



# Lithium Iron Phosphate (LiFePO<sub>4</sub>) Batteries for Electric Boats

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This article explains the basic features and benefits regarding the latest developments in lithium ion battery technology which are now available for use in electric boats.

Up to the present time the electric boat owner has only had available one type of battery chemistry to provide propulsive power for their electric motor no matter whether the motor is an inboard or outboard motor. This battery type is of course the lead acid battery. There are two main variations to the lead acid battery depending upon its specific application. Broadly speaking the lead acid engine start or “cranking battery” in its intended application is designed to provide a short, high power burst of electrical current to crank over either a petrol or diesel engine while starting. The other main type of lead acid battery is the deep cycle or gel/AGM type which is used to provide sustained power for electrical devices and equipment over a long period. This is the type of battery which commonly provides house power on boats as well as presently being the most common type to power electric boat motors.

Both types of lead acid batteries however have severe limitations. Lead acid batteries are extremely heavy and while weight may not be an important factor for batteries in a stationary environment, for use in a motive application such as a boat, having to move (accelerate/decelerate) such a heavy dead weight does not make much common sense. In addition lead acid batteries contain nasty chemicals such as sulphuric acid and toxic heavy metals like lead which are potentially hazardous to the environment.



*The author with one of the Lithium batteries, to be built in to a 53ft sailing catamaran.*

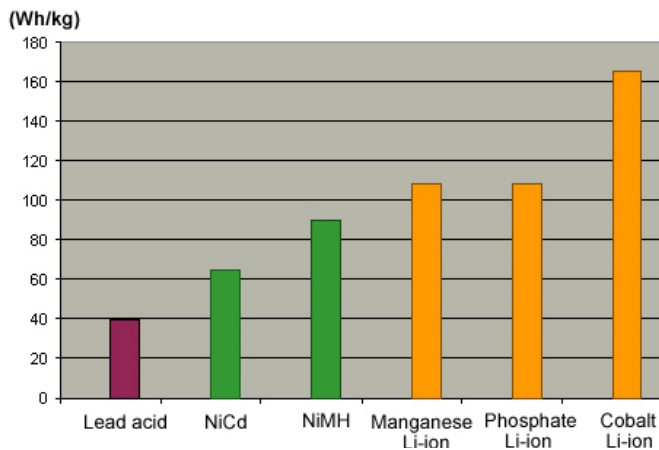
Lead is a very heavy metal and for many years the search has been on to make a better battery that is also lighter in weight. Lithium is the logical choice since it is the lightest metal known to man. However in addition to being extremely light in weight, lithium is also extremely reactive and for this reason pure lithium metal is never found in nature. Lithium metal is manufactured from lithium salts which are extracted through mining activities mainly from brine lakes. It can also be extracted from sea water.

Lithium ion batteries have been available for several years for many consumer applications which most people would be familiar with. As with lead acid batteries, lithium ion batteries also are available in several chemistries, each having their particular good and bad points. The earliest lithium battery chemistries which became a commercial reality and which are still in use today for consumer items like mobile

phones, notebook computer and camcorders etc. are cobalt oxide lithium ion batteries. Li-Co batteries have high energy densities but have the disadvantage that in large format applications and in cases where many separate cells are used which can potentially become unbalanced during several charge cycles, they can pose a dangerous risk of fire or explosion is a possibility. While these batteries are generally considered quite safe in small format applications such as for mobile phones and the like (generally one cell only is used therefore this is why the battery voltage of a typical mobile phone battery is 3.6 -3.7 volts) there could be disastrous consequences should a large lithium battery of this chemistry fitted to a boat catch fire.

In the mid 1990's Dr John B Goodenough and his research team from the University of Texas developed material used to make the Lithium Iron Phosphate battery (LiFePO<sub>4</sub> for short). Dr Goodenough patented his invention and gave permission to Phostech Lithium/Hydro Quebec Canada to manufacture this material in commercial quantities for the production of LiFePO<sub>4</sub> batteries which would be a superior replacement for lead acid batteries.

Unlike the hazardous nature of the earlier chemistry lithium battery types, lithium iron phosphate batteries are extremely stable and safe to use. This safety combined with their light weight has found wide use for these batteries for military applications and now for the emerging electric vehicle markets including electric boats. They are in fact even safer than lead acid batteries and do not suffer from some of the problems which are inherent to lead acid batteries such as, thermal runaway, sulphation when left in a discharged condition and high rates of self discharge if not used. Lead acid batteries generally have a life of only a few hundred deep charge cycles while a quality LiFePO<sub>4</sub> battery can typically be charged in excess of 2000 times.



*Energy density comparison*

Though not as high in energy density as the earlier lithium battery types, the lithium iron phosphate battery still has a far higher energy density compared to the lead acid battery as can be seen from the graph on the left.

In recent years large format LiFePO<sub>4</sub> batteries have been made to replace lead acid batteries and these batteries are now being widely used for battery packs to power electric

vehicles as well as hybrid electric cars. They are also being used in high power electric cordless power tools.

The benefits to the boat owner of a quality LiFePO<sub>4</sub> battery are many. Lithium iron phosphate batteries are a truly multi-application battery type so the one battery or battery bank can be used to provide propulsive power for the boat's electric motor/s as well as to supply all the electrical loads on a boat. Normally the electric motor requires a voltage of 36V, 48V or higher voltage while 12V is required for house power, radios,

navigation lights, etc. In this case a suitable DC/DC converter should be used to provide the lower voltage from the higher voltage main battery bank. It is very bad practice and still used by some manufacturers to simply tap off 12V from a single battery in the main battery pack to supply this lower voltage. This can lead to uneven discharging of different batteries due to varying loads which can further result in some batteries being over charged while others end up being less than fully charged. By fitting a DC/DC converter all batteries are discharged evenly regardless of varying loads. This will result in the longest life from all batteries and will minimise the chances of individual batteries failing prematurely which is a strong possibility if a DC/DC converter is not used.

Another major factor which should be taken into consideration when replacing a lead acid battery with a LiFePO4 battery is that due to the higher energy density and greater performance of the lithium battery often a smaller battery can be used which will provide equivalent or better performance compared to the original lead acid battery. For many applications a 60Ah LiFePO4 battery will provide equivalent performance to a 100Ah lead acid battery. This difference in performance can clearly be seen if both battery types are compared side by side in high current drain applications (for example if used to power an electric boat motor at high power settings). What many people fail to realise about a lead acid battery is that its capacity (Ah) rating is usually specified at the 20 hour discharge rate. At high rates of discharge the effective or "real" battery capacity is reduced considerably due to "Peukert's Effect". A typical 100Ah lead acid battery when discharged in an hour or two may have an actual measured capacity of as little as 60-70Ah. LiFePO4 batteries are not negatively affected in the same way by Peukert's Effect as are lead acid batteries.

When a lead acid battery is connected to a load (such as an electric motor for example) the voltage slowly continues to decrease until the battery is completely discharged. By contrast the discharge characteristic of a LiFePO4 battery is quite different. The discharge curve of LiFePO4 battery is close to being linear for about 90% of its capacity. Therefore a LiFePO4 battery can be almost fully discharged yet it will provide very close to the same power as when it was fully charged. During the last 10% of the batteries capacity the voltage will drop very suddenly.

Another great benefit of Lithium Iron Phosphate batteries for boating applications is due to their inherent safety features. Since they do not produce flammable hydrogen gas under any circumstances (even if overcharged) a LiFePO4 battery can be safely installed in a confined place in a boat or ship without fear of a fire or explosion occurring. There is absolutely no maintenance required so a battery can be fitted into an out of the way space in an electric boat such as under seats, under stair wells, in the hull, etc.



*Lithium battery bank*

Due to slim cylindrical nature of many LiFePO<sub>4</sub> cells a custom battery of virtually any shape can be made which will fit into any tight space in a boat. Battery cells can even be fitted inside a mast or inside hollow railings.

Another advantage of LiFePO<sub>4</sub> batteries is their rapid charge capability. High quality batteries can be re-charged extremely quickly. In fact premium quality LiFePO<sub>4</sub> batteries can be re-charged from a completely discharged state to more than 90% fully charged in only fifteen minutes with a suitable fast charger from shore power. Of course they can also be more slowly trickle charged by solar panels or more quickly aboard the boat via an engine driven back up generator/alternator. A deeply discharged deep cycle/AGM lead acid battery can only be re-charged in a matter of hours and not minutes. For many electric boats this rapid charge capability will be a godsend.

Weight is another factor of concern to owners of electric boats. A Lithium Iron Phosphate battery is usually about half the weight of an equivalent capacity lead acid battery. For example the photo of the battery bank below shows a large LiFePO<sub>4</sub> battery bank used to power three motors fitted to a 55ft electric racing catamaran. It was originally planned to fit more than half a ton of AGM lead acid batteries to this boat before the owner learned of the benefits of LiFePO<sub>4</sub> batteries. Due to the many benefits the owner of the boat decided to install LiFePO<sub>4</sub> batteries instead and was able to reduce the total weight of the battery bank by more than half with the total of all twelve batteries weighing in at less than 200kg.

**To sum up, an overview of the benefits of Lithium Iron Phosphate batteries:**

- Safe technology, will not catch fire or explode with overcharge
- Over 2000 discharge cycles life compared to typically around 300 for lead acid
- Double the usable capacity of similar amp hour lead acid batteries
- Virtually flat discharge curve means maximum power available until fully discharged (no "voltage sag" with time as with lead acid batteries).
- Unlike lead acid batteries, can be left in a partially discharged state for extended periods without causing permanent damage
- Extremely low self discharge rate (unlike lead acid which will go flat quite quickly if left sitting for long periods)
- Does not suffer from "thermal runaway"
- Can be used safely in high ambient temperatures of up to 60 deg.C or more without any degradation in performance
- Can be connected in series for higher voltages or parallel for higher capacity.
- Absolutely maintenance free for the life of the battery
- Can be operated in any orientation
- Does not contain any toxic heavy metals such as lead, cadmium, nor any corrosive acids or alkalis thus making LiFePO<sub>4</sub> batteries the most environmentally friendly battery chemistry available
- LiFePO<sub>4</sub> cells are of solid construction. There are no fragile/brittle plates made of lead which can be prone to failure over time as a result of vibration.
- Can be safely rapidly recharged. When fully discharged can be re-charged to more than 90% full battery capacity in only 15 minutes.

There are already several brands of LiFePO<sub>4</sub> batteries which are available to boat owners and are suitable for powering many kinds of electric motors from tiny trolling motors to large inboard electric motors of several horsepower. The prospective battery purchaser should be aware that the majority of the LiFePO<sub>4</sub> batteries manufactured in China are of very poor quality and correspondingly provide poor overall performance. These batteries will also have a shorter life than a quality LiFePO<sub>4</sub> battery. Only high quality LiFePO<sub>4</sub> batteries should be used by the electric boat owner so as to provide peace of mind in terms of battery reliability. One way a battery buyer can gauge the quality of any particular battery brand is to check what kind of warranty the manufacturer/supplier will provide and whether it is a factory backed warranty or only a distributor backed warranty in the country of sale since many distributors of Chinese batteries are required by law to provide a minimum warranty period when a battery is sold in a western country. If a battery manufacturer is not prepared to stand behind their own products by providing a lengthy factory backed warranty then it is best to steer well clear of these companies so as to avoid any possible headaches in the future.

Chinese battery cell manufacturers will often assemble their cells using less expensive manufacturing techniques thereby reducing the final cost of the battery to the customer at the expense of shorter cycle life and/or poorer performance. For example some manufacturers will simply crimp end terminal caps on the cells while other manufacturers will spot weld or even fully laser weld the cell ends. Obviously a cell which is merely crimped will be cheaper to manufacture than a cell which is fully laser welded. By the same token the crimped cell is also more prone to fail prematurely due to slow ingress of moisture, humidity and other atmospheric contaminants which in a laser welded cell are totally excluded from entering the cell for the life of the cell. It really is a case of having to pay more for quality. By paying more for a quality battery a great deal of frustration can be avoided and allow the electric boat owner to enjoy the tranquillity of silent, electric boating without any noise or exhaust fumes.

There are a handful of manufacturers of A-grade quality Lithium Iron Phosphate batteries which will outlast several lead acid batteries and provide vastly superior performance and thereby bring much enjoyment to the owner of the electric boat they are fitted in.

Lithium Iron Phosphate batteries are sure to revolutionise and bring about the growth of the electric boating market in the years to come.

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