Lithium-Ion Battery Pack
Shelf Life

INSPIRED ENERGY™
SOLUTIONS FOR PORTABLE POWER

The shelf life of a Lithium-Ion battery pack is dependent upon a number of key parameters:

1. The self-discharge rate of the cells and the storage temperature.
2. The additional current drain resulting from the attached electronics.
3. The customer expectations for the pack when taken from storage.
4. The state of charge of the batteries when put into storage.
5. The capacity of the battery – including how many cells are in each parallel string.
6. Component cell construction & manufacturer.

What is Lithium-Ion cell Self Discharge:
Lithium-ion cells slowly self-discharge or lose charge retention due to physical and chemical reactions that spontaneously occur inside the cell as they sit unused resulting in the loss of chemical energy. Typical cell self-discharge rates are minimal, about .5% to 3% per month, with the greatest effect on the rate of self-discharge is storage temperature. Higher temperatures increase self-discharge. Storage of cells and batteries in non-temperature-controlled facilities in hot climates causes more rapid self-discharge hence the storage method plays a significant role in the shelf life of the product.

Current Drain from On-board Electronics
In smart batteries the electronics place additional drain on the battery. Although cell self-discharge plays a role in the early days of storage, it is soon overshadowed by the drain from the electronics in standby mode.

A well-designed smart battery will have a minimal current drain and will have a number of different operational states, each intended to successively reduce the drain on the battery and hence lengthen the storage life.

We can look at the range of Inspired Energy batteries to illustrate the effect of the electronics on the overall self-discharge of the battery pack.

Inspired Energy battery packs typically have the following states:

Parameter	Limits	Remarks
Active mode current consumption	<745uA	When a host is detected (charging, discharging or communications).
Standby mode current consumption	<200uA	When no host activity is detected.
Shut-down mode current consumption	<1uA	Any cell voltage falls below 2300mV.

Using these figures, we can calculate the amount of battery capacity consumed by the battery electronics during normal storage: 6.24mAh/day equates to ~187mAh per month.

So each battery has two components affecting its shelf life; a fixed component from the on-board electronics & a variable component resulting from the cell self-discharge.

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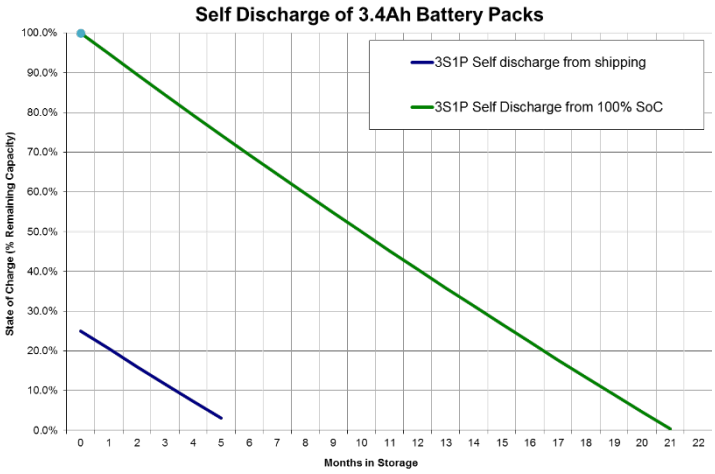
Adding this capacity loss due to on board electronics, to an estimated cell self-discharge results in a battery self-discharge estimate as shown below.

This graph assumes a discharge rate from the electronic BMS and an amount of cell self-discharge stored in optimal conditions.

Typical storage conditions are rarely ideal and play a part in reducing charge retention or shelf life.



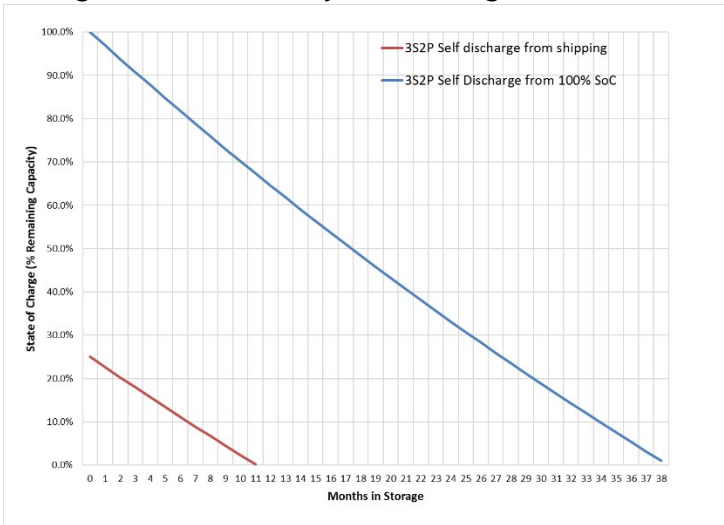
We can see that the battery electronics and the cell self-discharge both play important roles in determining the shelf life of the battery – which can vary tremendously.

Smaller, lower capacity batteries are more impacted by on-board electronics than cell self-discharge because the fixed parasitic drain from the on-board electronics is a larger proportion of the total discharge.

All Inspired Energy Standard batteries and chargers are SBS / SCS compliant.

Storage after the Shutdown point

Changes in the industry addressing Lithium-Ion cell safety now recommend permanent under-voltage lockout (PUV) to mitigate cell damaged from over-discharge.



When the battery pack capacity hits zero, (i.e. The voltage of any parallel cell stack drops to 2.3V) the electronics switch to shutdown mode. The current consumption in this mode is approximately 1µA. At this point the self-discharge of the cells is extremely low and this gives additional shelf life before the cell permanent under-voltage lockout (PUV) threshold is reached.

The smart battery system (SBS) has a provision for determining if a battery has experienced a (PUV) event from over discharge. The Smart Charger specification includes a “wake-up” charge for batteries in the shutdown

condition. When a deeply discharged SBS-compliant battery is placed into a compliant smart charger, the charger delivers a very low-level charge to wake up the electronics. If the battery voltage recovers, not in (PUV) the electronics will become active and begin communicating with the charger instructing it to deliver the appropriate charge. If the battery voltage does not recover within the specified time, the charger shuts off and the battery is no longer useable.

Although exact calculations are difficult at such low levels of charge (SCO), we advise that a Li ion battery should not be stored more than 5-months at 21°C. Recharge to 30% if stored more than 5-months to avoid reaching the (PUV) threshold.

Performance Expectations After Storage

A key factor in a shelf-life calculation is what the battery is expected to do when removed from stock. Some requirements dictate that the battery should be able to start-up the device and maybe run it for a prescribed period of time, or that it should have a specific amount of capacity remaining.

However, batteries that have been discharged to the point of shutdown may require fuel gauge re-calibration upon being woken-up. Hence, if the customer requirement is that the battery should not require recalibration after storage, then the shelf-life estimate should not include any point at which the electronics go into shutdown.

One alternate approach is to implement a boosting regime for batteries stored for extended periods of time.

State of Charge when placed into Storage

The natural follow-on to the above self-discharge discussion is to investigate the amount of charge in the packs from new. After all if you start from full, you will have longer shelf life. This deserves some explanation in its own right and it involves the following factors:

1. Safety in Shipping
2. Full charge capacity loss
3. The capacity of the battery

Safety In Shipping

In 2016 the IATA / UN / DOT limited the battery state of charge to <30%. Inspired Energy follows these recommendations: all our products are shipped at <30% state of Charge.

Inspired Energy does not hold finished goods stocks, and our products are typically shipped within 1-2 days of being charged to 30%. Shipping anywhere in the world can be achieved within a week; hence there should be no significant loss in capacity by the time our batteries arrive at your premises.

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Full Charge Capacity Loss
Lithium-Ion cells permanently lose capacity if stored continuously at 100% state of charge. This is common in UPS applications & notebook computers. When continually maintained in a fully charged condition, Li on cells will lose between 5% & 10% of their original capacity.

The Capacity of the Battery
The more capacity in the battery pack, the longer it will withstand the fixed-rate parasitic drain from the on-board electronics. The discharge graphs shown above illustrate the longer shelf lives of higher capacity batteries (3S2P) compared to their smaller, lower capacity siblings (3S1P).

Summary
There are many factors which play into the actual shelf life of a Li Ion battery.

For general care & wellbeing of Li Ion batteries, we follow a few rules of thumb:

- Check batteries in inventory every 4 months; especially if, upon removal from storage, you require the batteries to perform a specific function in your device without recharging.
- Do not store Li Ion batteries for longer than 6-months at low % SOC.
- Store batteries at or slightly below room temperature (10-20°C is ideal)
- Shipping Li Ion batteries at <30% state of charge meets regulatory requirements & should always be undertaken.
- Rather than buying large quantities of battery packs & storing them for long periods, we recommend using a blanket order to schedule your shipments to more closely coincide with your demand. Using this Just-in-Time system ensures you always have fresh battery packs to meet your needs.
- Li Ion cells typically lose 5% capacity per year / 5% capacity every 100 cycles in general use.
- Maintaining Li Ion cells at 100% state of charge can cause 5-10% capacity loss.

(Note: These are considered conservative rules of thumb, intended to provide a general guide to use & maintenance of your Li Ion battery pack. They do not represent a specification or warranty.)

Small changes in storage temperature can have a large effect on shelf life & cell discharge rates can vary significantly. Inspired Energy does not specify a fixed self-discharge rate due to the large number of variables playing a part. Our products are specified for 6 months of shelf life from the date of shipment after which we recommend a capacity check & recharge if required.

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