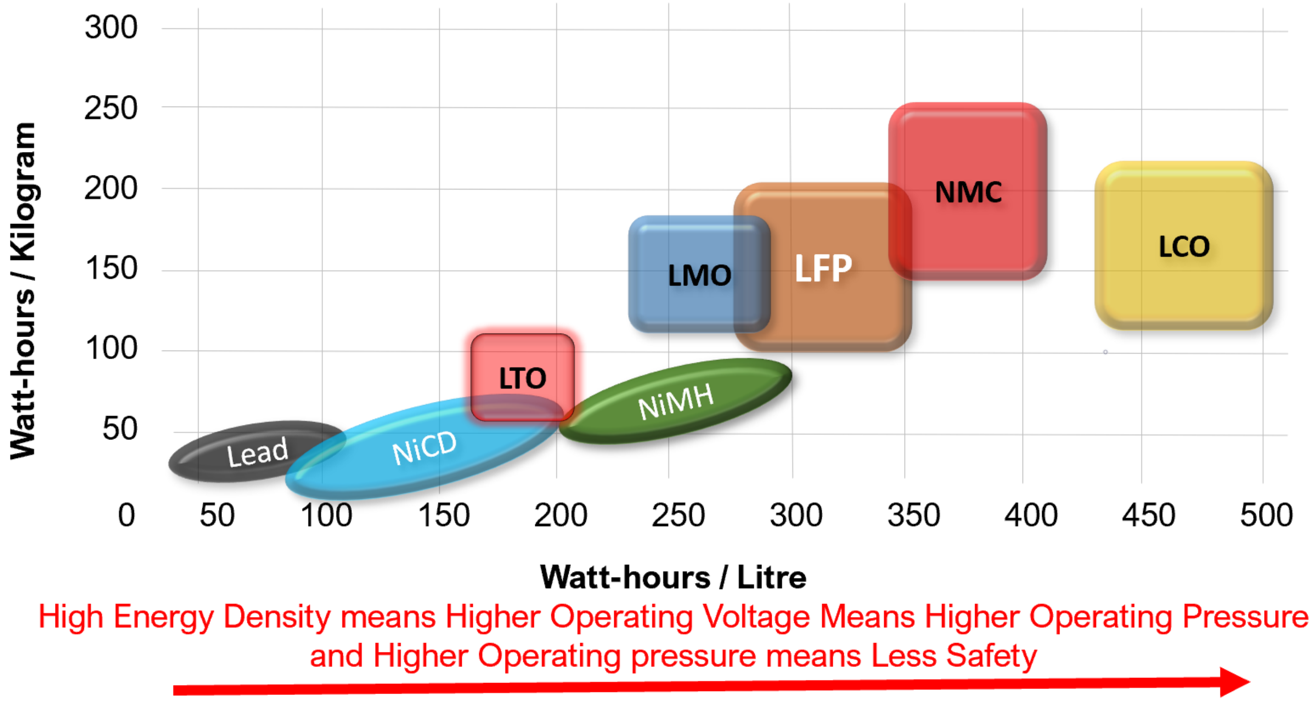
First, the iron phosphate cathode material used in LFP cells develops a far more robust and stable crystalline structure with well defined roadways for the in and out movement of the LI+ during the charge and discharge electrochemical process. This allows for the Li+ to intercalate with (move into or out of) the cathode material through these well-defined tunnels within the active material structure without significantly altering the iron phosphate active material framework. Because of this stability no lithium remains in the cathode material of a fully charged $LiFePO_4$ LFP cell compared with approximately 40%-50% in NMC, LCO or LMO lithium cell.

Secondly, because the crystalline structure of LFP active material is very stable its oxygen atoms are able to tightly bond within the active material of the cell so it is very resistant to oxygen release as compared to NMC, LCO and LMO cell technology. Since any combustive reaction of the electrolyte and the graphite anode is dependent upon oxygen, and there is no external supply of oxygen available, LFP cells are an order of magnitude safer than NMC, LCO or LMO lithium cell technology. Gas emissions testing of NMC/LMO cells versus LFP cells show results 18 times higher for the NMC/LMO cells than LFP cells at 780 L kg^1 and 42 L kg^1 respectively.*

Simply stated, the cause of the more combustive reactions of NMC/LMO cells is the cathode materials propensity to release oxygen very easily;, and since the active material is less robust and is less stable it breaks down easily and more readily as temperatures increase. These activities combine to create a negative accelerating loop that leads to the combustion of a continually growing proportion of the electrolyte solvent in the cell.

If an Iron Phosphate battery FIRE occurs it can be put out by an standard water sprinkler systems

******Analysis of Li-Ion Battery Gases Vented in an Inert Atmosphere Thermal Test Chamber by David Sturk, Lars Rosell, Per Blomqvist, Annika Ahlberg Tidblad, Autoliv Sverige AB; SE-447 37 Vårgårda, Sweden, Research Institute of Sweden (RISE), Box 857, SE-501 15 Borås, Sweden, Volvo Car Corporation, SE-405 31 Gothenburg, Sweden*



Finally, LFP cells have an operating voltage of 3.2 to 3.3 volts per cell and volumetric and gravimetric energy densities of 260-360 **Wh/L and** up to **220 Wh/kg** compared to NMC, LCO or LMO having operating voltages of 3.6 to 3.9 volts per cell and energy densities of 220 ->500 **Wh/L** and **110 - 270 Wh/kg**. Because voltage is pressure, and high pressure blow-outs are capable of causing more damage than low pressure blow outs, it is easy to reason that; because LFP operates at a lower voltage; and its power potential (Watt-hours / Litre) is also lower, that LFP has significantly less potential to cause catastrophic damage when subject to misuse or abuse during charge or discharge than NMC and LCO.

- Higher **Voltage** = Higher **Pressure** (Voltage is Pressure)
- Higher **Pressure** = Higher **Heat**
- Higher **Heat =** Higher **Active Material Breakdown**
- Higher **Active Material Breakdown =** More **Capacity Loss, Material Breakdown and Short Circuits**
- More **Material Breakdown and Short Circuits = Battery Failure**

- **Pressure creates heat and HEAT KILLS BATTERIES by accelerating active material breakdown!**

For these reasons and others $LiFePO_4$ (LFP) technology:

- is a very robust chemistry, which makes it safer to use as a cathode than other lithium chemistries. Lithium iron phosphate provides a significantly reduced chance of thermal runaway, a condition that occurs when the chemical reaction inside a battery cell exceeds its ability to disperse heat, resulting in an explosion. Thermal runaway may be caused by overcharging, an internal fault, physical damage to the battery, or a hot environment.
- has a thermal runaway temperature of 518°F (270°C), which is much higher than other lithium battery chemistries. LFP batteries can deliver rapid discharge and recharge while generating very little heat. They require less ventilation or cooling, and can withstand higher temperatures without decomposing. When exposed to air due to an accident (e.g. piercing of the battery casing), the lithium iron phosphate chemistry will not react with oxygen, and therefore will not cause an explosion or fire.
- environmentally safer than a Li+ batteries made with cobalt dioxide chemistry which considered a hazardous material and which causes allergic reactions to the eyes and skin when exposed. It can also cause severe medical issues when swallowed. So, special disposal considerations must be made for these Li+ cells. Lithium iron phosphate is non-toxic and can be disposed of more easily by manufacturers.
- and because they contain unstable elements, the chemistries in lithium NMC, LCO or LMO batteries break down at much lower temperature and can release far more potentially hazardous energy. LCO/LMO Cobalt-based lithium batteries actually generate heat in their normal battery operation, which increases the risk of thermal runaway. There is no effective fire retardant against a cobalt fire; your only option is to let the fire burn itself out. But if a fire occurs with an LFP battery, it can be extinguished by an ordinary water sprinkler system.

If an Iron Phosphate battery FIRE occurs it can be put out by an standard water sprinkler systems

- LiFePO4 is harder to ignite in the event of mishandling (especially during charge).
- LiFePO4 active material is much more robust and does not readily decompose at high temperatures.
- $LiFePO_4$ is very safe and secure technology with little thermal runaway potential
- $LiFePO_4$ materials have very low environment toxicity (iron, graphite and phosphate and no cobalt)
- $LiFePO_4$ has long calendar life of >10 years and potentially 15 years in Telecom/standby applications
- $LiFePO_4$ cells have 100% DOD at 1C laboratory cycle life to 70% remaining capacity of 8000-9000 cycles
- $LiFePO_4$ battery packs have 100% DOD at .5C1 cycle life to 70% remaining capacity of 4500-5500 cycles
- $LiFePO_4$ has an operational temperature range of up to 70°C
- $LiFePO_4$ presents stable and low internal resistance throughout its calendar life
- $LiFePO_4$ delivers constant power throughout the discharge range
- $LiFePO_4$ is easy to recycle and overall,
- $LiFePO_4$ offers the best mix of safety, performance, longevity, and cost effectiveness

Lithium Iron Phosphate batteries have long Deep Cycle life?

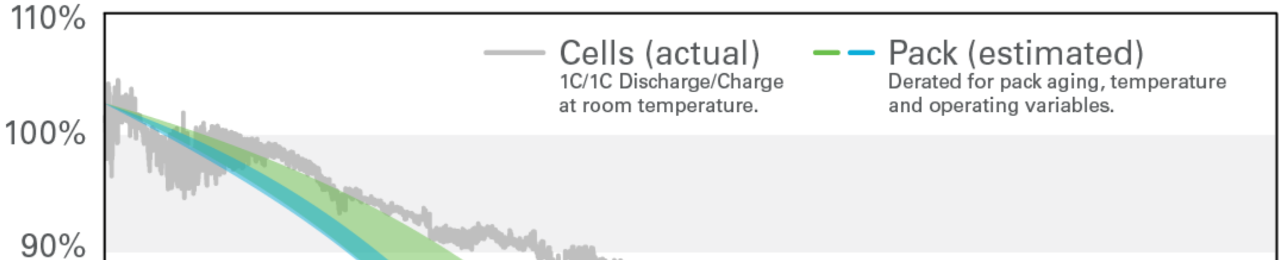
Cell manufacturing and quality control processes have a direct impact on the final quality of an LFP cell. High-quality Lithium iron phosphate cells have been tested and shown to consistently deliver deep cycle life of up to 10,000 100% DOD cycles at 1C/1C discharge and charge rates at room temperature in a controlled laboratory environment to 50% remaining capacity.

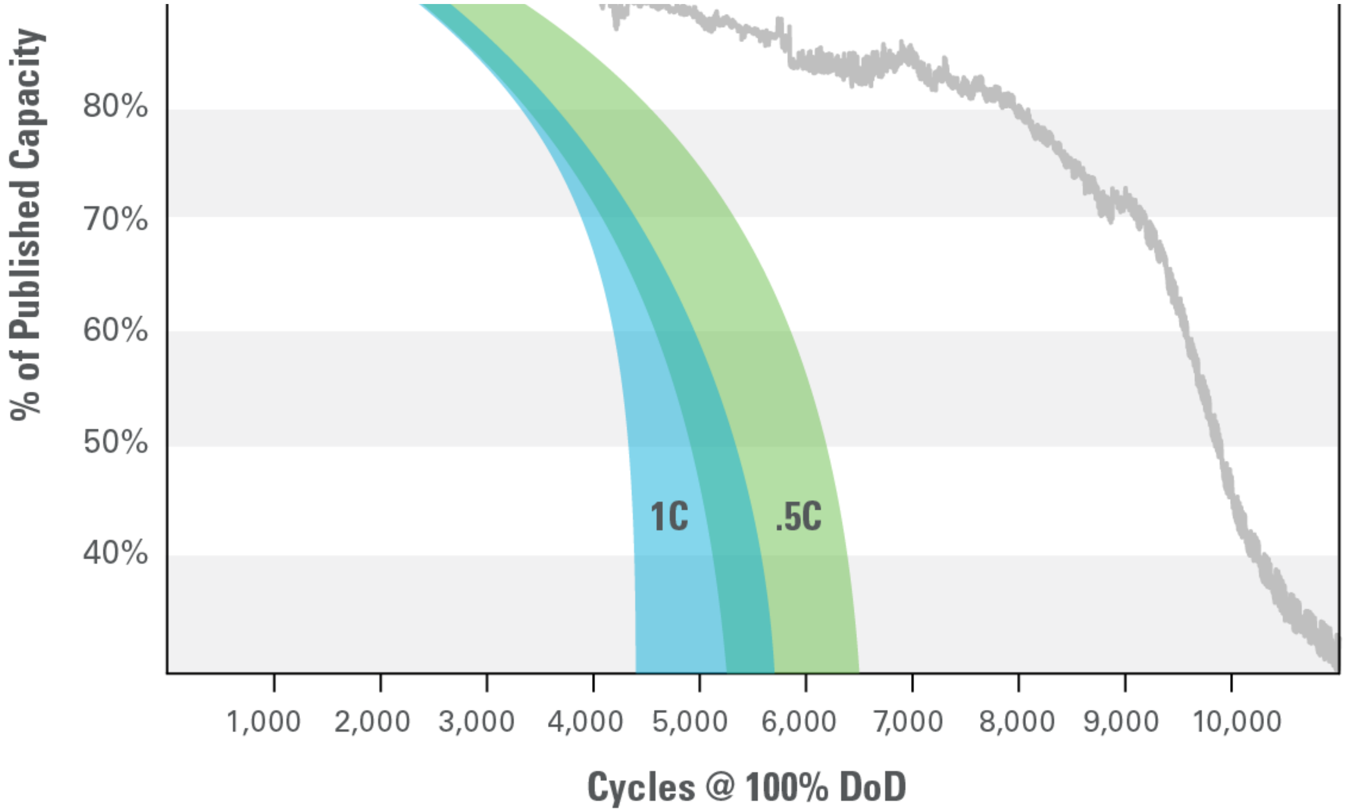
Complete batteries can be found advertised in the market with life cycles ranging from1000 cycles to 5000 or more cycles.

Discover Lithium Iron Phosphate batteries have long Deep Cycle life.

As guidance to battery pack engineers and battery buyers, Discover's Lithium iron phosphate ***cells*** are continuously tested and constantly deliver deep cycle life of up to 10,000 100% DOD cycles at a 1C/1C discharge and charge rate at room temperature in a controlled laboratory environment. End of life is determined to be the point at which the cell is no longer capable of providing at least 50% of the cells original capacity before reaching its low voltage cutoff. Discover lithium iron phosphate ***batteries*** (not just the cells) have a maximum expected deep cycle life of up to 6500 cycles to 50% remaining capacity* when being cycled at a .5C/.5C (2Hr) discharge and charge rate to 100% DOD when responsibly de-rated for pack aging, and a +/- 5°C temperature variance. See also how does temperature affect a lithium battery. Systems engineers and battery buyers must consider any and all applicable operating and environmental variables when determining the required design life characteristics of their particular installation/application.

*** BCIS-06 REV.DEC.02 Accelerated cycle life testing standard 06**





Discover's Designed For Excellence philosophy combines safe long life Lithium Iron Phosphate cell technology with proprietary Protection Control Circuits and Battery Management and Communication power electronics that monitor and manage balance of systems integration and all of the batteries operating limits including internal battery temperature. This provides control of charging and discharging, and prevents operation at unsafe temperatures. Additionally to guarantee you receive long resilient and reliable life all Discover Lithium Solutions have industry leading automotive grade cells. vibration resistant cell cradles and case and cover designs that include added safety and user convenience features such as carry handles and external user replaceable fuses.

Discover Lithium Iron Phosphate batteries have long stationary/standby life!

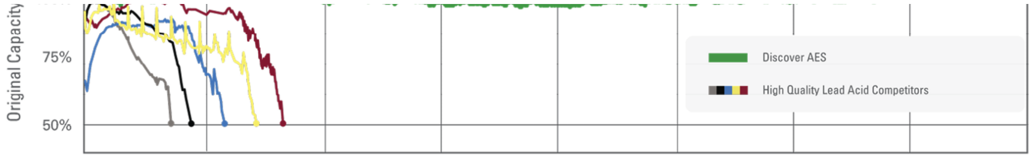
LiFePO4 or LFP is the ideal lithium chemistry to use to replace lead acid batteries in stationary, standby, and mission critical infrastructure and data center backup applications. While we provide exacting guidance on cyclic life (see above), the inconvenient truth is very few laboratories (if any) will spend the years of time or money to actually run a real world end of life test on any battery technology to determine actual life expectancy in ***float*** service at room temperature. The test procedures we run (and that most manufacturers run) are typically "accelerated life tests" that are usually performed at elevated temperatures and that we then extrapolate out to provide float service life guidance. While our ***actual*** life cycle data provides hints that the cell technology has the potential - to be extrapolated on paper - of up to 30 years of float service life, another inconvenient truth that no one talks about is the power electronics will most likely "not" last as long as the cells might and, the decomposition rate of the cells active material will also reduce the extrapolated life prediction. While it may be "theoretically" possible for the cells to last up to 30 years, we would provide guidance to system design engineers and cost accountants of 10 -15 years above 70% of original capacity,

Discover Lithium Iron Phosphate batteries are reliable!

We know! Because we have built, sold, and serviced lead acid batteries since 1949 and Lithium Solutions since 2008, we have hands on knowledge of how lead-acid compares with lithium solutions across a wide variety of applications. We are knowledgeable in their use, misuse and abuse and it is indisputable that Discovers LFP (also see Discover EXTREME LTO) battery solutions offer increased reliability and provide at least 10x the cyclic life of high-quality lead acid batteries. Subject to the ambient operating temperature of the installation, and its minimum end of life performance requirements, Discover Lithium Solutions have the ability to last the 12-15 year lifetime of the average UPS system.

As guidance to battery pack engineers and battery buyers and if you have been reading our Lithium 101 FAQs carefully, you know by now that to achieve the longest lithium battery life (and safety) you need to reduce maximum and minimum operating voltage (pressure) and it is important to manage temperature.

INCREASED RELIABILITY



DISCOVER LITHIUM SOLUTIONS to 100% DOD 1C x 1Hr rate discharges until the battery fails to deliver at least 60% of its original capacity above 2Vpc	**HIGH-QUALITY LEAD ACID at 80% DOD .5C x 2Hr rate discharges until the battery fails to d5C 2Hr rate discharges until the battery fails to deliver at least 50% of its original capacity above 1.75Vpc acc. to BCI-S-06**
Discover Lithium Solutions will provide 10x the high and sustained capacity life of the highest quality lead-acid options even when discharging and charging at 1C rates to 100% DOD versus lead-acid at .5C rates to 80% DOD	
Can last the life of the equipment	Requires multiple replacement batteries
>500 cycles at 100% of Original Capacity	>50 cycles at 100% of Peak Capacity
>1000 cycles above 90% of Original Capacity	>100 cycles at 90% of Peak Capacity
>3500 cycles above 70% of Original Capacity	>350 cycles at 70% of Peak Capacity
>5500 cycles above 60% of Original Capacity	>550 cycles at 50% of Peak Capacity

DISCOVER LITHIUM SOLUTIONS at 80% DOD 1C x 1Hr rate discharges until the battery fails to deliver at least 60% of its original capacity above 2Vpc	**HIGH-QUALITY LEAD ACID at 60% DOD .5C x 2Hr rate discharges until the battery fails to d5C 2Hr rate discharges until the battery fails to deliver at least 50% of its original capacity above 1.75Vpc acc. to BCI-S-06**
Discover Lithium Solutions will provide 10x the high and sustained capacity life of the highest quality lead-acid options even when discharging and charging at 1C rates to 80% DOD versus lead-acid at .5C rates to 60% DOD	
Can last the life of the equipment	Requires multiple replacement batteries
>1000 cycles at 100% of Original Capacity	>100 cycles at 100% of Peak Capacity
>2000 cycles above 90% of Original Capacity	>200 cycles at 90% of Peak Capacity
>7000 cycles above 70% of Original Capacity	>700 cycles at 70% of Peak Capacity
>11000 cycles above 60% of Original Capacity	>1100 cycles at 50% of Peak Capacity

Discover Lithium batteries provide ROI certainty for big data and critical infrastructure

Subject to the ambient operating temperature of the installation, and its minimum end of life performance requirements, Discover Lithium Solutions provide investment certainty with the ability to last the 12-15 year lifetime of the average UPS system.

However. in the case of stationary, standby, and critical infrastructure applications there is often the need for high rate short-duration discharge events tempting some to chose a higher energy density lithium technology that is capable of higher momentary discharge rates. If we give in to this temptation we would be sacrificing safety, temperature related performance and calendar life. Therefore, to achieve **BOTH** the desired long service life desired by critical infrastructure **AND** the required 10 or 15 minute discharge capacity necessary for some critical data/UPS systems, and both at potentially extreme temperatures, we need to first chose a safe, proven and robust lithium cell technology and then become a little more conservative in our Lithium Battery Solution sizing and control circuitry (BMS and fusing) and the overall mechanical design. As with anything good in life - no matter the temptation - we need to sacrifice to achieve greatness. At Discover this means:

- using LFP or LTO cell technology for critical infrastructure support battery solutions and not simply high energy cells that “can not” meet calendar life expectations or required safety levels.
- sizing the total LFP or LTO battery capacity to support the load amount and the load duration without over-stressing the cells ability to deliver. This will increase solution cost (a little) but will also guarantee we achieve the desired calendar life and performance characteristics
- including control circuitry that can communicate with the balance of systems and/or ensuring BMS controls and system fusing protects the battery from being operated outside of its safe operating limits.

With this Design For Excellence approach to battery solutions using LFP and LTO cell technology Discover can guarantee total cost of ownership (TCO) savings over lead acid and other lithium battery systems in Stationary/UPS backup power applications

Also, by migrating their lead-acid battery usage to Discover’s Lithium Solutions major data center owners and co-location providers can take advantage of the lower weight and smaller footprint benefits to redesign or reorganize their data centers, reserving more floor space for cash

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generating IT infrastructure. Traditional and high-rise data centers will be easier and less expensive to build, and modular data centers will be easier to design, utilize, and transport to their destination. Companies can re-invest the cost savings they achieve into new capacity, new technologies and the development of new product or service offerings. Now improved ROI predictability allows for better capital planning with the added ongoing benefit of reduced maintenance and service related costs. If you're a data center owner, co-location provider, or UPS OEM, now is the time to start considering Lithium Solutions.

Discover Lithium Iron Phosphate batteries increase Return on Assets!

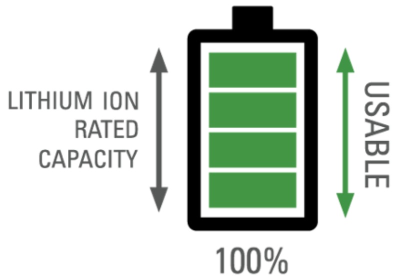
Discover's LFP lithium battery solutions are for commercial and industrial business with mobile and stationary applications that require the highest level of productivity from their battery powered equipment, and unlike lead acid batteries, deliver a predictable return on their battery investments.

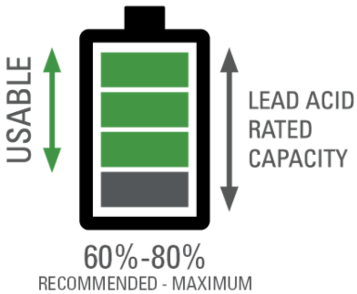
RETURN ON ASSETS

DISCOVER LITHIUM SOLUTIONS	HIGH-QUALITY LEAD ACID
Delivers Peak Capacity for 100s of time longer than lead acid	Operates at peak capacity for a fraction of total their useable life
Clean the same square feet daily for years	Predictably cleans less square feet daily
Sustained return on people and equipment assets	Declining return on people and equipment assets

Discover Lithium Iron Phosphate batteries increase Productivity!

INCREASED PRODUCTIVITY

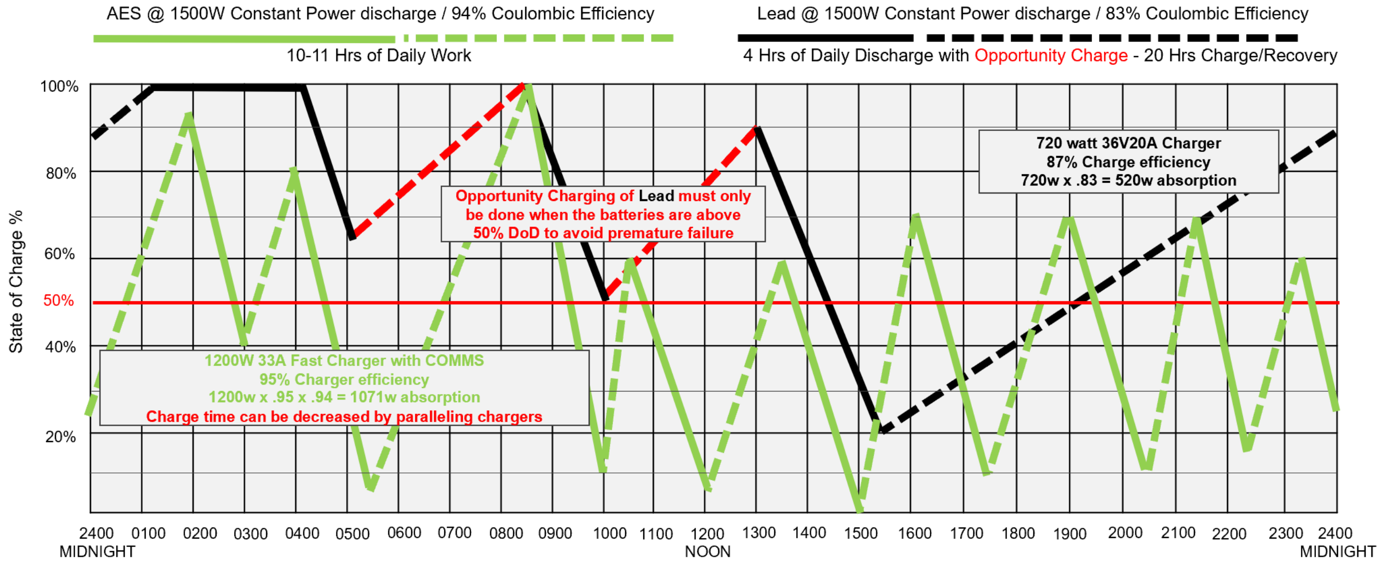




DISCOVER LITHIUM SOLUTIONS	HIGH-QUALITY LEAD ACID
No Capacity loss with partial state of charge use	Partial State of Charge uses causes premature failure
Discharge and charge multiple times a day including to 100% DOD without consequences	Opportunity charging and daily DOD >50% are not recommended
Opportunity charge at any time without consequences (25% charge in 15 minutes)	To avoid negative consequences opportunity charging below 50% SOC and daily DOD >50% are not recommended
Increase daily multi-shift productivity by 400% with fast chargers	

	Battery change-out or additional equipment needed for multi-shift operations

Discover Lithium Solutions can increase daily equipment productivity by up to 400% with fast chargers. Even with standard 1500 watt chargers Lithium Solution productivity is >200% greater than lead-acid battery options.



Discover Lithium Iron Phosphate batteries increase energy savings!

ENERGY SAVINGS

DISCOVER LITHIUM SOLUTIONS	HIGH-QUALITY LEAD ACID
Up to 99% Charge Efficiency at 1 hour charge rates allows for faster charging and lower AC power bills	Requires long absorption charge times at down to 67% charge efficiency
Dramatically reduced 0% to 95% charge times with average charge times of 1 hour desirable for LFP. Faster for LTO	Charge times easily average 10-12 hrs. with absorption and equalization time… or 6-8 hours with fast chargers
Hundreds of dollars in energy savings annually per machine	Low charge efficiency increases energy costs by over 40% versus Lithium

Dramatic increases in Round Trip Energy Efficiency (up to 70% improvement over lead acid in charge discharge charge round trip energy efficiency) makes charging with solar panels a meaningful reality for remote installations. Improved RTE translates into reduced alternator /generator run times and fuel savings when the charge source is powered by an engine.

Discover Lithium Solutions offer improved trouble shooting and zero maintenance!

Discover Lithium Solutions are purpose-built to eliminate many of the age old challenges related to lead-acid maintenance and performance diagnostics. They do not require active maintenance to extend their service life, Also, they experience no memory effects and due to low self-discharge can be stored for extended periods of time. You should think of a Discover Lithium Solutions as a lap top computer or hand held smart device with a much bigger battery.

DISCOVER LITHIUM SOLUTIONS	DATA LOGGING AND DIGNOSTIC SOFTWARE

Do you need two machines on site or can one now do the job	Our SMART battery will tell you
Do you need more battery capacity or will higher output chargers do the job	Our SMART battery will tell you
Are your equipment operators following your procedures for maximum productivity	Our SMART battery will tell you
Do you really have a battery issue or is there another component problem	Our SMART battery will tell you

Lithium titanate battery advantages Li_2TiO_3 / $Li_4Ti_5O_{12}$ (LTO)

Lithium LTO batteries offer lots of benefits compared to all lead-acid or lithium batteries used in extreme applications or high cost to serve environments. Batteries made with LTO technology require no maintenance and are by far the safest, most robust, fastest charging and discharging, and longest life batteries commercially available in the market today (even at extreme low and high temperatures).

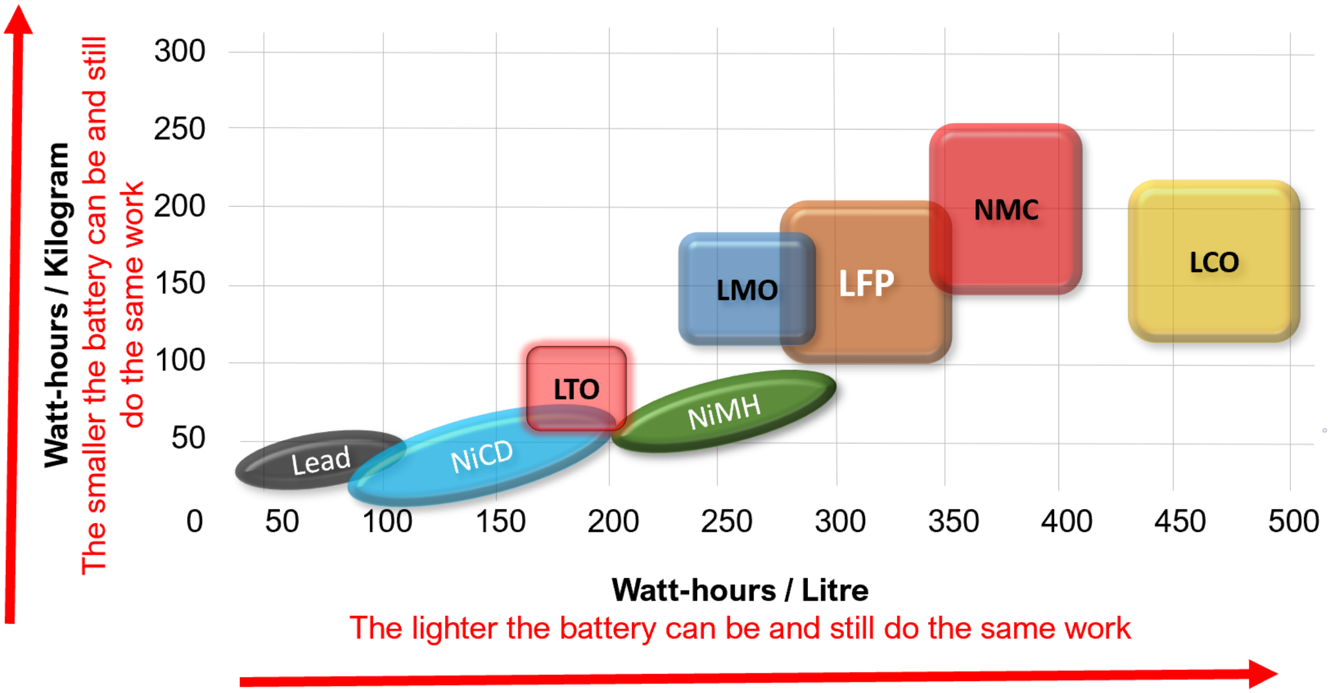
LTO is an advanced modified Li+ battery that employs Lithium Titanate Nanotechnology in the production of its active material versus the normal carbon material in conventional Li+ cells . The advantage of this nanotechnology is that the anode has a surface area of about 100 square meters per gram of active material versus the 3 square meters per gram typical of conventional Li+ cells. This advancement allows the Li+ and electrons to enter and leave the anode active material much more rapidly without causing active material breakdown allowing for faster charging and enhanced lifetimes.

LTO cells have an operating voltage of 2.4 to 2.5 volts per cell and volumetric and gravimetric energy densities of 110-220 Wh/L and 60-120 Wh /kg. LTO cells have cyclic durability of between 6000 and 20000 cycles. and a wide safe operating temperature range of -40°C/-40°F to 80°C/176° F.

Lithium titanate battery disadvantages Li_2TiO_3 / $Li_4Ti_5O_{12}$ (LTO)

A disadvantage of LTO cell technology is their lower operating voltage of 2.4 to 2.5 which leads to its lower specific energy of up to **120 Wh/kg** versus other Li+ technologies which have an operating voltage of up to 3.9V and specific energy densities of up to 260 Wh/Kg.

This is where the disadvantages end for LTO versus all other commercially available Li+ technologies. Other than a Volumetric or gravimetric energy deficit differential, LTO is a far superior lithium chemistry in every other measurable way.



Discover's DLX lithium titanate (LTO) battery advantages!

Discover's Mission Critical Lithium Titanate (LTO) EXTREME series batteries are purpose-built with unique lithium Electrolyte additives and we apply Nano-technology to the development of an improved 3D crystal structure in the cells active materials. This advancement works to Increase the surface area of the anode active material by more than 30 times which dramatically decreases internal resistance, increasing safety, charge and discharge performance and efficiency throughout a wider temperature range of -40°C/-40°F to 80°C/176°F.

Discover Extreme batteries can be safely discharged at very high rates and with tight voltage control can be charged from 0% to 90% in as little as 6 minutes at 20°C/68°F to 25°C/77°F while still maintaining a coulombic efficiency of >98%. Discover's Lithium EXTREME batteries with Nano-technology represent a major breakthrough for mission critical and/or extreme environments with difficult or high cost to serve applications.

Discover' Extreme LTO batteries are purpose-built to solve the challenges of extreme temperature challenged and hard and high cost to service applications.

Discover's DLX lithium titanate (LTO) batteries are very Safe!

For all of the same reasons that Discover's LFP batteries are safe versus other Li+ technology, Discover's Extreme LTO Lithium Solutions are orders of magnitude safer than LFP.

Specifically, the lower operating voltage of this technology makes it safer for the consumer and as Lithium Titanate batteries are entirely free of carbon, they **avoid thermal runaway or overheating** which is the main cause of fires in traditional energy storage systems.

Discover's DLX lithium titanate (LTO) batteries have extremely long life.

As discussed above in "Lithium Titanate battery advantages", the advanced nanotechnology utilized in LTO cell production is specially designed to enhance the lifetime of these batteries in high cyclic applications and in the most extreme environments. Cell manufacturing and quality control processes have a direct impact on the final quality of an LTO cell. Discover Lithium Titanate cells have been tested and shown to deliver deep cycle life of up to 20,000 100% DOD cycles at high 3C/3C discharge and charge rates at room temperature in a controlled laboratory environment to 70% remaining capacity.

Discover's high temperature accelerated life cycle testing in the Laboratory where the cell is maintain in a partial state of charge state and cycled within an SOC range of 80% and 20% (Never charged to more than 80% SOC and never discharged below 20% SOC) at 3C/3C discharge and charge rates at 35°C/95°F has reached over 40,000 cycles or double the life of the 3C/3C 100% DOD life cycle test to 70% remaining capacity at room temperature.

At 1C/1C discharge and charge rates at room temperature LTO cells can be found advertised with up to 40,000 100% DOD cycles to 80% remaining capacity, 62,000 80% DOD cycles to 80% remaining capacity and 110,000 60% DOD cycles to 80% remaining capacity.

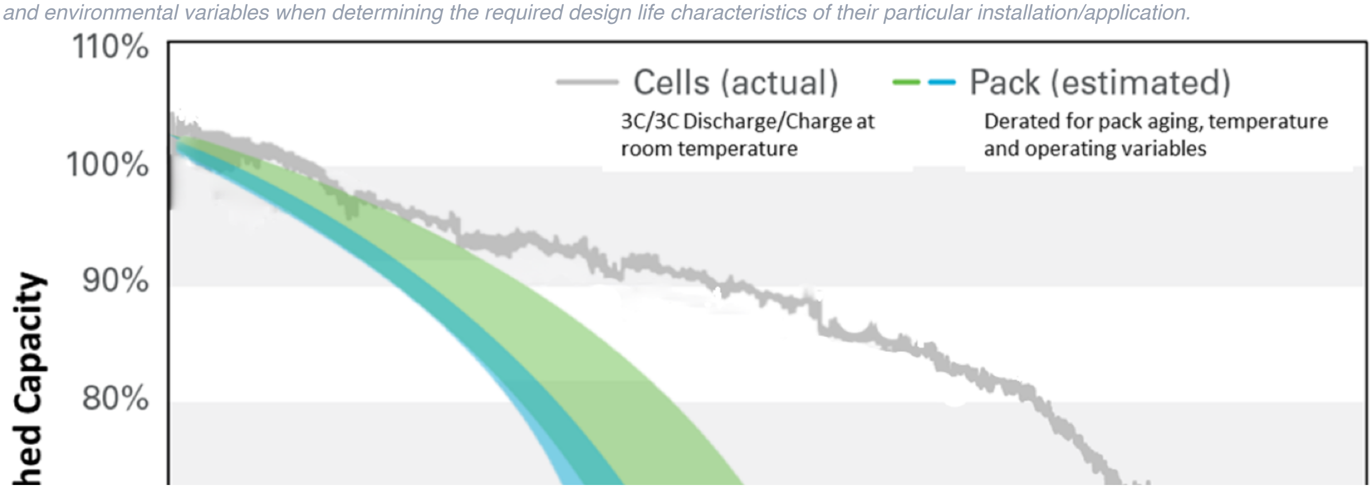
Complete batteries can be found advertised in the market with life cycles ranging from 5000 cycles to 70000 or more cycles.

Discover's DLX lithium titanate (LTO) batteries have very long deep cycle life!

As guidance to battery pack engineers and battery buyers, Discover's LTO cells have been tested and shown to deliver deep cycle life of up to 18,000 100% DOD cycles at 3C/3C discharge and charge rates at room temperature in a controlled laboratory environment. End of life was determined to be the point at which the cell was no longer capable of providing at least 80% of the original capacity before reaching low voltage cutoff.

While "old battery guys like me" find it hard to accept, Discover EXTREME lithium solution (DLX Series) batteries (not just the cells) have a recommended maximum de-rated design life of 7,000 cycles to 80% remaining capacity when tested at constant 3C/3C discharge/charge cycles. Technology has a way of sneaking up on us and in the case Discover DLX batteries the time is "now" for a massive leap forward in battery related system design life.

See also how does temperature affect a lithium battery. Systems engineers and battery buyers must consider any and all applicable operating and environmental variables when determining the required design life characteristics of their particular installation/application.



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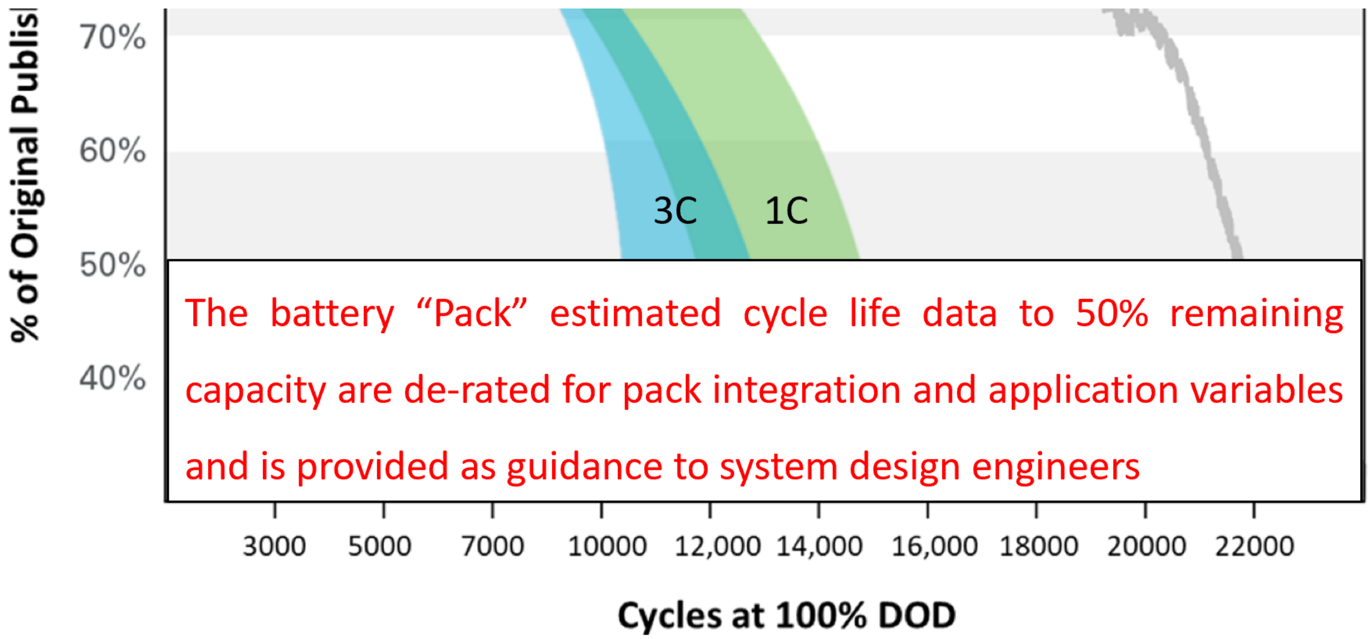

DISCOVER DLX LITHIUM at 100% DOD **100% Discharge cycles at 3C rates until the battery fails to deliver at least 80% of its original capacity above 2Vpc**	**HIGH-QUALITY LEAD ACID at 100% DOD 100% Discharge cycles at .5C (2-hour) rates until the battery fails to deliver 50% of its original capacity above 1.75Vpc acc.**
Discover EXTREME Lithium Solutions will provide 20x the high and sustained capacity cycle life of high-quality lead-acid options to any remaining capacity	
Can last the life of the equipment	Requires multiple replacement batteries
>1000 cycles at 100% of Original Capacity	>50 cycles at 100% of Peak Capacity
>2000 cycles above 90% of Original Capacity	>100 cycles at 90% of Peak Capacity
>7000 cycles above 80% of Original Capacity	>350 cycles at 80% of Peak Capacity
>9000 cycles above 70% of Original Capacity	>450 cycles at 70% of Peak Capacity
>11000 cycles above 60% of Original Capacity	>550 cycles at 50% of Peak Capacity

DISCOVER DLX LITHIUM at 60% DOD **Constant 3C discharge/charge cycles between 80% SOC and 20% SOC until the battery fails to deliver at least 50% of its original capacity above 2Vpc**	**HIGH-QUALITY LEAD ACID at 60% DOD** **60% DOD Discharges at .5C 2Hr rates to 50% Remaining Capacity acc. to BCI-S-06**
Discover EXTREME Lithium Solutions will provide at least 25x the high and sustained capacity life of the highest quality lead-acid battery options to any remaining capacity	
Can last the life of the equipment	Requires multiple replacement batteries
>2500 cycles at 100% of Original Capacity	>100 cycles at 100% of Peak Capacity
>5000 cycles above 90% of Original Capacity	>200 cycles at 90% of Peak Capacity
>10000 cycles at 80% of Peak Capacity	>450 cycles at 80% of Peak Capacity
>20000 cycles above 70% of Original Capacity	>700 cycles at 70% of Peak Capacity
>30000 cycles above 50% of Original Capacity	>1100 cycles at 50% of Peak Capacity

Discover's DLX lithium titanate (DLX LTO) batteries have very long stationary/standby life!

Li_2TiO_3 / $Li_4Ti_5O_{12}$ (LTO) is a potential game changer as a replacement for lead acid and other lithium batteries in stationary, standby, mission critical infrastructure and data center backup applications. Partial State of Charge cycle life testing at 35°C/95°F within an SOC range of 80% and

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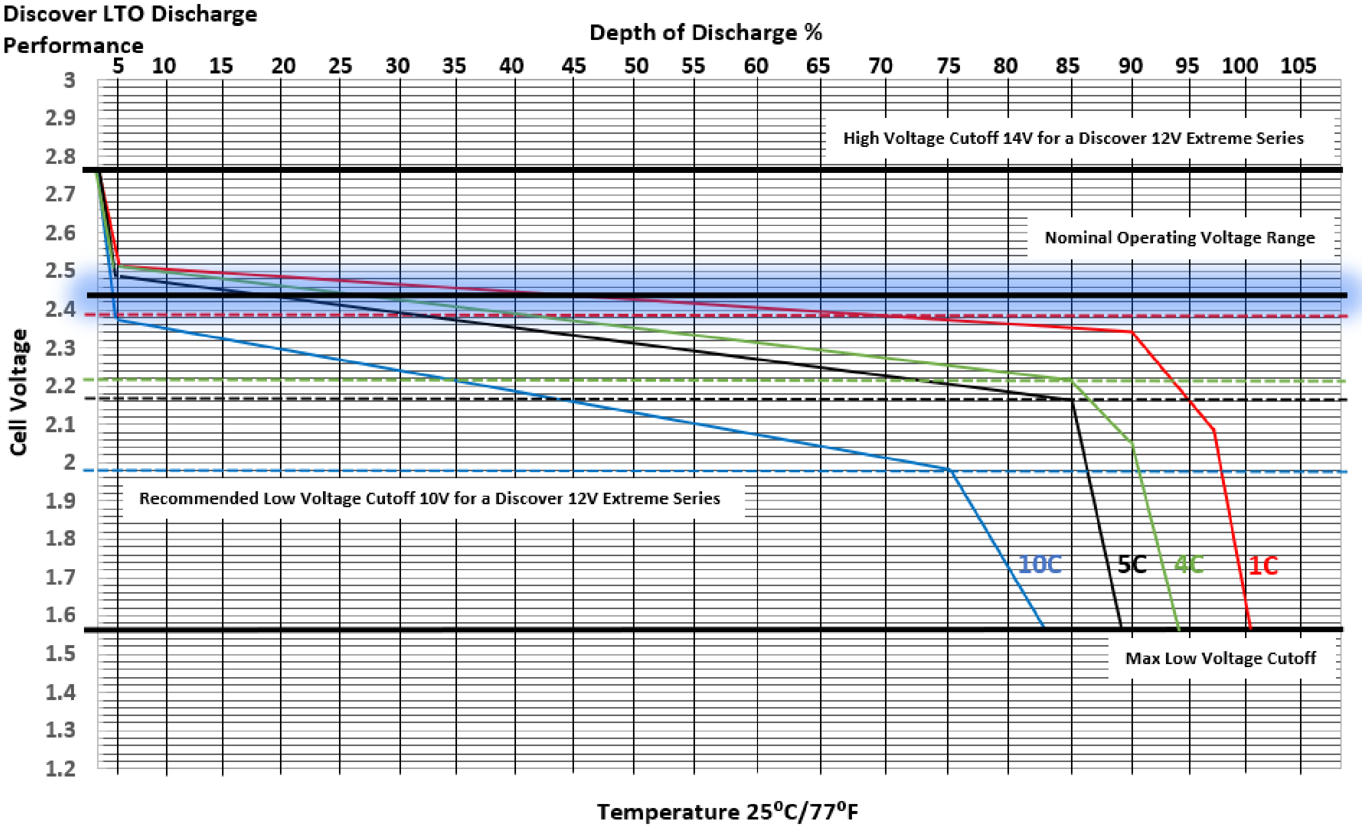
20% (Never charged to more than 80% SOC and never discharged below 20% SOC) shows that a Discover Extreme Lithium (DLX series) battery can deliver at least 80% of its original capacity for the 12-15 year life of the average UPS equipment even when operated at elevated temperatures. That represents more than one high rate cycle per day for 5475 days at 35°C/95°F. Partial State of Charge testing has shown the ability to double the high rate cycle life of Discovers Lithium Iron Phosphate (LFP) batteries

Discover's DLX lithium titanate batteries can be discharged at high rates

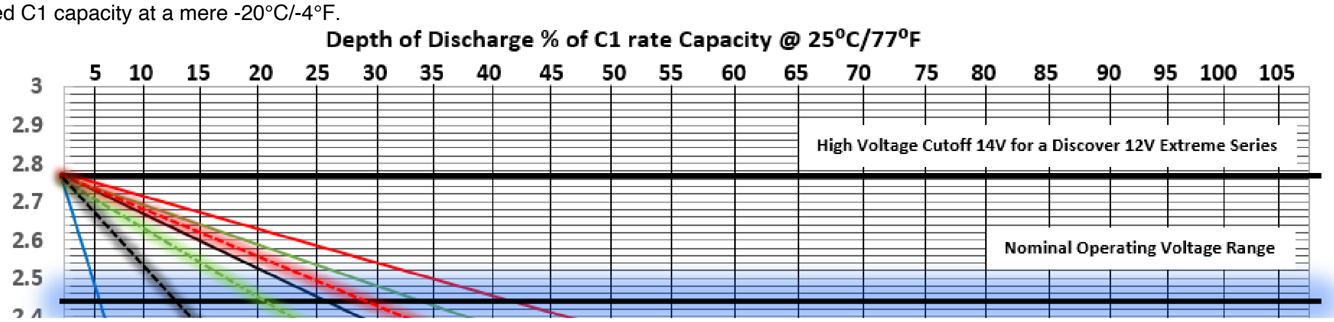
Lithium Titanate batteries (LTO) are made using an **advanced modified Li+ technology that employs** lithium Titanate nanocrystals instead of normal carbon material as an oxide. The result is an active material surface layer that is approximately 100 square meters per gram of active material versus 3 square meters per gram in other Li+ technologies. This extra surface area allows the electrons to enter and exit the active material faster, thus making it possible **to charge and discharge the battery very rapidly**.

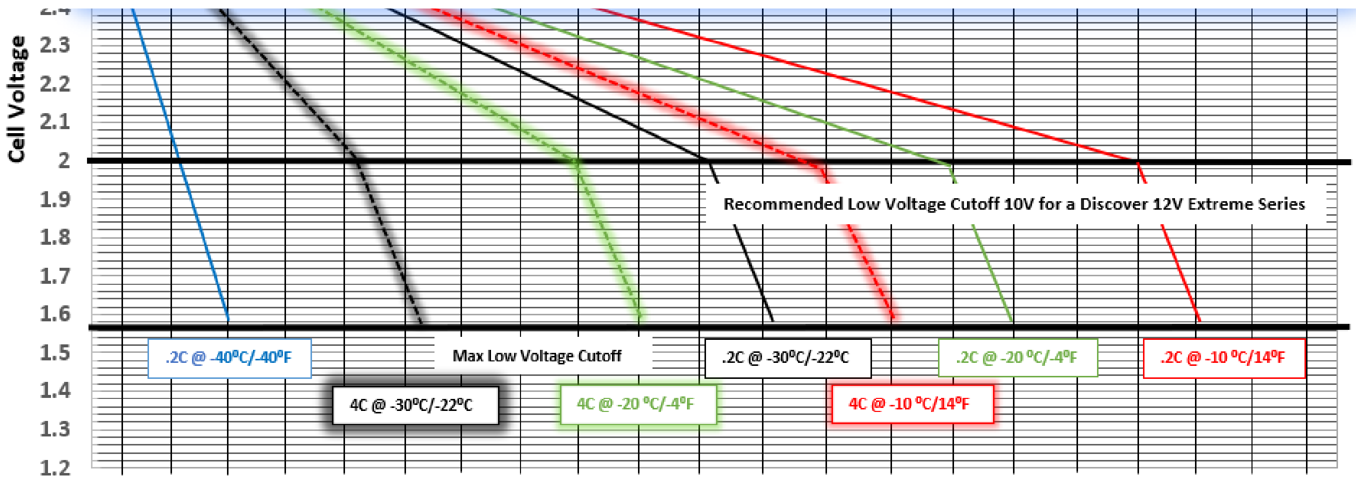
- Discover DLX Series batteries can be safely operated at extreme temperatures from -40°C/-40°F to -80°C/176°F including the ability to charge at -40°C/-40°F at reduced currents.
- Discover DLX Series batteries can be safely charged from 0% to 90% in as little as 6 minutes with constant voltage control while still maintaining a coulombic efficiency of >98%. Up to 4C charge rates are recommended for standard CC/CV charge profiles.
- Discover's DLX Series batteries with Nano-technology have extremely low internal resistance and can be easily charged with solar PV and represent a major breakthrough for mission-critical and/or extreme environments with difficult or high cost to serve applications.



Discover's DLX lithium titanate batteries can be discharged at low temperatures

The greater active material surface area of Discover's LTO batteries allows for increased low temperature performance. This extra surface area allows the electrons to enter and exit the active material faster, thus making it possible **to charge and discharge the battery very rapidly with very little internal resistance giving** these batteries a **much better low-temperature performance** in comparison to other battery technologies. Due to these low-temperature discharge characteristics Discover's Extreme Series batteries are able to provide up to 80% of their rated C1 capacity at a mere -20°C/-4°F.





Guidance for Discover LTO Low Temperatures Discharge Performance

Lithium starter batteries

High-energy lithium batteries are design for deep-cycling and are "NOT" generally" suitable for starting use!

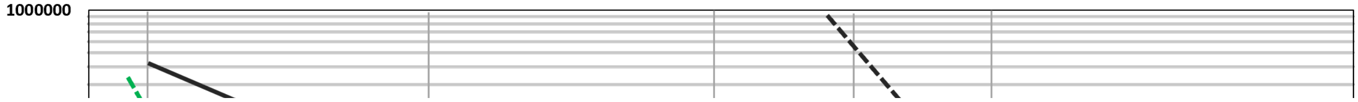
For more than a few reasons, you should be wary of claims made by companies selling Lithium batteries as starting batteries or as dual-purpose starting/cycling batteries.

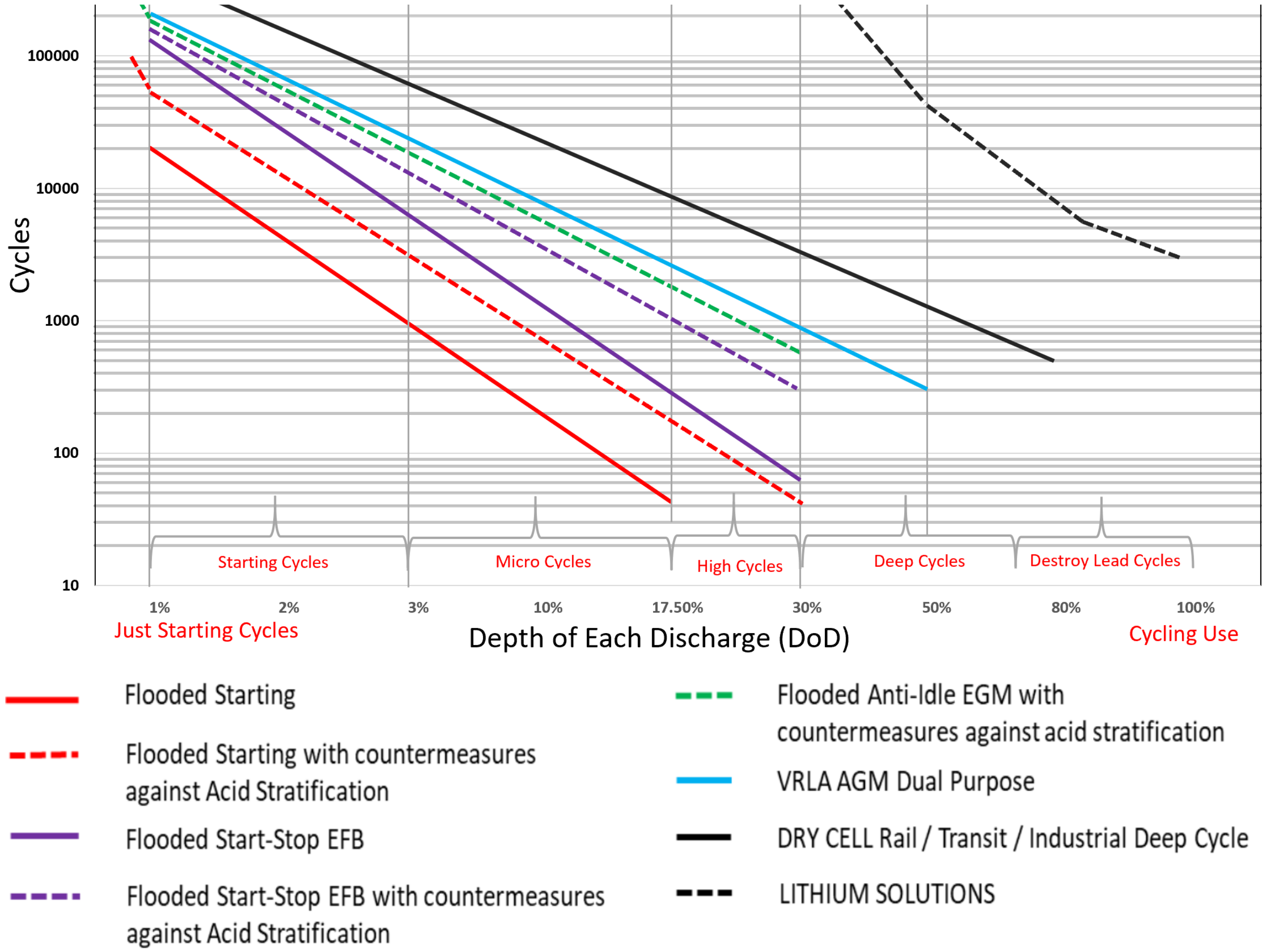
- It is **"extremely"** unlikely that any lithium battery offered for sale in the market as a "primary" starting battery will have the required **safet y certifications** you should be looking for when making your buying decision! For Lithium batteries to pass the required safety and performance certifications, stringent tests are performed on the battery's Battery Management System (BMS). The BMS is essentially an advanced protection system that prevents the battery and battery's cells from being operated outside of their safe limits.
- For a high-quality *high-energy* deep-cycle lithium battery to work as a *high-power* starting battery the BMS high current protection circuits would need to be switched off.
- Actual built-for-starting-purposes Lithium batteries use *"high-power"* lithium cell technology. They are usually low capacity (30Ah to 50Ah) batteries that can be discharged at 20 to 30 times the their rated capacity (20C or 30C). When installed they are normally installed in places that are not exposed to high temperatures so if in a vehicle as a backup battery they are normally in the trunk or under a seat but not in the engine bay.
- No matter what anyone tries to tell you, *high-power* lithium technology is not suitable for deep cycle applications; *high-power* lithium technology does not handle high temperatures well, and *high-power* lithium technology does not provide the long life expected of advanced technology buyers in deep-cycle applications.
- A lithium battery offered as a starting battery might only have a protection circuit (PCS) that does not even try to protect from over current events. **Do not buy this battery!**
- Robust high-quality *"high-energy"* deep-cycle Lithium technology degrades quickly if discharged at high C rates (current) such as is required by a *high-power* starting battery.
- High C Rate *high-power* Lithium technologies (10xC or 20xC) degrade quickly at the high temperatures typical of under the hood or engine room installations and they do not have the high-cycle life that deep-cycle *high-energy* battery buyers are looking for.
- Without highly engineered electronic operating controls such as in OEM automotive applications High C Rate lithium technologies are not safe enough for use in most applications. This is why when used in these OEM applications sophisticated temperature, voltage and current management systems are included.
- If you wish to use your high-quality *high-energy* deep cycle lithium battery for starting, confirm that the peak starting current (peak starter draw) is less than the peak surge current rating of the lithium batteries BMS. If you confirm this to be true, you are good to go. **NEVER DISABLE A LITHIUM BATTERIES BMS PROTECTION CIRCUITS.**
- Do not consider using a deep-cycle lithium battery as your primary starting battery particularly if you have large or hard starting engines.
- Do not consider using a lithium battery as your primary starting battery if it will be operating at high temperatures

Discover builds a wide variety of lithium and lead-acid batteries

We have been doing this since 1949. Discover has a complete range of purpose-built lithium and lead-acid battery solutions for a wide variety of Transportation, Marine, RV/Caravan, Work Vehicle, Commercial Truck, Bus/Rail/Transit, Motive and Mobile Power, Renewable and Stationary /Standby applications. Each technology is more or less suitable for starting or cycling use. Please trust us when we say that choosing the right combination of batteries for your application is best and will save you money. Choosing one technology to try to do different things will end up costing you money.

Starting & Cycling Ability of Lead Acid & Lithium* Batteries





***For various reasons high-energy lithium batteries are not generally suitable for starting use!**

Can I charge my lithium battery with an alternator?

If you are considering using your vehicle or vessels alternator as a charging source for your lithium battery you must consider the following:

Will your existing alternator handle the load a lithium battery will put on it?

- Unlike a lead-acid battery the internal resistance and corresponding voltage of a lithium battery does not rise until it is nearly 95% fully charged. This can cause alternators to run longer at full out-put which can cause alternator burnout.
- The length of a time a lithium battery can draw a constant current at or above the alternators max output can exceed the design parameters of the alternator. This can cause the alternator to over heat and burn-out.

- Alternators are internally cooled by a fan on its rotor. Lithium batteries will draw a high charge current at all times. Alternators are prone to burn-out at low RPM when charging lithium batteries at high currents.
- If you have a large alternator that can easily output more than the load the lithium battery(s) will request it may not be subject to burnout.
- Depending upon your lithium battery bank capacity, this may require a heavy duty alternator capable of running at a high output across various RPM all day and possibly for many days.
- If you have a large alternator that can easily output the draw a lithium battery will put on it, it must still be temperature compensated throughout its RPM range to avoid overheating and burnout.
- Even a heavy duty alternator may need current limiting as well temperature compensation to avoid premature failure.
- For any other alternator it would be wise to consider some kind of current limiting to prevent it from self destructing when charging Lithium Batteries at high output for an extended time.

Does your alternators output in amps exceed the maximum current limits of the lithium battery?

- **CHECK IT!** Other than choosing an alternator with a maximum output equal to the maximum draw a lithium battery can put on it - or at least 1x the batteries amp-hour capacity - choosing a temperature sensing alternator that has an external programable regulator - capable of communicating with your lithium battery - offers the easiest way to limit the current and protect your investment.
- With temperature sensing, if the alternator gets too hot the temperature adjusting regulator dials the alternator output down to keep it within its operating temperature limits preventing it from burning out.
- In all cases the alternator output cannot exceed the maximum safe continuous charging current limit of the lithium battery's BMS. **CHECK IT!** You should never be using a lithium battery without a certified BMS and no responsible company would be selling a lithium battery without a certified BMS….. **ESPECIALLY IN APPLICATIONS BEING CHARGED BY ALTERNATORS!** For maximum battery life and to protect the electrical system the alternator output should not exceed the batteries recommended charge current and it would be best if the alternators maximum output was no more than 50% of the batteries rated capacity (50 amps for a 100AH battery).
- The charging systems regulator cannot allow the voltage to rise higher than the BMSs preset maximum voltage limit. If the BMS is forced to protect due to over current or over voltage faults while the alternator is still charging, the potential voltage snap-back can back-feed and destroy the alternators diodes.

Charge Voltage Regulation when using an alternator to charge Discover's lithium batteries

Voltage regulate your alternator at the lithium batteries maximum charge voltage?

This is normally only possible with an externally regulated alternator. When the regulator is turned off the alternator can no longer charge the battery. NOTE that in this case the alternator will not be able to charge any other batteries connected to the charging system. NOTE also that your lithium battery will need to be able to communicate with the voltage regulator in order for it to safely stop the alternator.

All of Discover's lithium solutions have published recommended charge voltages. Most alternators will not be able to get the lithium battery to that voltage until the battery is nearly full. When it does get to the full voltage the BMS (Battery Management System) will act to protect the battery and will interrupt and isolate the battery from the circuit as it shuts off the charge to the battery. This may damage the alternator and potentially other equipment in the electrical system

Lead-acid batteries are essentially dumb and do not speak up when they are absorbing load dumps or voltage spikes or are otherwise being used and abused. For safety and to protect the users investment, high-quality lithium solutions are designed to be smart smart and to prevent any type of operation outside of their pre-set operating parameters.

Along with our desire to educate lithium technology buyers, Discover has a wide variety of integration technologies that can assist you as you adopt this new and exciting technology.

Temperature sensing is required when using an alternator to charge lithium batteries in cold weather environments below 0°C/32°F

For safe operation in below-freezing conditions, without the lithium batteries BMS being able to communicate with the alternators regulator that is programmed to temperature adjust charge currents when necessary, the only solution is to heat the batteries to above freezing before charging using a thermal heating blanket or by locating a heater near the battery.

Discover's lithium AES and PRO series batteries are purpose-built with LYNK Port features that allow the batteries BMS to communicate with a wide variety of chargers, motor controllers, SOC gauges and most importantly advanced voltage regulator technology. This advanced feature allows smart regulator technology to utilize exact current, voltage and temperature information to precisely manage the alternator.

Smart voltage regulators for lithium batteries.

One of the most recent entrance into the advanced smart regulator category comes from the **Wakespeed corporation** in Anacortes Washington, USA.

WS500 Alternator Regulator
(Shown with P-Type Wiring Harness)

At the time of this publishing, the Wakespeed WS500 is the only alternator regulator that we are aware of that can process the necessary current, voltage and temperature data required to precisely charge from 12V to 48V Lithium Iron Phosphate LiFePo$_4$ (LFP) batteries and battery banks.

The WS500 can also be connected to a current shunt to monitor current flow to and from the batteries, enabling the regulator to control charging based on a combination of system voltage and amperage delivered from the alternator to the batteries. The WS500 can also monitor alternator and battery temperatures and modify charging output to ensure optimal safety and charging performance. When connected to Discover's BMS via the available LYNK ports system, the WS500 can process critical voltage, current and temperature data via the CAN J1939 pathway and be able to safely turn off the alternator before the BMS protects. Even if you had a 400A alternator the WS500 can control the alternator current limit to the BMSs maximum current limits.

The **Balmar MC-614-H** multi-stage voltage regulator provides a high degree of charging safety and control for many types of 12-volt batteries. Amongst other features, www.balmar.net states that the most recent version of the MC-614-H voltage regulator includes charging ability for Lithium Iron Phosphate LiFePo4 (LFP) batteries. However, without manual programming/intervention it is not clear how the Balmar MC-614-H is capable of safely turning off the alternator before the BMS protects because there is no way for it to know what is actually happening inside the battery. Balmar makes the following statement in their installation operations manual for the MC-614-H:

"Many LiFePO4 batteries have a Battery Management System (BMS) that may disconnect the battery from the alternator as a protective action or when charging is complete. The regulator must be shut down before the battery is disconnected .Running an alternator without a battery will damage the alternator and may damage any attached systems. This is doubly true if the battery can be disconnected during high current charging, causing a load dump. The load dump can easily cause a high voltage spike which will destroy the alternator's rectifier, at minimum. This is not a warrantable failure. To reiterate: THE ALTERNATOR MUST BE SHUT DOWN BEFORE DISCONNECTING THE BATTERY. THE ONLY SAFE WAY TO SHUT DOWN THE ALTERNATOR IS TO TURN OFF THE REGULATOR. The preferred method of turning off the regulator is disconnecting the regulator's ignition (brown) wire, but if used as an EMERGENCY ONLY shutdown, disconnecting the regulator's power input (red) wire in addition to the ignition wire has a very low chance of damaging the regulator."

*Balmar further states: "LFP batteries will readily accept a damaging amount of current. Applying too much charge current to a LFP battery will, at the very least, permanently damage the battery's capacity. It is CRITICAL to ensure that the alternator is not capable of exceeding the maximum continuous charge current rating of your battery (or batteries). As always, check with your battery manufacturer for specifics. Your battery manufacturer may supply you with a "C-rate" for charging and discharging. The maximum amount of charging current your battery can safely handle is determined by multiplying the "C-Rate" by the capacity of the bank. i.e. 4x 100Ah 12V batteries rated at 0.5C charge = 400 Ah * 0.5C = 200amps MAX. If your alternator is capable of outputting more current, at any time or condition, than the battery (or batteries) can handle, you may use the Belt Manager feature on the MC-614 to lower the maximum field drive output, and thereby lower the maximum alternator output current. See page 10 of your regulator manual for details and instructions. Be aware that it is not an exact 1:1 correlation between field output and alternator output, so start with more reduction (lower output) than you think you need and adjust accordingly."*

Do not interrupt or disconnect the alternator's output while it is charging a lithium battery!

Because with nowhere for the power to go when the BMS suddenly interrupts and disconnects the battery from the system leaving the regulator no time to react, the internal voltage at the alternator will rise quickly initiating an inductive voltage spike (load dump) which may destroy the alternator diodes and/or other equipment on the electrical system.

Within the vehicle or vessels electrical system the lead-acid starting battery acts like a sponge or a balloon letting amps out while providing the momentary surges of power needed when electrical devices are turned on or the starter engages, and absorbing momentary excess power dumps from the system when devices are turned off. The lead-acid battery prevents major and sudden voltage (pressure) changes in the system. Having the lead-acid battery in the circuit to act as a cushion will protect your alternator from the inductive voltage spikes that destroy alternator diodes.

Unlike a lead-acid battery, high-quality lithium batteries are built with an internal battery management system(BMS). When the lithium battery is full, to protect the battery, the BMS will quickly cutoff the charge interrupting the connection between the battery and the alternator. In this case - *w ithout a highly advanced voltage regular* - **there must be another lead-acid battery in the electrical circuit for the alternator to charge. (dump its remaining load)**

Protect the alternator by installing a lead-acid battery in the system along with the lithium battery!

Make sure to also install a lead-acid battery in the electrical circuit to protect the alternator, other components connected to the system and the lithium battery. There must be another lead-acid battery in the electrical system to be able to absorb the inductive spikes (load dumps) that will result when the lithium battery BMS interrupts the charging process. Install the lead-acid battery closer to the alternator than the lithium battery.

Use a DC to DC charger to isolate and protect Protect your lithium battery and your electrical systems!

A DC to DC battery charger will pull power from your alternator via your starter battery and safely charge your auxiliary lithium battery.

input DC2DC options and information

Lithium batteries for cold weather

Many lithium battery users are unaware that consumer-grade Li+ batteries cannot be charged below 0°C/32°F. Although the battery may appear to be charging normally, plating of metallic lithium is certainly occurring on the anode if the battery is being charged at freezing temperatures. The severity of the damage is directly proportional to the charge rate. While this negative process is *somewhat* reversible for negative plate sulfation in a lead-acid battery, Li+ plating is not reversible and cannot be repaired by cycling or conditioning a Li+ battery. Once developed, Li+ batteries with lithium plating are more vulnerable to catastrophic failure if exposed to vibration or other stressful conditions.

Suffice it to say that a change in temperature will change the viscosity of the electrolyte and porosity of the active materials and accordingly the chemical reaction speed and efficiency of the Li+ movement is impacted as they shuttle back and forth through the electrolyte and into the active materials of the cathode**(+)** or anode**(-)** during the discharge and charge process.

So Li+ batteries are faster charging at warmer temperatures than at cool temperatures as the electro-chemical process diffuses progressively faster as temperature rises and slower as temperature falls. At temperatures below 0°C/32°F the Li+ does not diffuse fast enough at the anode interface for safe and effective charging to continue in most Li+ battery types. For charging at cold temperatures heating blankets or internal BMS controlled circuitry or different purpose-built Li+ cell technology must be used that allows for charging at below zero temperatures.

All of the reactions taking place in the electrochemical process are related to the relationship between the speed or rate of the charge or discharge activity and the temperature before, during and at the end of the charge or discharge process.

Discover Lithium Solutions for cold weather charging

To make lithium-ion batteries safer and more practical for low-temperature use, Discover has developed two Lithium Solution series that can be charged “effectively” at low temperatures. The first solution features proprietary cell technology that allows for cold temperature use down to -40° C/-40°F in the case of the Discover EXTREME series. The second solution is the Discover PRO series that incorporates proprietary power electronics controlled heating technology that allows for cold temperature use down to -20°C/-4°F.

Discover EXTREME Series Lithium Titanate (LTO)

Discover’s Mission Critical EXTREME battery series utilizes advanced cell chemistry to adjust the battery electrolyte and to replace the carbon-graphite oxide typical of Li+ technology with a titanium-based oxide. Oxides that utilize proprietary lithium nanocrystals form a spinel 3D crystalline structure that increases the active surface area of a Discover Lithium **EXTREME** battery to approximately 100 sq. meters per gram compared with about 3 square meters per gram within the active material of a standard Li-ion battery. This increased surface area allows the battery to charge and discharge faster; operate safely at extreme temperatures without negative consequences, and to deliver enhanced overall dependability and life in the harshest high cost to serve environments with operating temperatures in the range of -40°C/-40°F to 80°C/176°F and,

Discover PRO Series Lithium Iron Phosphate

Discover’s Low-temperature PRO series batteries utilize advanced power electronics to make Li+ batteries safe for low-temperature use. Discover PRO series models feature proprietary internal components and BMS controlled heating algorithms to provide effective charging at temperatures as low as -20°C/-4°F without the need for any additional external components such as heating blankets. Safe and easy to use, connect the charging source and let the battery management system do the rest. The charge time will be extended by the time it takes to pre-heat the battery to its safe-to-charge temperature. The increase in charge time will be dependent upon the relationship differential of the ongoing ambient temperature of the installation and the internal battery temperature during pre-heat and charge. Suffice it to say that because time is needed to pre-heat the cells before the full charge rate will be allowed, the charging process in below freezing temperatures will take longer.

Protecting your Lithium Battery Investment

IMPORTANT: PROPERLY PROTECT YOUR LITHIUM SOLUTION INVESTMENT WITHIN THE OVERALL INSTALLATION

1. Proper grounding, isolation, fusing, breakers and disconnects must be correctly used throughout the balance of systems to effectively isolate and protect all components of the system against faults, short circuits, reverse polarity or component failure.
2. The sizing of all system components should be determined using established electrical codes and standards and evaluated by certified engineers, electricians, and licensed installers.
3. Although every Discover Lithium Solution has system protection and fusing components such as BMS, PCS, Fusing, Relays, Contactor, Controls, Communication, Firmware and Software built-in to protect the Lithium Solution from operation outside of its pre-set limits, addition balance of system protections must always be included such as charge controllers that protect the Lithium Solution battery from high voltage sources such as open PV (Solar Panel) voltage.
4. The internal Lithium Solution circuitry, protection and fusing will not protect it from extreme electrical phenomena. Failure to adequately incorporate and protect the the Lithium Solution battery within the balance of system components will void the Warranty.
5. Always check the Lithium Solutions constant power capabilities against the maximum starting power needs of connected loads.

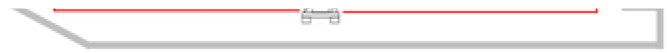
CAUTION: DC MOTOR BREAKING VOLTAGE SPIKES

1. In operation DC motors build up a lot of energy (like a rubber band). If a Discover Lithium Solution battery (AES, PRO, BLUE, EXTREME) is allowed to reach its low voltage *"fault"* level and the BMS is forced to disconnect or interrupt the load, this built up load energy has to go somewhere (the stretched rubber band has to release the energy by "snapping-back")! This energy cannot be used as current or amperage flow any longer (because the BMS has entered protection mode) so the energy converts to high voltage spikes when the DC motor is breaking or stopping. This happens quickly and aggressively and can damage the BMS electronics. Direct connection to DC motors without low voltage cut-outs, proper safety protection, motor controllers, and external motor voltage clamping systems (such as high power anti-parallel diodes or braking resistor systems) may result in damage to the internal pack protection system which will result in unsafe situations and will void the warranty

WARNING: DC MOTOR INRUSH CURRENT

1. A 1 horse power DC motor will continuously draw 746 watts of energy. At 24 volts that is over 30 amps (746 / 24 = 31). When typical induction motors become energized, a much larger amount of current (in amps) than normal rushes into the motor to set up the magnetic field surrounding the motor to overcome the initial load. As the motor overcomes the initial resistance and increases in speed, the current draw subsides to a steady state level that equals (a) the current required at the supplied voltage to supply the motor load, plus (b) losses to windage, cabling and friction in the motor and in the load. Initial inrush currents normally reach 3 x the steady state level but can easily equal 6 times the horse power rating in watts of the motor. INRUSH CURRENT LIMITORS MUST BE USED WHEN CONNECTING TO DC MOTORS TO PROTECT THE BATTERIES BMS and electronics. Failure to do so may result in damage to the internal pack protection system which will result in unsafe situations and will void the warranty

Lithium vs. lead-acid batteries for trolling motors



Component #	Description
1	Trolling Motor (12V, 24V, 36V, or 48V)
2	Discover Lithium Battery Solutions (12V, 24V, 36V, or 48V options that can be paralleled for more capacity)
3	Negative DC wiring (Wiring size is dependent on current carrying needs - the higher the voltage the smaller the cable size can be)
4	Positive DC wiring (Wiring size is dependent on current carrying needs - the higher the voltage the smaller the cable size can be)
5	Circuit breaker (Sizing is dependent upon current protection needs) Always locate in the positive circuit and as close as possible to the energy source.
6	Easy Cable Connect/Disconnect (for easy disconnect and removal of trolling motor)

Trolling motor thrust vs. horsepower explained

Pounds of thrust

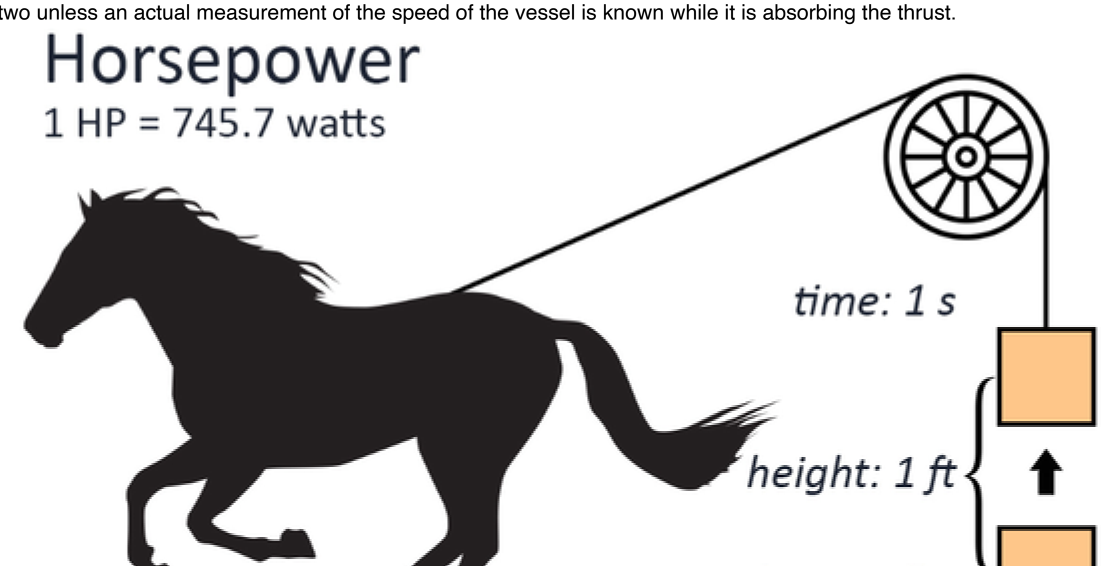
is a Static-Force measurement that references the amount of force that can be called upon to move a static object. Most trolling motors are sold using a POUNDS-OF-THRUST size rating which is a reference for how powerful the motor is.

A general rule-of-thumb suggest you will need 1 kilogram or 2.2 pounds of thrust for every 45 kilograms or 100 pounds of fully loaded boat weight in calm waters. Experienced uses suggest that if you are planning to use you trolling motor in tidal waters or in areas that will be influenced by wind and currents you should purchase a motor with higher thrust ability.

Horsepower

is a measurement of the ability to perform work over a period of time. 1 (one) Imperial horsepower is based on the ability to move 550 pounds one foot in one second (LB f/s.). 1 (one) imperial horsepower converts to a power rating of 745.69987 W (746 watts). 1 (one) Metric horsepower is based on the ability to lift 75 kg (at standard gravity) one meter in one second (N m/s). 1 (one) Imperial horsepower converts to a power rating of 735.49875 W (736 watts).

Since Thrust is a static force measurement and Horsepower is a measurement of work over time it is difficult to make a direct comparison between the two unless an actual measurement of the speed of the vessel is known while it is absorbing the thrust.



weight: 550 lbs

Power rating

While there is no perfect direct comparison between Thrust and Horsepower you can reliably estimate the horsepower of a given electric trolling motor by multiplying the voltage of the motor by its maximum amp draw to find its maximum power rating in watts.

The wattage power rating result can then be divided by the power rating of 1 imperial horsepower (746 watts) to give you an imperial horsepower estimate for the motor as every 746 watts is roughly equivalent to 1 imperial horsepower.

The power rating, in watts indicates the rate at which the device converts electrical energy into another form of energy, such as light, heat, or "MOTION". Please understand that energy will be lost to resistance from wiring, wiring distance, wiring connections, bearing losses and more so the actual available energy for the motor it self will be lower.

Trolling motor pound thrust to horsepower conversion table

Motor Thrust Rating	Motor Voltage	Peak Amp Draw	Horse Power Reference
30	12	30	.48
35	12	32	.51
40	12	35	.56
45	12	40	.64
50	12	50	.80
55	12	52	.83
60	12	55	.88
65	12	58	.93
70	12	62	1.00
70	24	40	1.28
75	24	45	1.44
80	24	50	1.60
85	24	55	1.76
90	24	60	1.93
100	36	40	1.93
110	36	45	2.17
120	36	50	2.41

Trolling motor circuit breaker and wiring guide

Choosing the right wire size and safety circuit breaker for your DC electrical project is important. The American Boat and Yacht Council (ABYC) publishes guidance and detail to help boatbuilders and installers determine safe and proper wire and circuit breaker sizing (ABYC-E-11).

As specified by ABYC standards, wiring should always be stranded rather than solid and always tin-plated copper. In addition, wire insulation ratings must be considered. A lower rating will decrease the current-carrying capacity of the wire. Chose wire with a rating at or above 220°F/105° C

Wire/cabling should be sized for allowable voltage drops of no more than 5%. Wiring/cabling supporting critical circuits should be sized to as close to zero allowable voltage drop as is possible but definitely no more than 3%.

CAUTION: An over-current protection (circuit breaker or fuse) must be installed. Safety requirements dictate that each ungrounded current-carrying conductor (wiring/cabling) must be protected by a manually reset, trip-free circuit breaker or fuse. The type (voltage and current rating) of the fuse or circuit breaker must be sized accordingly to the maximum load. The table below gives recommended guidelines for circuit breaker sizing. Maximum amp draw plus 20% is a good guide to sizing a circuit breaker.

Circuit breakers should be properly sized, installed within the positive circuit and as close as possible to the energy (battery) source.

NOTE: Volts x Amps = Watts. The higher the system voltage is, the lower the amps will be resulting in smaller wire/cabling and circuit breaker needs.

		Peak Amp Draw	Horsepower Rating		

Motor Thrust Rating	Motor Voltage			Circuit Breaker Size	Wire Sizing for Various Round Trip Cable Runs (Total cable run Length to and from motor)			
					20 Feet 6M	30 Feet 9M	40 Feet 12M	50 Feet 15M
30	12	30	.48	12V 35A	6AWG	4AWG	4AWG	2AWG
35	12	32	.51	12V 40A	6AWG	4AWG	4AWG	2AWG
40	12	35	.56	12V 45A	6AWG	4AWG	4AWG	2AWG
45	12	40	.64	12V 50A	6AWG	4AWG	4AWG	2AWG
50	12	50	.80	12V 60A	4AWG	2AWG	2AWG	1AWG
55	12	52	.83	12V 65A	4AWG	2AWG	1AWG	0AWG
60	12	55	.88	12V 60A	4AWG	2AWG	1AWG	0AWG
65	12	58	.93	12V 70A	4AWG	2AWG	1AWG	0AWG
70	12	62	1.00	12V 75A	2AWG	1AWG	0AWG	2/0
70	24	40	1.28	24V 50A	6AWG	4AWG	4AWG	2AWG
75	24	45	1.44	24V 55A	4AWG	2AWG	2AWG	1AWG
80	24	50	1.60	24V 60A	4AWG	2AWG	2AWG	1AWG
85	24	55	1.76	24V 70A	4AWG	2AWG	1AWG	0AWG
90	24	60	1.93	24V 70A	4AWG	2AWG	1AWG	0AWG
100	36	40	1.93	36V 50A	6AWG	4AWG	4AWG	2AWG
110	36	45	2.17	36V 50A	4AWG	2AWG	2AWG	1AWG
120	36	50	2.41	36V 60A	4AWG	2AWG	2AWG	1AWG

Trolling motor battery sizing facts

Fact 1: Only true deep-cycle lead-acid or high-energy lithium batteries should be used to power trolling motors

When choosing a battery to power your trolling motors do not settle for starting or dual-purpose lead-acid batteries or high-power lithium battery options. High-power lithium technologies are designed for high-power bursts of energy and not for long duration high-energy discharges. Just like lead-acid starting batteries are designed for high bursts of starting power and not for long duration discharges of sustained energy like true deep-cycle batteries are designed to provide.

Fact 2: Battery capacity and life is affected by temperature.

While 100% of a lead-acid battery's rated capacity is available at 77°F/25°C, less than 85% is available at 60°F/15°C. Just as temperature affects your capacity to do work, temperature affects a battery's potential capacity to do work. The temperature effect on a battery's state of charge is defined as the ratio of available capacity at different temperatures compared to the overall potential capacity at a fixed reference temperature. (usually the 20-hour or 5-hour potential capacity at 20°C/68°F or 25°C/77°F).

Remember that all of the reactions taking place in the battery are related to the relationship between the speed or rate of work (the discharge current) and the temperature during the discharge period.

The speed or rate of the discharge current also affects the totality of the temperature-related impact on the batteries' state of charge or ability to do work. Due to the Peukert effect, the higher the discharge current above the batteries reference rate, the lower the total available capacity will be at any temperature below the reference temperature (usually 20°C/68°F or 25°C/77°F). While lithium batteries are affected by the Peukert effect the impact is minimal when compared with lead-acid when lithium is being discharged at comparable discharge rates.

Battery life is also negatively affected as temperatures rise. Every battery technology (lead-acid and lithium) is affected by temperature. In fact, its the law* that for every 10° increase in temperature above 25°C/77°F the chemical reaction inside your battery will approximately double cutting battery life in half *. Eliminating or mitigating the high-temperature environments of battery compartments will reduce the related electrochemical reactions that accelerate premature capacity loss and battery failure. Lead or Lithium, no matter the battery technology, Heat Kills all Batteries!

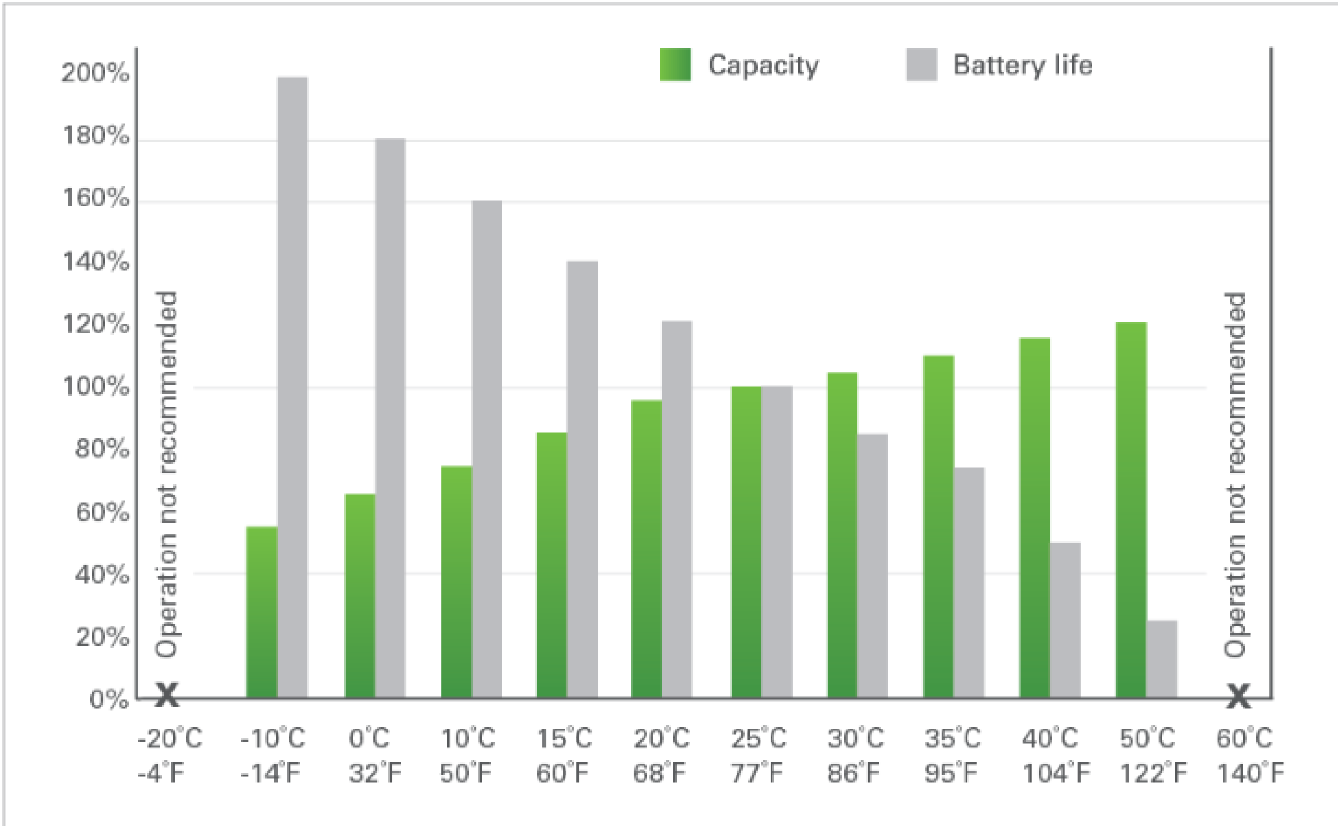
This same Law explains why as temperatures drop your battery's available capacity drops along with it as the chemical reaction inside your battery decreases. Keeping batteries cool will work to reduce the related electrochemical reactions that accelerate premature capacity loss and battery failure.

***Arrhenius' Law**

While the effect that temperature has on battery life in a controlled test environment is clearly defined by the Arrhenius Law, in the real world your battery may not be subject to a high steady-state temperature. The following chart gives you a *reasonable estimation* of the affects of temperature on battery life based on our experience.

Please be sure to consider your operating temperature when sizing your battery purchase and estimating you run time.

TEMPERATURE EFFECTS ON CAPACITY



Fact 3: Lead-acid battery useable capacity changes as the rate of discharge increases.

Due to the Peukert affect a typical deep-cycle lead-acid battery that provides 100AH when discharge at the 20 hour rate of 5 amps, will provide only 70Ah of useable capacity if discharged at 35Amps.

Lead-acid battery USEABLE CAPACITY to 100% DOD is reduced as the rate of discharge increases (Typical 100AH lead-acid battery)			**Lead-acid energy to weight ratio at 100% DOD**
Total Useable Capacity to 100% DOD	Rate of Discharge	Discharge time to 100% DOD	66lbs/30Kgs
100AH	5 Amps	20 Hour (C20)	18 watts per pound
95AH	9.5 Amps	10 Hours (C10)	17 watts per pound
87AH	17 Amps	5 Hours (C5)	15 watts per pound
78AH	26 Amps	3 Hour ((C3)	14 watts per pound
70AH	**35 Amps**	**2 Hour (C2)**	**12 watts per pound**
65AH	65 Amps	1 Hour (C1)	11 watts per pound

Up to approx. a 40-45 minute rate (1.25-1.50 x the batteries rated capacity), deep-cycle Lithium high-energy battery technology does not suffer from the Peukert effect.

Lithium battery USEABLE CAPACITY at 100% DOD is unchanged as the rate of discharge increases (Typical 100AH lithium battery)			**Lithium battery energy to weight ratio at 100% DOD**
Total Useable Capacity to 100% DOD	Rate of Discharge	Discharge time to 100% DOD	28lbs/12.7Kgs
100AH	5 Amps	20 Hour (C20)	45 watts per pound
100AH	10 Amps	10 Hours (C10)	45 watts per pound
100AH	20 Amps	5 Hours (C5)	45 watts per pound
100AH	33 Amps	3 Hour ((C3)	45 watts per pound
100AH	50 Amps	2 Hour (C2)	45 watts per pound

100AH	100 Amps	1 Hour (C1)	45 watts per pound

Fact 4: Trolling motor peak amp discharge rates can easily equal 35 amps which is equivalent to a 2 Hour rate of discharge for the average 100AH C20 rated battery.

Most lead-acid battery manufacturers recommend sizing battery storage applications for a maximum depth of discharge (DOD) of 50%…. but certainly no more than 80% DOD.

Lead-acid battery USEABLE CAPACITY at 50% DOD is reduced as the rate of discharge increases (Typical 100AH lead-acid battery)			**Lead-acid energy to weight ratio at 50% DOD**
Total Useable Capacity to 50% DOD	Rate of Discharge	Discharge time to 50% DOD	66lbs/30Kgs
50AH (50% of100AH)	2.5 Amps	20 Hour (C20)	9 watts per pound
47.5AH (50% of 95AH)	4.75 Amps	10 Hours (C10)	8 watts per pound
43.5AH (50% of 87AH)	8.7 Amps	5 Hours (C5)	7 watts per pound
39AH (50% of 78AH)	13 Amps	3 Hour ((C3)	7 watts per pound
35AH (50% of 70AH)	17.5 Amps	2 Hour (C2)	6 watts per pound
32.5AH (50% of 65AH)	32.5 Amps	1 Hour (C1)	5 watts per pound

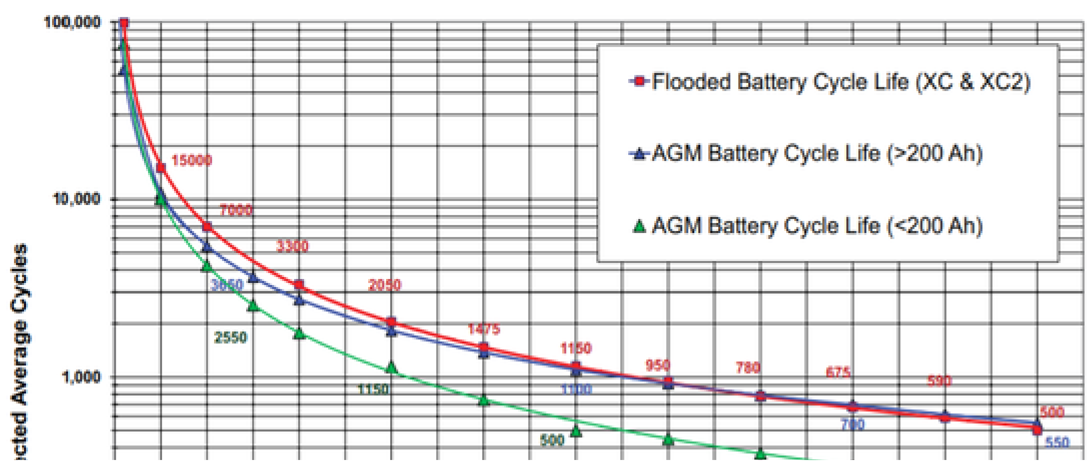
With Discover's Lithium battery technology for deep-cycle use what you see is what you can use. A Discover Lithium battery rated at 100Ah can be sized for 100Ah useable capacity or 100% DOD. Discover recommends system designers use a 90% DOD sizing guideline.

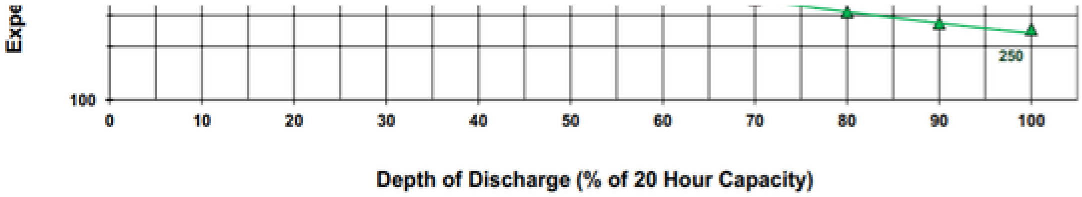
Lithium battery USEABLE CAPACITY at 100% DOD is unchanged as the rate of discharge increases (Typical 100AH lithium battery)			**Lithium battery energy to weight ratio at 100% DOD**
Total Useable Capacity to 100% DOD	Rate of Discharge	Discharge time to 100% DOD	28lbs/12.7Kgs
100AH	5 Amps	20 Hour (C20)	45 watts per pound
100AH	10 Amps	10 Hours (C10)	45 watts per pound
100AH	20 Amps	5 Hours (C5)	45 watts per pound
100AH	33 Amps	3 Hour ((C3)	45 watts per pound
100AH	50 Amps	2 Hour (C2)	45 watts per pound
100AH	100 Amps	1 Hour (C1)	45 watts per pound

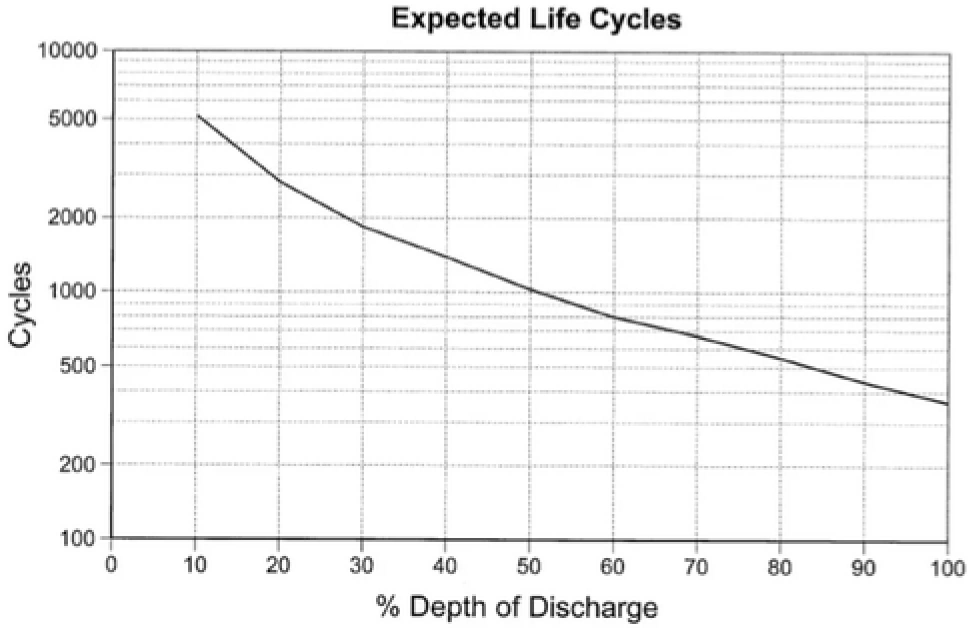
Fact 5: Lead-acid battery life is dramatically affected by depth of discharge.

Most high-quality lead-acid batteries will provide 50% fewer cycles at 100% DOD than can be achieved at 50% DOD in laboratory settings. Cycle life is a major issue because of a lack of understanding on the part of the user and a lack of absolute clarity on the part of the manufacturers. In the following manufacturer published graphs by US Battery, Lifeline, Trojan and Discover it is clear that battery life is affected by depth of discharge.

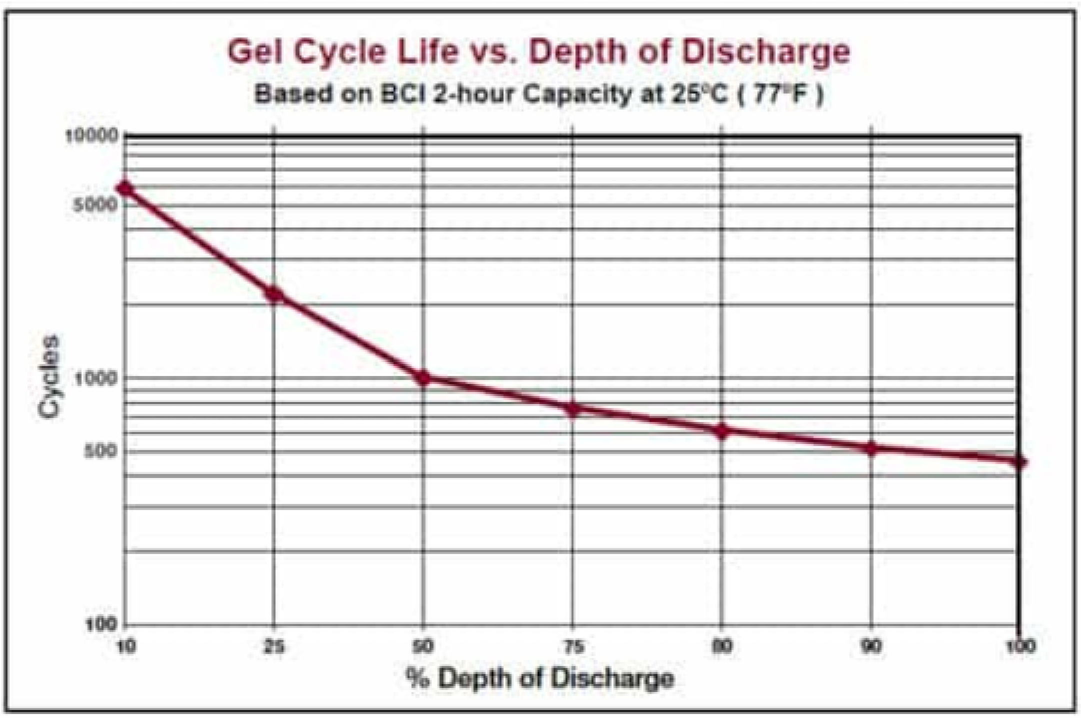
EXPECTED LIFE CYCLES VS. DOD (XC, XC2 & AGM)



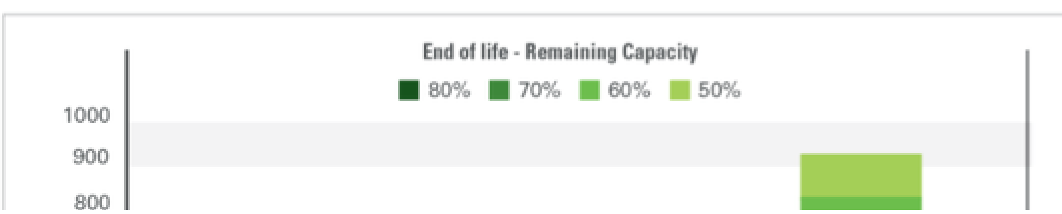


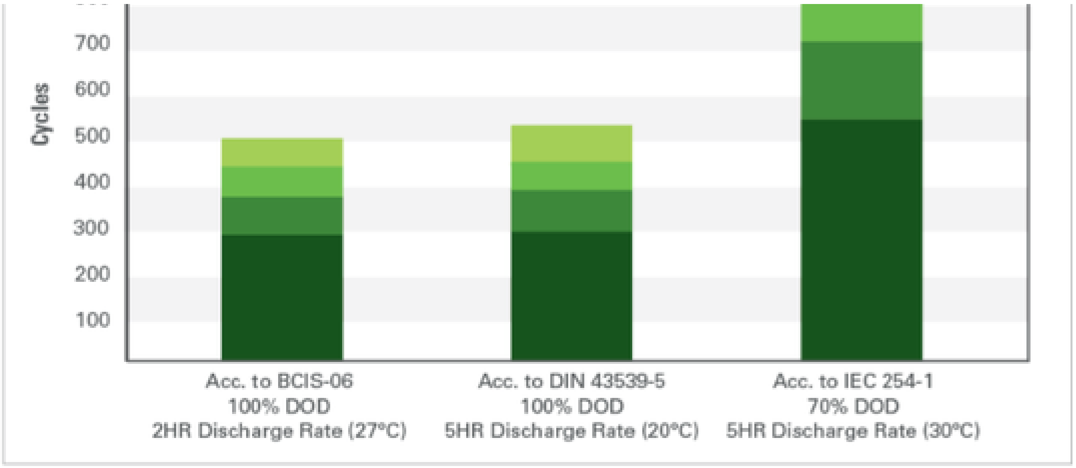


Test Conditions:
1. Discharge Voltage=1.75 Volts/Cell 2. Charge Voltage=2.40 Volts/Cell 3. DOD=100 % 4. Battery Temperature=25°C 5. End of Life=80 % of Capacity

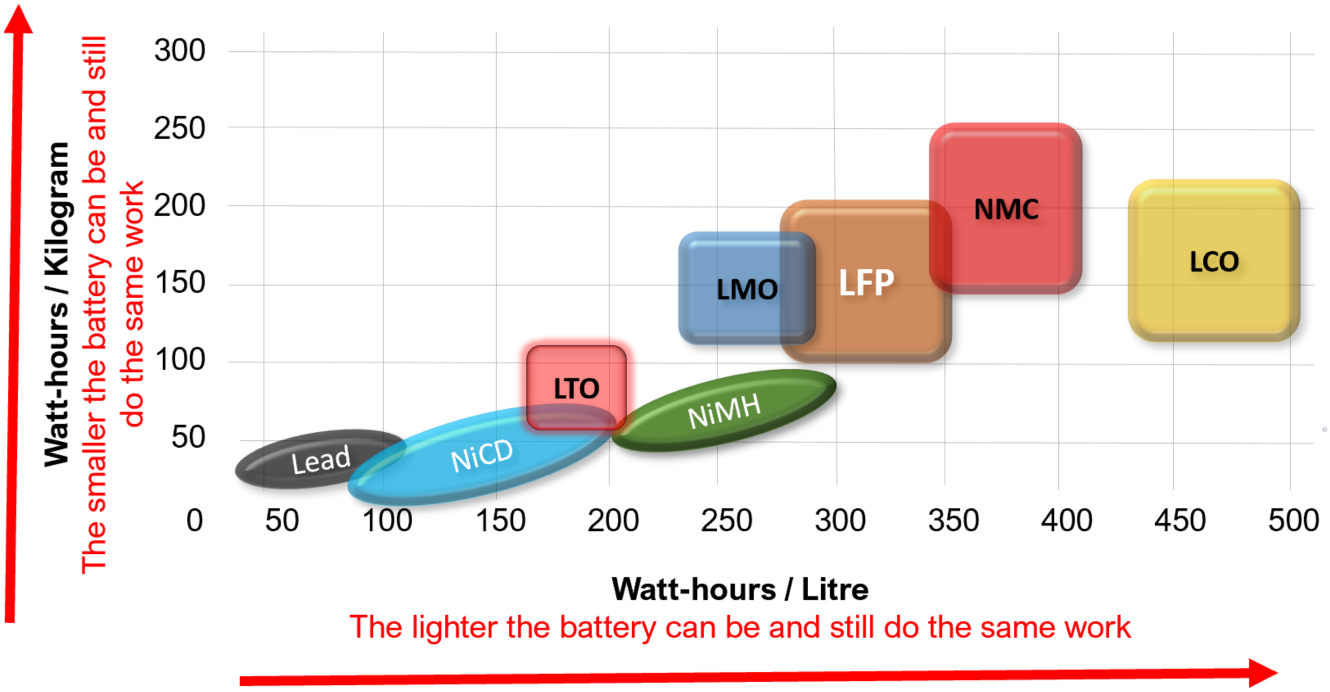


CYCLE LIFE VS. DEPTH OF DISCHARGE





Fact 6: Lead-acid batteries are heavy and their energy to weight ratios are low when compared to Lithium



Fact 7: Lead-acid batteries have long charge times and low charge efficiencies

To overcome their low coulombic efficiency (high average internal resistance to charge acceptance and absorption) Lead-acid batteries require an over charge of between 105% and 125% of the previous discharged capacity to reach a fully charged state. Removal of 50AH during discharge can require a charge of 62AH with 12AH being lost to resistance and heat. Lead-acid batteries that are repeatedly deeply discharged require an equalization charge at higher finishing voltages to overcome the internal resistance and to achieve a full and complete charge wasting energy and time.

As well as being an established fact it should generally be understood that the charge efficiency of flooded lead-acid batteries is non-linear and that it declines with increasing state-of-charge. Years of laboratory testing has established that from 0% to 70% SOC (+/-10%) the average charge efficiency is up to 90%; and that the incremental battery charging efficiency from 70% to 85% SOC is only 50%, and it continues to drop above 90% SOC.

Depending upon the charge rate and the lead-acid battery type, Discover's lithium battery solutions are up to 50% more charge efficient than new lead-acid batteries allowing for reduced charge times with the same size charger or smaller charging sources and/or greater utilization of renewable energy sources or generator time. As lead-acid batteries age, there dynamic charge acceptance continues to fall which causes their charge efficiency to drop even further.

Fact 8: Lead-acid battery life is dramatically affected by constant partial state of charge use

Lead-acid battery sustained capacity and life will be negatively affected by repeated deep discharges that are not immediately followed by a full and complete charge with proper countermeasures against acid stratification such as equalization charging

Lithium enjoys partial state of charge use and suffers no negative consequences from constantly being operated between a 80%-90% SOC and a 10%-20% SOC. Lithium technology does not suffer from acid stratification but lithium batteries benefit greatly from cell to cell balancing which should be designed into the batteries BMS.

Fact 9: Lithium battery technology is better than lead-acid technology for numerous reasons

Discover lithium battery solutions are less affected by temperature and will deliver a higher % of their capacity than lead-acid as temperatures drop

Discover lithium battery solutions do not suffer from the Peukert affect and will deliver 100% of their rated capacity regardless of the discharge rate up to 125%-150% (high-energy cell technology) of their rated capacity

Discover lithium battery solutions have a high energy density and will deliver 9x the high-rate energy to weight ratios of lead-acid batteries when lead-acid is properly sized for maximum life (50%-80% DOD).

Discover Lithium battery solutions are easy to charge and are up to 50% more charge efficient than lead-acid when using the same size charger and because of their low internal resistance can be effectively maintained with smaller solar panel arrays than lead-acid requires

Discover Lithium battery solutions do not suffer negative consequences from partial state of charge use and enjoy being stored in a partial state of charge condition between 50% SOC and 80% SOC

Lithium battery USEABLE CAPACITY at 100% DOD is unchanged as the rate of discharge increases (Typical 100AH lithium battery)			**Lithium battery energy to weight ratio at 100% DOD**
Total Useable Capacity to 100% DOD	Rate of Discharge	Discharge time to 100% DOD	28lbs/12.7Kgs
100AH	5 Amps	20 Hour (C20)	45 watts per pound
100AH	10 Amps	10 Hours (C10)	45 watts per pound
100AH	20 Amps	5 Hours (C5)	45 watts per pound
100AH	33 Amps	3 Hour ((C3)	45 watts per pound
100AH	50 Amps	2 Hour (C2)	45 watts per pound
100AH	100 Amps	1 Hour (C1)	45 watts per pound

Trolling Motor run time

To calculate maximum potential trolling motor run times at peak capacity:

1. For Discover Lithium Solutions use its published AH capacity rating. (We also publish Reserve Capacity Minute ratings)
2. For lead-acid use its published 5 Hour AH capacity rating. Typically lead-acid batteries are labeled with their 20 Hour capacity. DO NOT use its published 20 Hour AH capacity rating. If you cannot find a published 5 hour rating then de-rate the 20 Hour rating by 20% to arrive at its estimated 5 hour capacity. All true high-quality lead-acid deep-cycle batteries will have a published 5 hour rating.
3. De-rate the capacity by the manufacturers recommended or maximum allowable depth of discharge
    a. 50% is recommended for lead-acid (5 hour Battery capacity in amp hours x .50)
    b. 80% is maximum for lead-acid (5 hour battery capacity in amp hours x .80)
    c. 90% is recommended for lithium battery solutions (1 hour battery capacity in amp hours x .90)
4. Divide this capacity result by the maximum motor draw (Amps)
5. De-rate the result by 15% to allow for voltage drops and efficiency losses due to wiring/cabling, bearings, shafts, etc.
    a. For 100 AH (C5) lead-acid batteries: 100AH x 50% suggested or 80% maximum usable capacity / max motor draw x .85 = maximum “estimated run time result”
    b. For 100 AH Discover lithium solution batteries: 100AH x .90% usable capacity / motor draw x. 85 = maximum “estimated run time result”
6. Since you will not be using the motors maximum thrust at all times, the maximum “estimated run time result” will have a built in safety margin.
7. If you plan to add more electronics (GPS, Radio, VHF, fish finder, etc.) to your electrical system you need to add their combined draw to the maximum current draw in your calculation of “estimated run time result”.
8. **IT IS ADVISABLE TO HAVE A DEDICATED BATTERY FOR YOUR TROLLING MOTOR IF POSSIBLE.**

NOTE: If you record your initial run time (write it on the top of your battery) you will have a reference to compare your current run times against to help determine the battery/system state of health over time.

How to calculate battery capacity in Amp Hours

Deep Cycle batteries are sold with a wide variety of ratings.

- Reserve Capacity: The number of minutes a battery can deliver when discharged at a constant rate at 80°F (27°C) and maintain a voltage above 1.75 V/cell (10.5 volts for a 12V / 5.25 volts for a 6V battery).
    - Standard Minutes Reserve Capacity uses a 25 amp discharge rate
    - Heavy Duty Minutes Reserve Capacity uses a 75 amp discharge rate
- Amp Hour 20 Hour: The amount of amp-hours (Ah) a battery can deliver when discharged at a constant rate at 80°F (27°C) for the 20-Hour rate and maintain a voltage above 1.75 V/cell. (10.5 volts for a 12V battery and 5.25 volts for a 6V battery)
- Amp Hour 5 Hour: The amount of amp-hours (Ah) a battery can deliver when discharged at a constant rate at 86°F (30°C) for the 5-Hour rate and maintain a voltage above 1.75 V/cell. Capacities are based on peak performance.

For Example:

- Some of the most popular high-quality 12V Deep Cycle lead-acid batteries are rated at:
    - Amp Hour C20: 105AH (5.25 Amps per hour for 20 hours)
    - Amp Hour C5: 85AH (17 Amps per our for 5 hours).
        - **NOTE:** *the available capacity decreases as the hourly discharge rate increases from 5.25 to 17 amps.*
    - Reserve Capacity at 25A: 175 Minutes (2.91 hours at 25 amps per hour = 72.75 amp hours of capacity)
    - Reserve Capacity at 75A: 45 Minutes (3/4 of an hour at 75amps per hour = 56.25 amp hours of capacity)
        - **NOTE:** *the available capacity decreases as the hourly discharge rate increases from 25 to 75 amps*

Convert reserve capacity in to amp hours:

Many batteries only proved Reserve Capacity (RC) ratings. To convert RC ratings to AH Divide Minutes of Reserve Capacity rating by 60 minutes to determine “hours of Reserve Capacity”. Then multiply the result by 25A or 75A to arrive at the Amp Hour capacity rating at a 25A constant power discharge rate or 75A constant power discharge rate.

Lead-acid batteries vs Lithium batteries

For virtually all battery powered or battery backed-up applications including successful RV and Marine house battery bank designs it is essential to be able to predict the batteries useable capacity versus its rated capacity and how internal resistance and operating temperature will affect discharge/charge performance and life.

While there are several formulas such as Peukert’s empirical equation and Arrhenius’ Law - with there foundation in *mathematics* or *physics* - that can help with these predictions, none are practical or easy to apply by the average user… *let-alone an experienced engineer* with the patience and time to do so. The purpose of the following information is to provide simple, non-biased and easily confirmed (if you chose to do so) general guidance on the inter-relationship amongst:

· Available Capacity versus Operating Temperature

· Rated Capacity versus Useable capacity at different discharge rates

· Recommended useable capacity or depth-of discharge versus Design Life

· Charge Efficiency versus State-of-Charge or SOC

Fact 1. Battery capacity and life is affected by temperature.

Just as temperature affects your bodies capacity to do work and the ultimate speed that you will be able to do the work, temperature affects a battery's potential capacity to do work.

The temperature effect on a battery's state of charge and its ability to do work is defined as the ratio or % of available capacity at different temperatures compared to the overall rated capacity at a fixed reference temperature. (usually 68°F-77°F/20°C-25°C)

While 100% of a deep-cycle lead-acid batteries rated capacity is available at 77°F/25°C, less than 85% is available at 60°F/15°C and less than 40% is available at -4°F/-20°C.

Remember that all of the chemical reactions taking place in the battery are related to the relationship between the batteries ambient temperature during work and the speed or rate of work the battery is doing (the discharge current).

The speed or rate of the discharge also affects the total magnitude of the temperature-related affect/impact on the batteries' state of charge and ability to do work.

Most people (and bloggers) get this wrong!

Due to the Peukert effect, the higher the discharge current above the lead-acid batteries published or labeled reference rate, (C20/20-hour, C10 /10-hour, C5/5-hour, C1/1-hour, etc.) the lower the total available capacity will be at any temperature.

You cannot get 100Ah from a battery that is rated at 100 Ah C20 (or 5 Amps per hour for 20 hours) if you increase the discharge rate to 35A. Because of the Peukert effect that 100AH C20 battery will only deliver about 70 total Amp-hours.

While temperature and the Peukert effect is far less impactful on lithium batteries than lead-acid batteries it still does affect lithium cell technology as the discharge rates rise above 100% of the rated capacity (or the 1C/1-hour discharge rate).

A Discover high-energy lithium battery is capable of providing 100% of its rated capacity down to 32°F/0°C at any discharge rate up to 100% of its rated capacity.

While battery capacity is negatively affected as temperatures drop, battery life is negatively affected as temperatures rise. ***Every battery technology is affected by temperature.*** In fact, its the law* that for every 10° increase in temperature above 25°C/77°F the chemical reaction inside your battery will approximately double cutting battery life in half *. Eliminating or mitigating the high-temperature environments of battery compartments will reduce the related electrochemical reactions that accelerate premature capacity loss and battery failure. Lead or Lithium, no matter the battery technology, Heat Kills all Batteries! (High temperature under-hood installations should definitely be avoided for lithium batteries).

Some lithium cell technologies are specifically designed for extreme temperature use but their available capacity at extremely low temperatures and their life at high temperatures will still be negatively affected versus their reference capacity and design life at 25°C/77°.

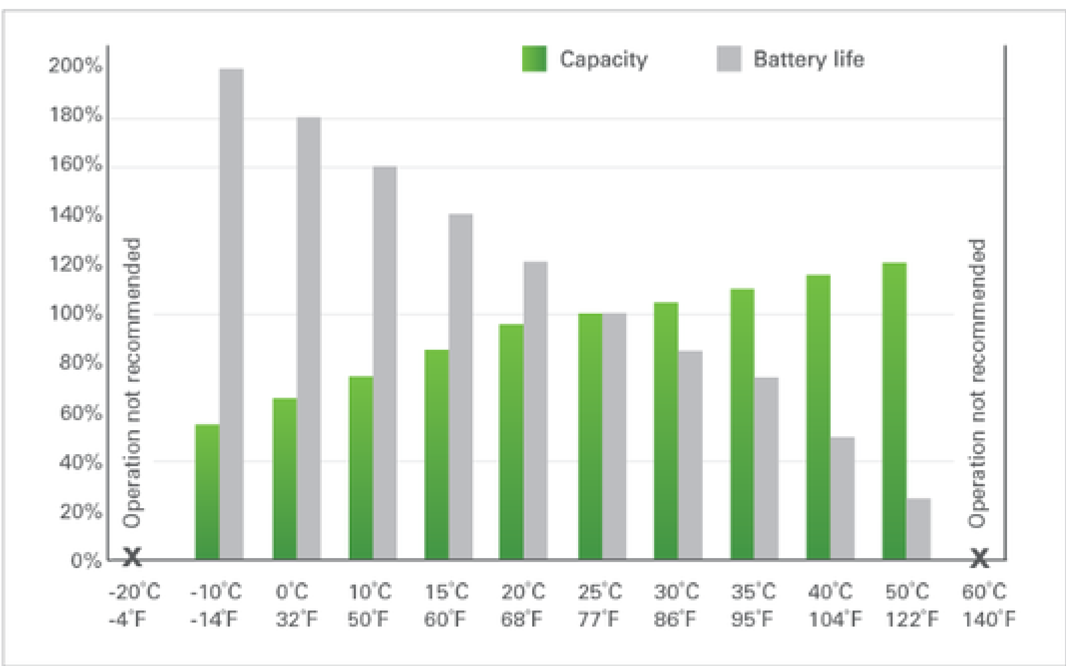
**This same Law explains why as temperatures drop your battery's available capacity drops along with it as the chemical reaction inside your battery decreases. Keeping batteries cool will work to reduce the related electrochemical reactions that accelerate premature capacity loss and battery failure.*

***Arrhenius' Law**

While the effect that temperature has on battery life in a controlled test environment is clearly defined by the Arrhenius Law, in the real world your battery may not be subject to a high or low steady-state temperature. The following chart gives you a ***reasonable estimation*** of the affects of temperature on lead-acid battery life and battery capacity. Because of their inherent lower internal resistance vs. lead-acid, lithium cell technology available capacity and life are less affected by temperature.

Please be sure to consider your operating temperature when sizing your battery purchase and estimating you run time.

TEMPERATURE EFFECTS ON CAPACITY



Fact 2: Lead-acid battery useable capacity is affected more than lithium as the rate of discharge increases.

A typical lead-acid battery that provides 100AH when discharge to 100% DOD at the 20-hour rate of 5 amps per hour, will provide only 70Ah of useable capacity to 100% DOD if discharged at 35Amps. Lithium will deliver 100% of its rated capacity at any discharge rate up to 125% - 150% of its rated capacity. *Research the Peukert affect!*

Lead-acid battery USEABLE CAPACITY at 100% DOD is reduced as the rate of discharge increases **(Typical 100AH lead-acid battery)**			**Lead-acid energy to weight ratio at 100% DOD**
Total Useable Capacity to 100% DOD	Rate of Discharge	Discharge time to 100% DOD	66lbs/30Kgs
100AH	5 Amps	20 Hour (C20)	18 watts per pound

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78AH	26 Amps	3 Hour ((C3)	14 watts per pound
70AH	35 Amps	2 Hour (C2)	12 watts per pound
65AH	65 Amps	1 Hour (C1)	11 watts per pound

Fact 3: Lead-acid battery life is dramatically affected by depth of discharge.

Most lead-acid battery manufacturers recommend sizing battery storage capacity using a maximum useable capacity or allowable depth of discharge (DOD) of 50% with allowances for the occasional discharge to 80%.

Lithium batteries can be sized for 100% DOD with no negative consequences. Discover recommends Lithium batteries be sized for a 90% DoD.

Fact 4: Lead-acid battery life is dramatically affected by constant partial state of charge use

Lead-acid battery life will be negatively affected by repeated deep or partial discharges that are not immediately followed by a full and complete charge with proper countermeasures against acid stratification such as an equalization charge.

lead-or-lithium-marine-rv-batteries-white-paper.pdf (discoverbattery.com)

Discover's lithium series batteries are purpose built to operate in a Partial State of Charge conditions (PSOC), High-quality lithium LiFePO4 technology does not suffer from acid-stratification, and does not suffer negative consequences from PSOC use. In fact, Discover lithium batteries will live longer if constantly operated and stored in a PSOC between 20% SOC and 80% SOC as compared to Lead-acid batteries that will fail faster if used or stored constantly in a partial state of charge (PSOC) condition!

Just like high-quality lead-acid batteries require equalizing charge periods (flooded), and special high voltage finishing stages (AGM and Gel) that help to eliminate acid stratification or balance the individual cells, lithium batteries benefit greatly from ensuring the BMS cell to cell balancing circuits are allowed to function for extended periods on a periodic basis.

Fact 5: Lead-acid batteries have long charge times and low charge efficiencies vs. Lithium

To overcome their low coulombic efficiency (high average internal resistance to charge acceptance and absorption) Lead-acid batteries require an over charge of between 105% and 125% of the previous discharged capacity to reach a fully charged and equalized state. Removal of 50AH during discharge can require a charge of 62AH with 12AH being lost to resistance and heat. Lead-acid batteries that are repeatedly deeply discharged require an equalization charge at higher finishing voltages to overcome the internal resistance and to achieve a fully balanced and complete charge which wastes energy and time.

It is a fact, and should generally be understood by system designers that the charge efficiency of flooded lead-acid batteries is non-linear and declines with increasing state-of-charge. Years of laboratory testing has established that from 0% to 70% SOC (+/-10%) the average charge efficiency of a lead-acid battery is up to 90% so during this period the charge current can be very high and many lead-acid battery manufacturers brag about their batteries fast charge ability. But, what is often not mentioned is the incremental charge efficiency from 70% SOC to 85% SOC is only 50%, and it continues to drop as the battery reaches 90% SOC. To overcome this higher internal resistance PV arrays need to be larger and generators need to run longer. Note also that as batteries age its internal resistance continues to increase causing charge efficiency to decrease.

Depending upon the charge rate and the lead-acid battery type, Discover's lithium battery solutions are up to 50% more charge efficient than new lead-acid batteries allowing for reduced charge times with the same size charger or smaller charging sources and/or greater utilization of renewable energy sources or generator time. As lead-acid batteries age, there dynamic charge acceptance and charge efficiency continues to fall.

Fact 6: Lead-acid battery charge efficiency in PV/Solar is extremely poor vs Lithium

Charge efficiency is very significant in PV/Solar systems where the designers recommend the batteries operate normally at or above 70% SOC (30% DOD) and a maximum 50% SOC (50% DOD) which allows the battery bank to support deeper discharges only during periods of extended bad weather. In such systems a lead-acid batteries high internal resistance and low charge efficiency at or above 70% SOC results in a substantial reduction in actual available stored energy because approximately 50% of the available charge source is serving losses to internal resistance processes rather than charging the battery.

This low charging efficiency results in the battery constantly being operated in a partial state of charge and at an average SOC significantly lower than the system designer anticipated. Note also that as batteries age its internal resistance continues to increase causing charge efficiency to decrease.

This better understanding of charge efficiency as a function of state-of charge (SOC), teaches us that while capacity degradation may not be evident during normal-weather, it is certain to manifest itself when the battery is called on to provide the full purchased name-plate capacity and we should not be surprised to find that it is unavailable. Extended operation in a low SOC environment can also result in permanent loss of capacity from acid stratification and sulfation if the battery is operated for long periods of time without a sufficient recovery or equalizing charge.

The impact of this low charge efficiency at high states of charge has the greatest potential impact on lead-acid battery systems where high energy charging availability is needed but not normally available from the PV array. Such systems usually utilize large battery banks to ensure energy availability during the longest stretches of bad weather…. and they may not be able to provide the energy required if the PV array is insufficient to overcome the high internal resistance and low charge efficiency or to provide a full recovery charge for these batteries that are often operating at 90% SOC where charge efficiency is its lowest because internal resistance is at its highest.

Charge efficiencies at 90% SOC or greater are on average less than 50% which requires a PV array that supplies more than twice the energy than the load consumes for the batteries to have any chance of achieving a full recovery charge. Many batteries that rely on PV systems to charge never reach a full state of charge which results in predictable battery capacity loss from stratification and sulfation over the life of the battery.

Depending upon the charge rate and the lead-acid battery type, Discover's lithium battery solutions have up to 50% less internal resistance than new lead-acid batteries and are up to 98% coulombic efficient allowing for reduced charge times with the same or smaller PV/Solar arrays.

For more information and an in-depth understanding of rated capacity vs useable capacity please read our TECHNICAL BRIEF on Lead-acid vs. LITHIUM battery capacity

885-0003 Technical Brief Lead-Acid Vs Lithium Battery Capacity - REV B.pdf I Powered by Box

What you need to know when connecting and charging lithium batteries in series, parallel and series parallel banks.

https://app.box.com/s/85hkzsps84pzm63mo503x7br0kaywshu