



Comparing Marine Battery Technologies

(Gel, Absorbed Glass Mat (AGM), Flooded Lead Acid, and Nickel-Cadmium)

While I was on a month long assignment in Washington DC in 1999, I read an article on battery management in the 1999 Ocean Navigator "Annual" issue that I thought was deeply flawed. The contributor, Chuck Husick, illustrated how he thought one should maintain and configure a marine battery system. Some of his key recommendations ran counter to accepted industry policies and physical laws that I had read about in Nigel Calders excellent [Boatowners Mechanical and Electrical Manual](#), as well as web-resources like the [Ample Power](#) web-site and their line of books.

The research I conducted for my letters to the editor led to this collection of web pages. For my purposes, Lifeline Absorbed Glass Mat (AGM) batteries are the best choice, but every battery technology has its strengths and weaknesses. Naturally, I have no commercial affiliation with any battery or charge system manufacturer. I suggest you [start off with my Lead-Acid Battery Glossary Page](#) to familiarize yourself with all the terms that will be used throughout this site.

Learn more about the different types of marine lead-acid batteries currently on the market with my page on [lead-acid battery technology \(Flooded, Gel, and AGM\)](#). I discuss the features of traditional flooded lead-acid batteries commonly found in cars and most boats versus Valve-Regulated Lead Acid (VRLA) batteries like Gel and AGM. Each battery technology has its virtues and its downsides, so it is important to understand them and then make the decision which best suits one's own needs.

Next, I researched what sensible people have written about how [to size your battery capacity](#). The industry consensus is usually 4x your daily energy needs, although it depends on the type of battery your have on board, as well as your charging system, available space, weight considerations, and usage profile. However, starting off with at least 4x allows you some breathing room later when/if you add more electric circuits.

On another page, I have assembled a number of arguments why the [average marine user would only want two battery banks on board](#) (house + starter) and how such a bank configuration leads to better battery performance, longer battery life, and higher safety. Basically, the less you discharge a battery, the better. Fast discharges are also harmful and lower available battery capacity (see Peukerts law).

Chuck Husick made a number of assertions in his responses about battery costs, so I looked into those as well. A cost model later, [I had a number of startling results](#). Namely, that AGMs worked out to be less-expensive for my marine application, despite having a high initial cost, due to their superior features. Over the life of the AGMs we would save a lot more on lower maintenance costs, fuel consumption, etc. than the premium we spent initially (when such a premium exists).

I then go on to explain [how my bulk charging model works](#). This is a rather simple cost model (hey, it's

my spare time) but it covers the battery conditions usually found on cruising sailboats (bulk-charging, i.e. not fully charging the battery banks except on occasion). The model is available for free and runs on Microsoft Excel (see the page for details). A later cost model also looks at replenishing batteries beyond the bulk stage.

I then go to wrap up my marine battery technology findings in the [Conclusions page](#). I detail what battery technology I chose and why.

For those who are interested in the written volleys between myself and Chuck Husick, [I have preserved the e-mails for your review](#). I found the exchange quite amusing and thought-provoking. While his essay made me research this topic enough to make an informed purchase decision, Chuck Husick has yet to convince me and the rest of the battery industry that his ideas are superior. After all, when confronted with contradicting evidence, he decided to "withdraw from the discourse".

Anyway, last but not least, I have assembled some

Some Great Battery Links:

Introductions to Batteries

- [William Darden's fantastic Battery Pages](#)

Battery Manufacturers / Distributors:

- [A primer on battery technology by windsun.com](#)
- [Amsolar on how Lead Acid batteries work](#)
- [Optima Battery FAQ](#)
- [Lifeline AGM batteries by Concorde](#)
- [Sierra Solar on Concorde AGMs](#)
- [DC Battery, great for battery information](#)
- [Rolls/Surrette, manufacturer of high end flooded cells](#)
- [A battery site for those down under](#)
- [Outback Marine](#) (scroll down to Battery

Experiences with AGMs:

- [Actual User Experiences with AGMs](#)
- [Switching from Flooded to AGM in off-grid applications](#)
- [A RV'ers perspective on AGMs](#)
- [AGMs as used in Electric Boats](#)
- [Solomon Technologies, manufacturers of powerful electric boat drives, use AGMs](#)

Marine electrical Systems:

- [Jim Thompson's Primer on Boat Electronics](#)
- [Ample Power on electrical systems](#)
- [The Red Beard Yacht Systems primer](#)
- [Anchor Yachts on marine electrical systems](#)

section)

- [Batteryweb on AGMs](#)
- [BatteryStuff Web site with some prices and capacities](#)
- [Jack Rabbit Marine on Batteries](#)
- [SALT Systems on Batteries](#)

Other Battery Sizing Recommendations:

- [Glacier Bay on battery bank sizing and charging](#)



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How Lead Acid Batteries Work

Here is a short run-through of how lead-acid batteries work. I'll start with some basics and work my way up - hence the absence of an alphabetical order. Depending on your familiarity with the subject, you may want to scroll down more or less.

Voltage

Voltage is an electrical measure which describes the potential to do work. The higher the voltage the greater its risk to you and your health. Systems that use voltages below 50V are considered low-voltage and are not governed by an as strict (some might say arcane) set of rules as high-voltage systems.

Current

Current is a measure of how many electrons are flowing through a conductor. Current is usually measured in amperes (A). Current flow over time is defined as ampere-hours (a.k.a. amp-hours or Ah), a product of the average current and the amount of time it flowed.

Power

Power is the product of voltage and current and is measured in Watts. Power over time is usually defined in Watt-hours (Wh), the product of the average number of watts and time. Your energy utility usually bills you per kiloWatt-hour (kWh), which is 1,000 watt-hours.

What is a Lead-Acid Battery?

A lead-acid battery is a electrical storage device that uses a reversible chemical reaction to store energy. It uses a combination of lead plates or grids and an electrolyte consisting of a diluted sulphuric acid to convert electrical energy into potential chemical energy and back again. The electrolyte of lead-acid batteries is hazardous to your health and may produce burns and other permanent damage if you come into contact with it. *Thus, when dealing with electrolyte protect yourself appropriately!*

Deep Cycle vs. Starter Batteries

Batteries are typically built for specific purposes and they differ in construction accordingly. Broadly speaking, there are two applications that manufacturers build their batteries for: *Starting and Deep Cycle*.

- As the name implies, *Starter Batteries* are meant to get combustion engines going. They have many thin lead plates which allow them to discharge a lot of energy very quickly for a short amount of time. However, they do not tolerate being discharged deeply, as the thin lead plates needed for starter currents degrade quickly under deep discharge and re-charging cycles. Most starter batteries will only tolerate being completely discharged a few times before being irreversibly damaged.
- *Deep Cycle* batteries have thicker lead plates that make them tolerate deep discharges better. They cannot dispense charge as quickly as a starter battery but can also be used to start combustion engines. You would simply need a bigger deep-cycle battery than if you had used a dedicated starter type battery instead. The thicker the lead plates, the longer the life span, all things being equal. Battery weight is a simple indicator for the thickness of the lead plates used in a battery. The heavier a battery for a given group size, the thicker the plates, and the better the battery will tolerate deep discharges.
- Some "Marine" batteries are sold as dual-purpose batteries for starter and deep cycle applications. However, the thin plates required for starting purposes inherently compromise deep-cycle performance. Thus, such batteries should not be cycled deeply and should be avoided for deep-cycle

applications unless space/weight constraints dictate otherwise.

Regular versus Valve-Regulated Lead Acid (VRLA) Batteries

Battery Containers come in several different configurations. Flooded Batteries can be either the sealed or open variety.

- Sealed Flooded Cells are frequently found as starter batteries in cars. Their electrolyte cannot be replenished. When enough electrolyte has evaporated due to charging, age, or just ambient heat, the battery has to be replaced.
- Deep-Cycle Flooded cells usually have removable caps that allow you to replace any electrolyte that has evaporated over time. Take care not to contaminate the electrolyte - wipe the exterior container while rinsing the towel frequently.

VRLA batteries remain under constant pressure of 1-4 psi. This pressure helps the recombination process under which 99+% of the Hydrogen and Oxygen generated during charging are turned back into water. The two most common VRLA batteries used today are the *Gel* and *Absorbed Glass Mat (AGM)* variety.

- Gel batteries feature an electrolyte that has been immobilized using a gelling agent like fumed silica.
- AGM batteries feature a thin fiberglass felt that holds the electrolyte in place like a sponge.

Neither AGM or Gel cells will leak if inverted, pierced, etc. and will continue to operate even under water.

Battery Cells

Battery Cells are the most basic individual component of a battery. They consist of a container in which the electrolyte and the lead plates can interact. Each lead-acid cell fluctuates in voltage from about 2.12 Volts when full to about 1.75 volts when empty. Note the small voltage difference between a full and an empty cell (another advantage of lead-acid batteries over rival chemistries).

Battery Voltage

The nominal voltage of a lead-acid battery depends on the number of cells that have been wired in series. As mentioned above, each battery cell contributes a nominal voltage of 2 Volts, so a 12 Volt battery usually consists of 6 cells wired in series.

State of Charge

The State of Charge describes how full a battery is. The exact voltage to battery charge correlation is dependent on the temperature of the battery. Cold batteries will show a lower voltage when full than hot batteries. This is one of the reasons why quality alternator regulators or high-powered charging systems use temperature probes on batteries.

Depth of Discharge (DOD)

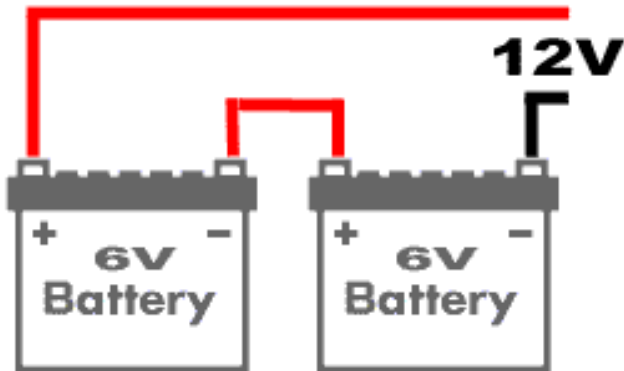
The Depth of Discharge (DOD) is a measure of how deeply a battery is discharged. When a battery is 100% full, then the DOD is 0%. Conversely, when a battery is 100% empty, the DOD is 100%. The deeper batteries are discharged on average, the shorter their so-called *cycle life*.

For example, starter batteries are not designed to be discharged deeply (no more than 20% DOD). Indeed, if used as designed, they hardly discharge at all: Engine starts are very energy-intensive but the duration is very short. Most battery manufacturers advocate not discharging their batteries more than 50% before re-charging them.

Battery Storage Capacity

The *Amp-hour (Ah) Capacity* of a battery tries to quantify the amount of usable energy it can store at a nominal voltage. All things equal, the greater the physical volume of a battery, the larger its total storage capacity. Storage capacity is additive when batteries are wired in parallel but not if they are wired in series.

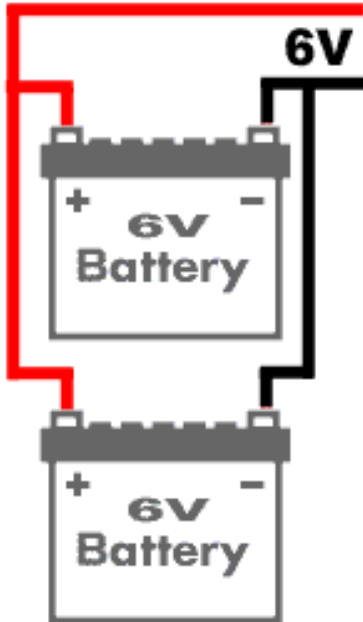
Most marine, automotive, and RV applications use 12V DC. You have the choice to either buy a 12V battery or to create a 12V system by wiring several lower-voltage batteries/cells in *Series*.



When two 6V, 100Ah batteries are wired in *Series*, the voltage is doubled but the amp-hour capacity remains 100Ah (Total Power = 1200 Watt-hours).

You may decide to wire batteries in series because a single 12V battery with the right storage capacity is simply too heavy, unwieldy, or awkward to lift into place. Batteries consisting of fewer cells (and hence lower voltage) in series can provide the same storage capacity yet be portable. It is not unusual to see solar power installations where the battery bank consists of a sea of 2V batteries

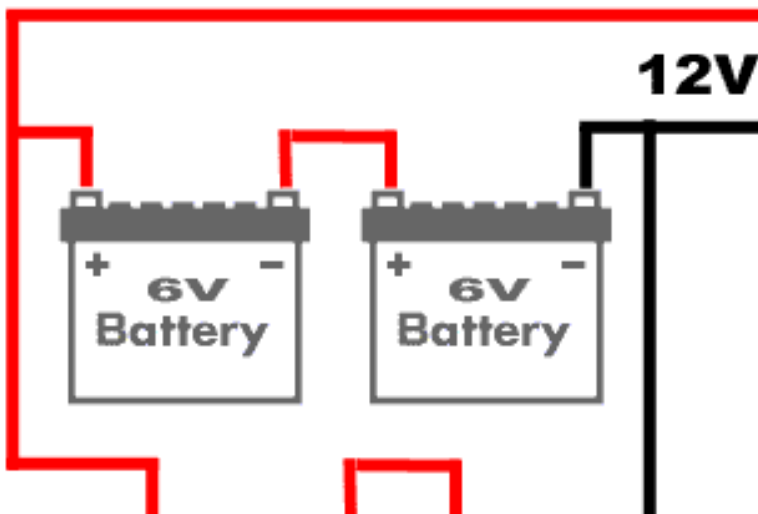
that have been wired in series.



Two 6V, 100Ah batteries wired in *Parallel* will have a total storage capacity of 200Ah at 6V (or 1200 Watt-hours).

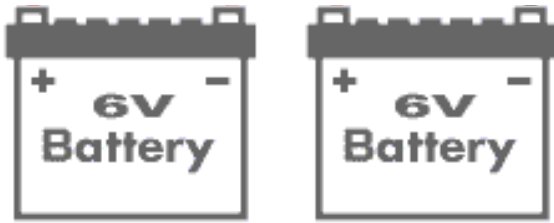
Battery banks consisting of 12V batteries wired in parallel are often seen on OEM installations in boats and RVs alike. Such banks are simple to wire up and require a minimum of cabling. However, the wiring must have the capacity to deal with a full battery bank.

You should fuse each battery individually in such a bank to ensure that a battery gone bad will not affect the rest of the bank.



Battery banks wired in *Series-Parallel* are even more complicated. Here, four 6V cells are wired in two "strings" of 12VDC that were then wired in parallel. Using 6V, 100Ah batteries, this system will have a storage capacity of 200Ah at 12V or 2,400Wh.

Since such a system has more wiring, it is very important to group "strings" logically and to label everything. Furthermore, it is a very good idea to fuse every "string" of series-wired batteries to ensure that a problem in one part of the battery bank does not take the whole bank down.



We use Group GPL4C batteries exclusively on our boat. Since these batteries have a nominal voltage of 6V, we have wired them in series for the starter bank (2 batteries) and series-parallel for the house bank (4 batteries).

Despite advances in instrumentation, the battery industry mostly still advertises amp-hours as a capacity measure instead of watt-hours. Hopefully, the battery and marine power instrumentation industry will make a transition to Watt-hours (Wh) in the future.

Available Capacity versus Total Capacity

Since batteries depend on a chemical reaction to produce electricity, their *Available Capacity* depends in part on how quickly you attempt to charge or discharge them relative to their *Total Capacity*. The *Total Capacity* is frequently abbreviated to *C* and is a measure of how much energy the battery can store. Available Capacity is always less than Total Capacity.

Typically, the amp-hour capacity of a battery is measured at a rate of discharge that will leave it empty in 20 hours (a.k.a. the *C/20* rate). If you attempt to discharge a battery faster than the *C/20* rate, you will have less available capacity and vice-versa. The more extreme the deviation from the *C/20* rate, the greater the available (as opposed to total) capacity difference.

However, as you will discover in the next section, this effect is non-linear. The available capacity at the *C/100* rate (i.e. 100 hours to discharge) is typically only 10% more than at the *C/20* rate. Conversely, a 10% reduction in available capacity is achieved just by going to a *C/8* rate (on average). Thus, you are most likely to notice this effect with engine starts and other high-current applications like inverters, windlasses, desalination, or air conditioning systems.

For example, the starter in an engine will typically quickly outstrip the capacity of the battery to keep cranking it for any length of time. Hence the tip from mechanics to wait some time between engine start attempts. Not only does it allow the engine starter to cool down, it also allows the chemistry in the battery to "catch-up". As the battery comes to a new equilibrium, its available capacity increases. A very elegant equation developed in 1897 by a scientist called Peukert describes the charging and discharging behavior of batteries.

The Peukert Effect

As you can see below, the Peukert equation consists of several factors.

Peukerts Equation: $I^n \times T = C$

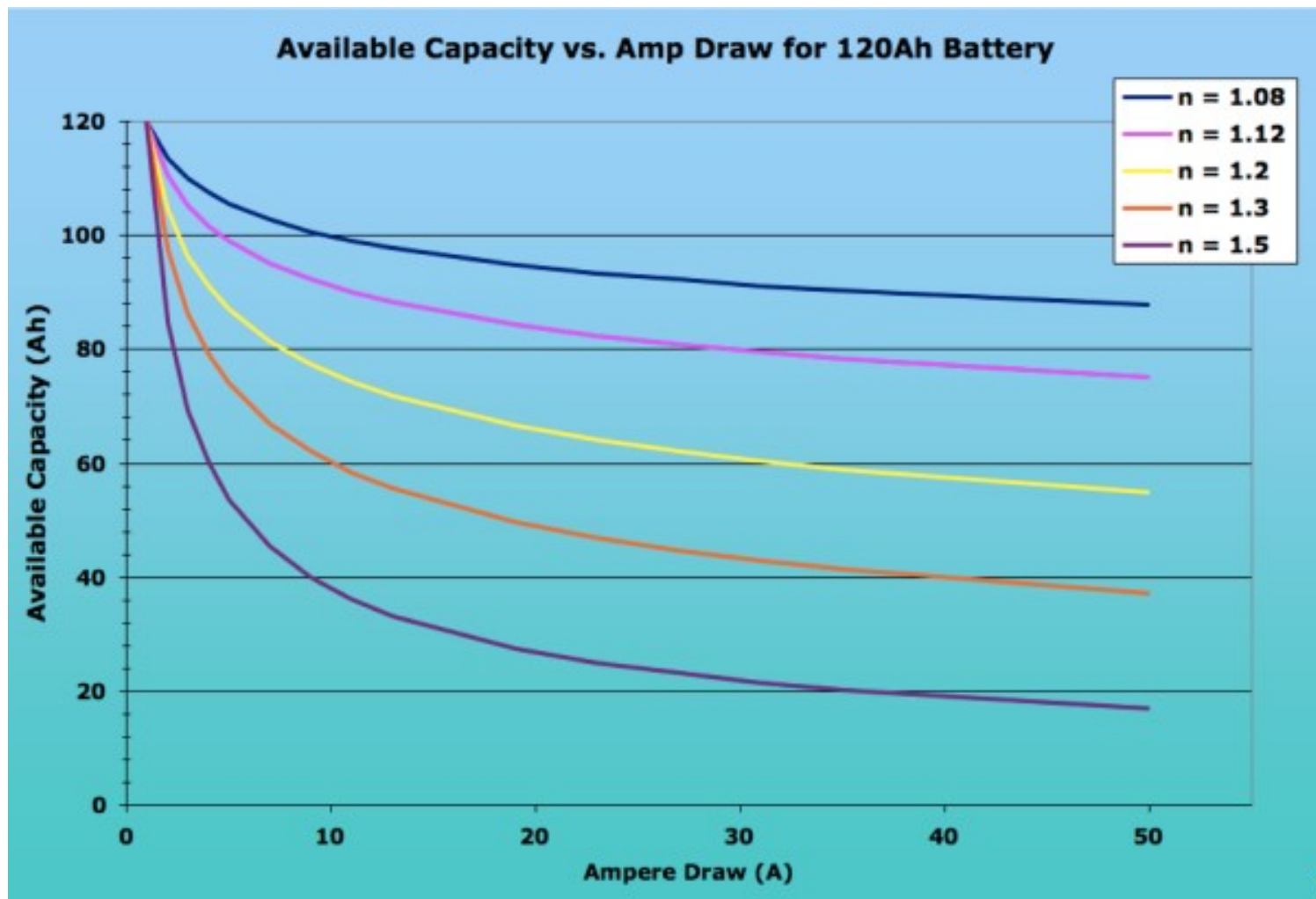
where

- *I* is the current (usually measured in amperes)
- *T* is time (usually measured in hours)
- *n* is the Peukert number / exponent
- *C* is the theoretical storage capacity of the battery (usually measured in amp-hours). Use the *C/100* capacity or add 10% to the storage capacity at the *C/20* rate.

As you can see, the available current is dependent on the rate of discharge and the Peukert exponent for

the battery. The closer the exponent is to 1 (one), the less the available capacity of a battery will be affected by fast discharges. Peukerts numbers are derived empirically and are usually available from manufacturers. They range from about 2 for some flooded batteries down to 1.05 for some AGM cells. The average peukerts exponent is 1.2 though the exact number depends on the battery construction and chemistry.

The following image shows the dramatic impact of the Peukerts exponent on the available capacity of a 120Ah battery, depending on the ampere draw. As you can see, the lower the Peukerts Exponent, the lesser the effect on available capacity. Note the dramatic difference in Available Capacity between the average flooded cell ($n = 1.20$) and a deep cycle AGM ($n = 1.08$) with high-current applications.



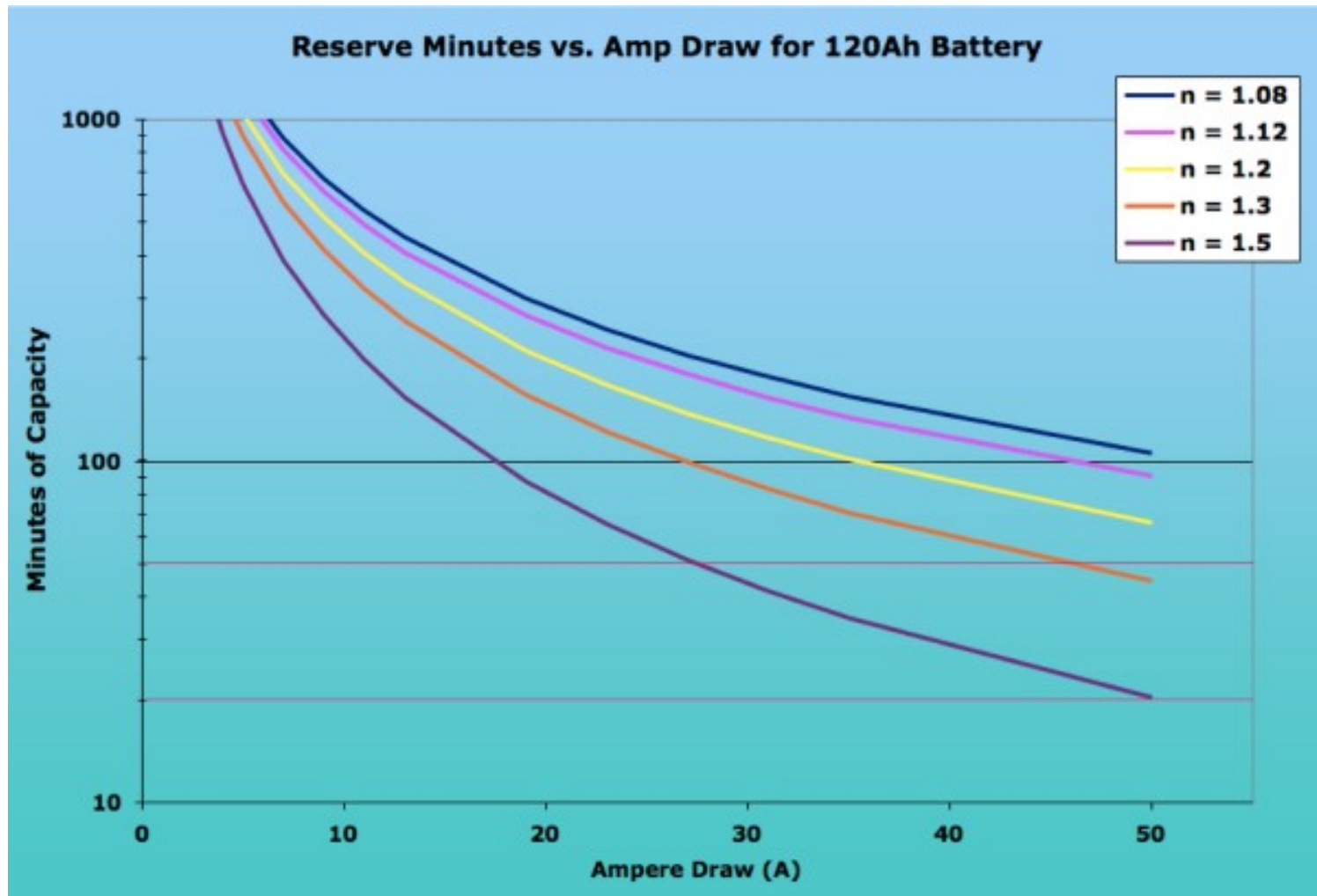
In the above picture, note how the low exponent battery (topmost curve) has more than four times the available capacity over a high-exponent battery (lowest curve). This chart uses a linear scale.

When the time comes to charge a battery, the Peukerts effect also comes into play. The capacity of a battery to absorb a charge during the bulk phase is also dependent on its Peukerts number. This is one of the reasons why AGM cells can be bulk charged at much higher rates than either Gel or Flooded cells.

Reserve Minutes

Reserve Minutes are a measure of how long your battery can sustain a load before its available capacity has been completely used up. This measure is especially useful for folks who want to run inverters,

fridges, and other large loads. The following chart has a logarithmic time scale (minutes) - hence, the non-linear nature of the Peukert effect is smoothed out quite a bit.



Note how batteries that have a high Peukerts Exponent will quickly run out of capacity with high loads. Here, the low-exponent battery will last over 100 minutes with a 50 ampere load, while the high-exponent battery will last about 20 minutes. Thus, anytime you deal with large loads relative to the battery capacity available, chose a low-exponent battery. This is why many wheel-chairs and other electrically motorized vehicles use AGMs.

This chart answers why starter batteries are built to have a low Peukerts exponent. Otherwise, they'd simply not be able to crank an engine for more than a few seconds. However, the thin plates that allow flooded cells to work as starter batteries also make them too fragile for deep-cycle use.

Conversion Efficiency

The conversion efficiency denotes how well a battery converts an electrical charge into chemical energy and back again. The higher this factor, the less energy is converted into heat and the faster a battery can be charged without overheating (all other things being equal). The lower the internal resistance of a battery, the better its conversion efficiency.

One of the main reasons why lead-acid batteries dominate the energy storage markets is that the conversion efficiency of lead-acid cells at 85%-95% is much higher than Nickel-Cadmium (a.k.a. NiCad)

at 65%, Alkaline (a.k.a. NiFe) at 60%, or other inexpensive battery technologies.

Battery Life

Battery manufacturers define the end-of-life of a battery when it can no longer hold a proper charge (for example, a cell has shorted) or when the available battery capacity is 80% or less than what the battery was rated for. The life of Lead Acid batteries is usually limited by several factors:

- *Cycle Life* is a measure of how many charge and discharge cycles a battery can take before its lead-plate grids/plates are expected to collapse and short out. The greater the average depth-of-discharge, the shorter the cycle life.
- *Age* also affects batteries as the chemistry inside them attacks the lead plates. The healthier the "living conditions" of the batteries, the longer they will serve you. Lead-Acid batteries like to be kept at a full charge in a cool place. Only buy recently manufactured batteries, so learn to decipher the date code stamped on every battery... (inquire w/manufacturer). The longer the battery has sat in a store, the less time it will serve you! Since lead-acid batteries will not freeze if fully charged, you can store them in the cold during winter to maximize their life.
- *Sulphation* is a constant threat to batteries that are not fully re-charged. A layer of lead sulphate can form in these cells and inhibit the electro-chemical reaction that allows you to charge/discharge batteries. Many batteries can be saved from the recycling heap if they are *Equalized*

Equalization

Sulphation layers form barrier coats on the lead plates in batteries that inhibit their ability to store and dispense energy. The equalization step is a last resort to break up the Sulphate layers using a controlled overcharge. The process will cause the battery electrolyte to boil and gas, so it should be only done under strict supervision and with the proper precautions.

It is much more tricky to equalize a VRLA battery than a flooded battery with removable caps. However it apparently can be done as described at the [Ample Power web site](#). Since I do not have the space here to describe the Equalization process in detail, [I'd consult some of the links on the index page instead.](#)

Gassing

Batteries start to gas when you attempt to charge them faster than they can absorb the energy. The excess energy is turned into heat, which then causes the electrolyte to boil and evaporate. The evaporated electrolyte can be replenished in batteries with *removable caps* such as most flooded deep-cycle batteries. Many car batteries are *sealed* and thus need to be replaced when their electrolyte evaporates over time.

Since AGM and Gel cells are always sealed, it is very important to guarantee they are not overcharged. The only way to ensure this is to use a *temperature-compensated* charging system. Such chargers use a temperature probe on the battery to ensure that the battery does not get too hot. As the battery heats up, the charging current is reduced to prevent thermal runaway, a very dangerous condition.

Thermal Runaway

This is a very dangerous condition that can occur if batteries are charged too fast. One of the byproducts of *Gassing* are Oxygen and Hydrogen. As the battery heats up, the gassing rate increases as well and it becomes increasingly likely that the Hydrogen around it will explode. The danger posed by high Hydrogen concentrations is one of the reasons that the [American Boat and Yachting Council \(ABYC\)](#) requires that batteries be installed in separate, well-ventilated areas.

Self-Discharge

The self-discharge rate is a measure of how much batteries discharge on their own. The Self-Discharge rate is governed by the construction of the battery and the metallurgy of the lead used inside.

For instance, flooded cells typically use lead alloyed with Antimony to increase their mechanical strength. However, the Antimony also increases the self-discharge rate to 8-40% per month. This is why flooded lead-acid batteries should be in use often or left on a trickle-charger.

The lead found in Gel and AGM batteries does not require a lot of mechanical strength since it is immobilized by the gel or fiberglass. Thus, it is typically alloyed with Calcium to reduce *Gassing* and *Self-Discharge*. The self-discharge of Gel and AGM batteries is only 2-10% per month and thus these batteries need less maintenance to keep them happy.

Battery Group Size

To further complicate matters, manufacturers for marine batteries make them in all sorts of sizes and voltages. Battery case sizes are typically denoted by a "*Group Size*" which has nothing to do with the actual size of the battery. For example, Group 8D batteries are much larger than Group 31 batteries. Here are some examples:

Table of Battery Group Sizes, Voltages, and Approximate Exterior Dimensions:

	Battery Group										Units
	21	24	27	30H	31	4D	8D	T105	GPL4C	L16	
Voltage	12	12	12	12	12	12	12	6	6	6	Volts
Length	8.19	10.25	12.06	13.5	13	20.75	20.62	10.38	10.35	11.62	inches
Width	6.81	6.81	6.81	6.81	6.72	8.75	10.95	7.13	7.06	7	inches
Height	8.75	8.87	8.75	9.25	9.44	9.88	10.17	11.2	11.57	17.56	inches

Note: Dimensions are approximate and vary by manufacturer. Consult manufacturer data sheets for exact dimension of container, location and type of terminals, etc.

The group size will merely indicate the approximate exterior dimensions (including terminals) and voltage of the battery in question. However, the exact dimensions can only be directly obtained from each manufacturer.

Nickel-Cadmium Cells

Several people have inquired about NiCad cells for Marine environments. I am not a great fan of them due to their toxicity and their low power conversion efficiency. [See my NiCad info page for more information about the pros and cons of NiCad technology for marine applications.](#)

Now that we understand the lingo, [let's move on to the differences between the various types of lead-acid batteries.](#)



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Battery Types: Flooded versus AGM and Gel

On the kinds of batteries we may use on board:

The most common kind of battery in Marine use today is the lead acid battery. Using an electrolyte consisting of sulphuric acid, these cells can store impressive amounts of electrical energy in a relatively small space. This energy is stored in chemical form within lead grids mounted inside the battery. The reliance on lead grids and paste explains the great heft of lead-acid batteries.

The battery universe is further divided along the lines of battery construction. Currently, there are three common lead-acid battery technologies: Flooded, Gel, and AGM.

- *Flooded or Wet Cells* are the most common lead-acid battery-type in use today. They offer the most size and design options and are built for many different uses. In the marine business, they usually are not sealed so the user can replenish any electrolyte the battery vented while charging the battery. Typically, the cells can be access via small ~1/2" holes in the top casing of the battery.

The plastic container used for flooded cells will have one or more cells molded into it. Each cell will feature a grid of lead plates along with an electrolyte based on sulphuric acid. Since the grid is not supported except at the edges, flooded lead-acid batteries are mechanically the weakest batteries.

Since the container is not sealed, great care has to be taken to ensure that the electrolyte does not come into contact with you (burns!) or seawater (chlorine gas!). The water needs of flooded cells can be reduced via the use of Hydrocaps, which facilitate the recombination of Oxygen and Hydrogen during the charging process.

- *Gel Cells* use a thickening agent like fumed silica to immobilize the electrolyte. Thus, if the battery container cracks or is breached, the cell will continue to function. Furthermore, the thickening agent prevents stratification by preventing the movement of electrolyte.

As Gel cells are sealed and cannot be re-filled with electrolyte, controlling the rate of charge is very important or the battery will be ruined in short order. Furthermore, gel cells use slightly lower charging voltages than flooded cells and thus the set-points for charging equipment have to be adjusted.

- *Absorbed Glass Mat (AGM)* batteries are the latest step in the evolution of lead-acid batteries. Instead of using a gel, an AGM uses a fiberglass like separator to hold the electrolyte in place. The physical bond between the separator fibers, the lead plates, and the container make AGMs spill-proof and the most vibration and impact resistant lead-acid batteries available today. Even better, AGMs use almost the same voltage set-points as flooded cells and thus can be used as drop-in replacements for flooded cells.

Basically, an AGM can do anything a Gel-cell can, only better. However, since they are also sealed, charging has to be controlled carefully or they too can be ruined in short order.

Gel and Absorbed Glass Mat batteries are relative newcomers but are rapidly gaining acceptance. There are some very compelling reasons to use VRLAs:

- Gel and Absorbed Glass Mat (AGM) batteries can dispense charge at a higher rate than flooded cells due to their lower Peukerts exponent. Deep-cycle Flooded Cells cannot deliver more than 25% of their rated amp-hour capacity in amps without plummeting Available Capacity.
 - Deep-Cycle Flooded cell battery manufacturers recommend a 4 to 1 ratio between battery bank size and the largest load encountered on board.
 - AGM and Gel cell manufacturers recommend a ratio of at least 3 to 1, a significant difference for loads such as the engine starter or windlass.
- Virtually no gassing under normal operating conditions: Unlike flooded cells, gel cells and AGMs are hermetically sealed and operate under pressure to recombine the oxygen and hydrogen produced during the charge process back into water. You find VRLAs in the bilges of high end yachts such as Hinckley, Hans Christian, Island Packet, etc.. Every boat benefits from a low center of gravity over the keel (good for righting purposes) and the minimal venting requirements make it possible.
- The ability to put VRLAs in the bilges (they can operate under water should you hole yourself) also lengthens their lives: For every additional 15 degrees of heat over 77 deg F, lead acid battery life (regardless of type) is cut in half (batteries self-destruct with time, you can only slow that process). Chances are, the bilges are the coldest place on board (outside the freezer) and the keel provides protection.
- VRLAs can operate in any orientation (although you may lose some capacity that way) and even if a container is broken, a VRLA will not leak. This is a feature particularly important to blue water sailors who may encounter survival storms - you don't want to coat the inside of your boat with sulfuric acid if you ever get rolled. Proper (heavy duty) battery restraints are a must, regardless of battery type.
- Gel cells and AGMs require no maintenance once the charging system has been properly set up. No equalization charges (usually), no electrolyte to replenish, no specific gravity checks, no additional safety gear to carry on board in order to protect yourself. If you want to be anal retentive about VRLAs you can load test them. However, proper charge control and protection is much more important with VRLAs because once fried it is impossible to revive them.
- The charge acceptance of AGMs can burn up an alternator. So if you're going to use AGMs on board, ensure you have a high quality charge system from a respected company such as [Ample Power](#), [Balmar](#), [Ferris](#), [Hehr](#), [JackRabbit Marine](#), [SALT](#), etc. Ensure that the alternator receives enough cooling air as a hot alternator will produce less energy than a cool one and last longer to boot. AGMs and to a lesser extent gel cell systems can benefit from using the thermal alternator protection offered by the Balmar [MaxCharge series](#) of regulators, particularly if you expect to bulk charge your system for extended periods of time and don't have good engine compartment ventilation.
- The higher charge efficiency of AGMs allows you to recharge with less energy: Flooded cells convert 15-20% of the electrical energy into heat instead of potential power. Gel-cells lose 10-16% but AGMs as little as 4%. The higher charge efficiency of AGMs can contribute to significant savings when it comes to the use of expensive renewable energy sources (wind generators, solar

panels, etc.) as your charging system can be 15% smaller (or just charge faster).

- While flooded cells lose up to 1% per day due to self-discharge, VRLAs lose 1-3% *per month*. Why employ a solar charger to trickle-charge your battery banks if you don't have to?
- High vibration resistance: The construction of AGMs allows them to be used in environments where other batteries would literally fall to pieces. This is another reason why AGMs see broad use in the aviation and the RV industry.

Thus, there are some significant differences between battery types in terms of features and construction. However, there are also some very important figures to consider when it comes to choosing the right battery: Various capacities, cost, warranty, etc. The following table tries to summarize across brands using batteries as close to the 8D Group Size as possible

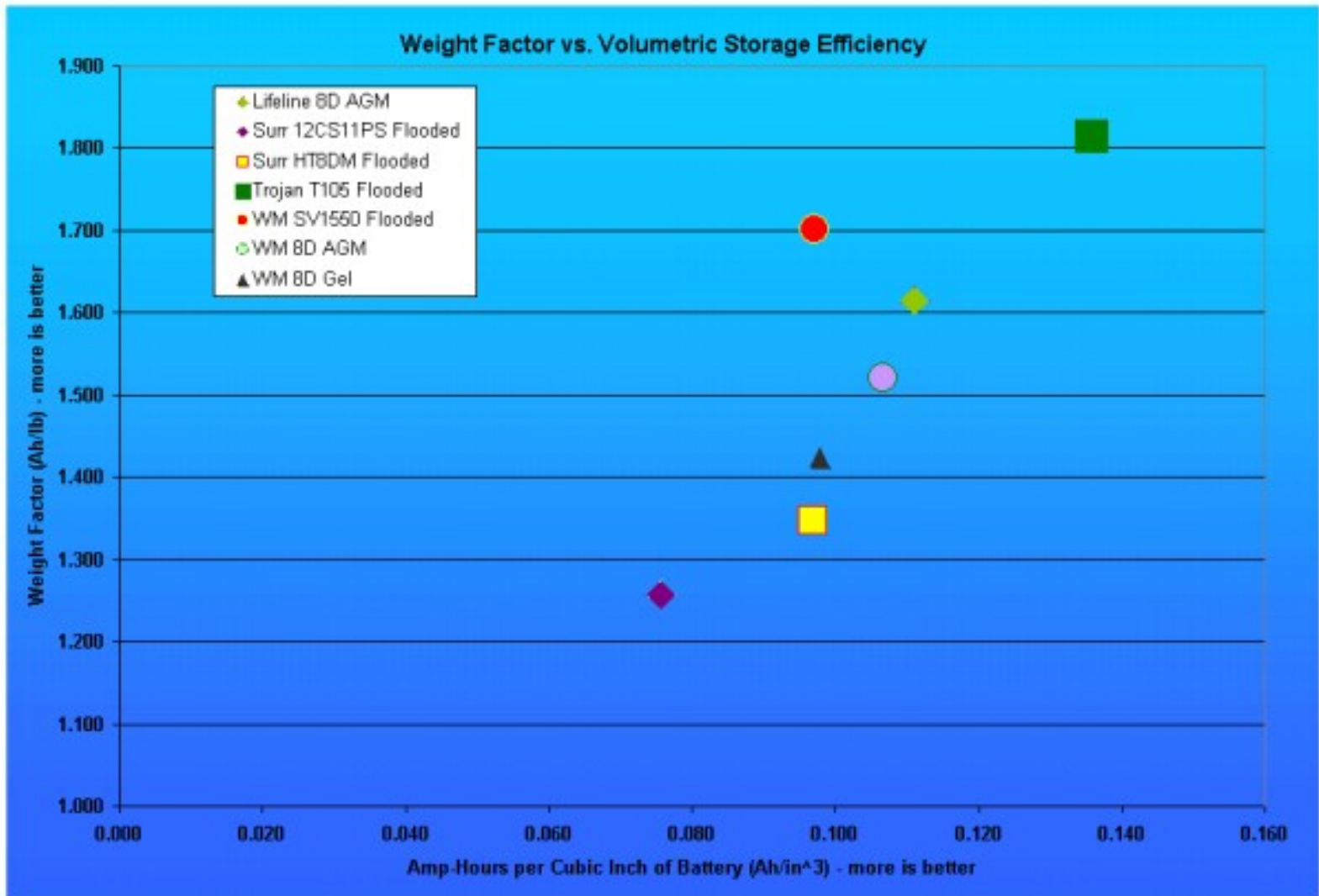
Comparison of Battery Types using several different measurements

Comparing physical attributes between VRLAs and Flooded Cells	VRLA			Flooded	
	Lifeline AGM (8D)	West Marine Gel (8D)	Inexpensive Trojan (2xT105)	Premium Surrrette 400 (HT8DM)	Premium Surrrette 500 (12CS11PS)
Amp-hour capacity (20hr rate)	255	225	225	221	342
Warranty (Replacement/Pro rated)	1/5 Years	1.5/5 Years	0.5/3 Years	2/5 Years	3/7 Years
Life Cycles (@ 50% DOD)	1,000	500	500	1,250	3,200
Initial Purch. Cost (USD/12V set)	387	449	152	246	683
Initial Purch. Cost (approx. \$/Ah)	\$1.52	\$2.00	\$0.68	\$1.11	\$2.00
Energy Density (Ah/in³)	0.111	0.098	0.136	0.097	0.076
Weight Factor (Ah/lb)	1.614	1.424	1.815	1.348	1.257
Max. net replenishment during bulk charge, accounting for charge limits, efficiency and assuming a 400Ah battery bank	1550A*	177A	85A	85A	85A

I tried to level the playing field by selecting as many group 8D batteries as possible. The two exceptions are the Trojan T105's and the Surrrette 12CS11PS (no series 500 Group 8D battery is manufactured by Surrrette for the marine market). The larger battery size is to the advantage of the Surrrette, although it does not impact results greatly. The Trojan T105's were used because I was not able to find ready pricing on the Trojan 8D. I would expect results to be somewhat comparable.

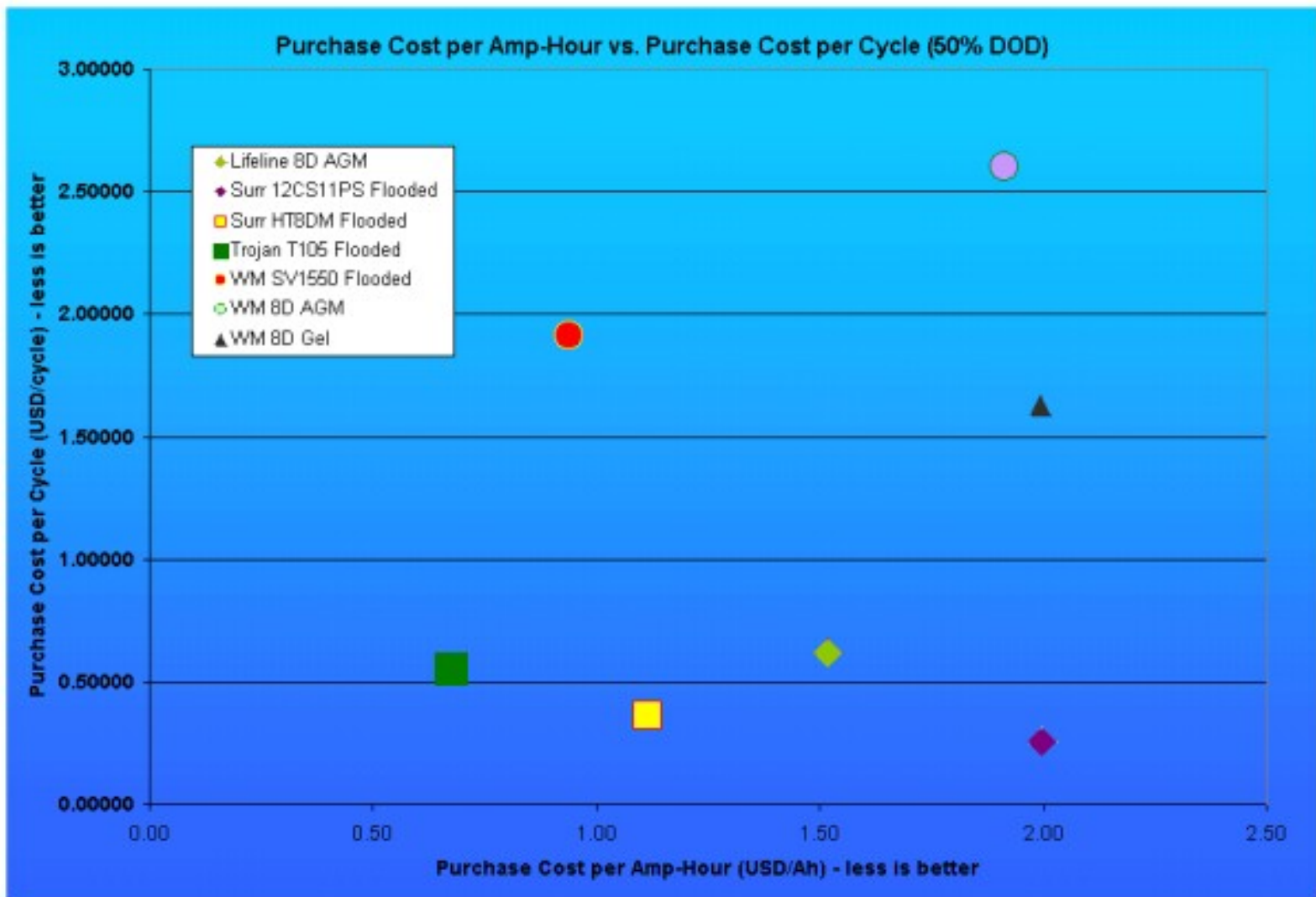
*Concorde Batteries used to claim no charge limit [on its web-site](#), while [Windsun.com](#) claims 4x amp-hour capacity. I limit charge current in the cost model to 100% of amp-hour capacity just to be on the safe side.

Energy Storage per unit Weight and Volume



Here is one of the classic comparisons that people like to make: How much charge the battery can store per unit weight and per unit volume. As you can see, the Trojan T105 comes out ahead in both departments due to its low weight and compact construction. However, this construction technique will also lead to a lower cycle and overall life.

Purchase Cost per unit Weight and Volume



As we can see from this chart, the purchase cost per amp-hour and purchase cost per cycle still make the Trojan T105 look like the most attractive battery. Thus, if you are strapped for weight, space, and cash, such a battery might be ideal. The Trojan product has thin lead plates that make these batteries lighter but also shorter lived. Rolls advertises very long pro rata warranty replacement periods for their premium line that are indicative of the confidence they place in their product.

Premium cells are handicapped by lower energy storage density but offer longer lives and greater resistance to the self-destructive habits of lead acid batteries: Thicker lead plates and a more complicated product make it possible. Hence, premium cells usually have a higher resistance to vibration, are easier to service, and have higher cycle lives than their budget competition. Many boat owners are willing to put up with the initial purchase price in return for reliability and not having to replace them every few years.

So what is a "Marine" Battery?

Perhaps it's shocking considering their retail prices, but most batteries sold through marine hardware stores do not qualify as premium batteries. Pay close attention to what you're buying. Batteries are not created equal and *brand or price are not the primary indicator for quality*. For example:

- Rolls/Surrette make a range of flooded batteries from the super-premium 500/CS series to the mid-range 300 series that is meant to compete with Trojan, Exide, etc.

- [WestMarine](#) is offering AGM batteries with a shorter warranty period and higher price than [Lifeline AGMs](#).

Thus, Caveat Emptor! Try to get as much information about your prospective marine batteries before you buy or you'll be sorry. Furthermore, consider that premium batteries usually only exist in non-standard form factors. For example, you will probably have to make some custom modifications to properly mount/restrain the tall and heavy Rolls/Surette 500 series (18"+ high, min. 128 lb+ each).

However, life cycle costs are not just a function of the initial purchase costs. You should also consider the fuel/engine wear savings of using VRLAs over flooded cells. AGMs offer the highest charge acceptance, efficiency, and a reasonably long life which makes them generally a better bargain ([see results in cost model section](#)). Unfortunately, there are fewer shapes and sizes of VRLAs to chose from (relative to the flooded cell universe anyway), and less familiarity and presence world-wide. On the other hand, VRLAs can be shipped anywhere by air. Flooded cells have to be bought locally or delivered by surface transport.

I used DEKA gel cells in the past for comparisons, but West Marine recently brought out a private label 6V gel cell series that they claim will sustain over 1,000 "full discharges". Given that reputable brands never claimed more than [600](#) cycles in the past, the West Marine claim may be a bit dubious. Due to West Marine's return policy, I'll give them the benefit of the doubt. West Marine also released a set of private label AGMs. Unless I'm missing something, these are very expensive and have a much lower cycle life than the Lifeline competition manufactured by Concorde Batteries. Thus, I don't see why anyone would want to buy a West Marine AGM.

Can I Mix AGMs and Flooded Cells?

While several sources state that you can mix AGMs with regular flooded cells, I would not recommend it (gel cells have sufficiently different set points to make them totally incompatible with flooded cells or AGMs). Ideally, your house bank would consist of a number of identical batteries wired in series and/or parallel that were manufactured on the same day.

So how can I save money with AGMs?

There are many attributes that determine the true cost of a battery technology. Much like incandescent versus compact fluorescent light bulbs, your choice of battery technology may cost you less up front but will cost you more over the life of the product. For example, the faster, more efficient bulk charging that AGMs and gel-cells allow will lead to reduced wear and tear on your charge source (engine, gen-set, etc.). More on all that later down. Suffice to say that I do not believe the T105 to be a bargain.

How about Nickel-Cadmium Cells?

They have their place. Usually in power plants where there is lots of excess energy, etc. Learn more about them on my [Nickel-Cadmium page](#).

Anyway, onwards to [sizing and charging requirements!](#) This is where Lifeline AGMs really start to shine, assuming your charging system can take advantage of them.



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Sizing a Lead-Acid Battery Bank

(Gel,AGM, or Flooded)

Industry recommendations for house battery bank sizing range from 3x to 4x of anticipated daily needs. This sizing also allows you to replenish the daily needs using a bulk charge in a minimum of time (batteries can be bulk charged until they are 80% full). Typical installations are also sized so that the battery does not discharge below the 50% mark that marine battery manufacturers typically use in their life-cycle estimates (the deeper you discharge a lead acid battery, the shorter its life).

Once batteries are 80% full a typical 3 stage charger will switch to absorption mode, where currents are much lower and charge time per unit energy necessarily longer. Thus, in order to minimize charge time while maintaining acceptable battery cycle life, you want to cycle the battery from 50% or more to 80% full.

- Flooded cells are usually bulk-charged at an ampere rate of about 25% of amp-hour capacity. For example, let's say you have to replace 100 Ah every day and chose to install a 400 amp-hour house battery bank. Using the 25% ratio, the maximum charge acceptance (the rate at which the battery can be safely charged) of your flooded battery during bulk charging would be around 100A. Assuming you have no other charge sources on board, after losses and other loads you would want to consider a 120 ampere (hot) rated alternator.
- If you use Gel cells, you can bulk charge with twice the current that flooded cells can sustain. A 400 amp-hour bank composed of gel cells can safely enjoy the benefits of a 200A charge source and bulk charge in less than 1/2 the time of a flooded cell (due to its higher charge conversion efficiency). Here, multiple small frame or a single large frame alternator may be ideal in order to reduce charge time and engine wear.
- The Lifeline AGM, is not current limited at all during bulk charging according to Concorde, the manufacturer. Theoretically, you could make your bulk charge time as short as you would like. In practice, people are charging AGMs with currents of up to 4x the amp-hour capacity. Accounting for conversion efficiency that would be 18x faster than your typical flooded cell but you'd have to install a charge system capable of delivering 1600 amperes to the battery bank (it would take about 5 minutes per day to replenish the 100 Ah with a 20 kW gen-set). In the real world, two large frame alternators may be more appropriate from a weight/cost standpoint.

Some important points to Remember When charging Batteries:

Any time your charge system is significantly smaller in ampere capacity than the charge acceptance of your battery banks, you need to ensure that the charging system can handle extended periods of maximum output. For example, the alternator that was easily capable of dealing with 400 amp-hours of flooded cell capacity could burn up when you switch to AGMs since AGMs can bulk absorb a lot more charge. However, installing a 4x bigger flooded cell bank could have the same effect.

The charge system has to be properly sized and protected to safely charge your batteries. Assuming you use your engine to charge, a KKK-rated alternator helps, as does thermal management. Alternators [should be well ventilated](#) and may even benefit from the Balmar [MaxCharge](#) system that senses alternator temperature to avoid costly burn-ups. At the very least use a good 3-step external regulator such as the Next-Step from Ample power. Your batteries and your wallet will thank you.

Lastly, fully recharge your banks from time to time (at least once a month) to ensure that sulphation does not set in. Sulphation can be removed through an equalization process, which is basically a controlled overcharge. Unfortunately, equalization attacks the lead plates and will weaken them over time. Furthermore, it is quite dangerous (the electrolyte will start to boil) and should only be done in controlled conditions and under strict supervision. Thus, equalization should be used as a last resort only.

VRLA batteries like Gel and AGM cannot be equalized using the same settings as wet cells. The electrolyte in them cannot be replenished the way it can in wet cells. Thus, any charger you attach to VRLAs should have the equalization circuit turned off (many chargers have a Gel and AGM setting for just that purpose). Most modern regulators have one way or the other of achieving this, whether it is a set of dip switches, a menu, or adjustment screws.

For the adventurous (or desperate) among us, VRLAs can be equalized under very controlled conditions. I recall instructions on how to do it over at [Ample Power](#) but don't seem to be able to find them right now. Since VRLAs are unlikely to need equalization, this step should be a last resort only (prior to recycling the batteries).



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Why you only want two battery banks on board:

Minimizing the number of battery banks maximizes battery life. Most reasonably sized boats only need two battery banks: One bank to start the engine, the other to power all other loads on board. While an emergency switch to combine them should exist (to use your house bank help start the engine if the engine bank is down), the two banks and circuits should be completely separate. There are several benefits:

Your starter bank is always full:

While starting engines requires a lot of power, the burst is relatively short. Thus the net drain on your starter battery is small and even a short commute out of the harbor will pretty much replenish the charge that had been used to start the engine. If you accidentally run the house bank flat, you can still start the engine and recharge the house bank.

Most external regulators have outputs that allow you to drive a solenoid that combines the two battery banks during charging and disconnects them afterwards. You can also use battery combiners to achieve the same effect. I would stay away from diode systems because of the voltage losses associated with them. A more elaborate, battery life maximizing solution can be found in the [isolator/eliminator](#) manufactured by Ample Power that treats your starter bank as a completely separate bank and charges it accordingly.

Your electronics will behave better:

When the starter and the house banks are completely separate your electronics and other circuits will not experience the voltage transients that starting an engine produces. For example, our electronics would drop out every once in a while during engine starts, suggesting that the voltage levels on board dropped below the 10V threshold that the instrument and GPS package could still run on.

Battery banks last longer, provide more charge:

Less depth of discharge and lower rate of discharge (i.e. battery bank Amp-hour capacity vs. discharge) will make your batteries last longer in terms of cycle life and in terms providing energy. In his excellent tome on boat maintenance, the ["Boatowners Mechanical and Electrical Manual"](#), author Nigel Calder provides convincing arguments why a large bank of cells will always outperform the constituent batteries by themselves. [Ample Power](#) and other manufacturers of charging systems come to the same conclusion.

Not only will a collective bank be affected less by Peukerts Effect (the smaller the rate of discharge, the more juice you can extract from a battery or battery bank) but the depth of discharge for a large bank will

be less than if a constituent battery had to carry the load alone. Depth-of-Discharge (DOD) is one of the most important variables that determines the life of your batteries. The faster, deeper you charge/discharge lead acid batteries, the shorter their life.

Some things to keep in mind:

The only caveat to large banks of batteries is proper internal fusing. If a cell shorts out in a battery, the battery voltage will drop approximately 2 Volts. All batteries in the bank will start discharging into the shorted battery, unless fuses take the bad battery out of the circuit. Thus, battery banks need to be fused internally as well as externally.

Remember, your entire electrical system has to meet all requirements: Wires, fuses, chargers, batteries, alternators, etc. The [ABYC](#) requirements are a good first step in that direction and guides such as Mr. Calders are easy to understand. More fusing and wiring information can be found at [Blue Sea Systems](#).

Onwards then to some [Cost Comparisons!](#)



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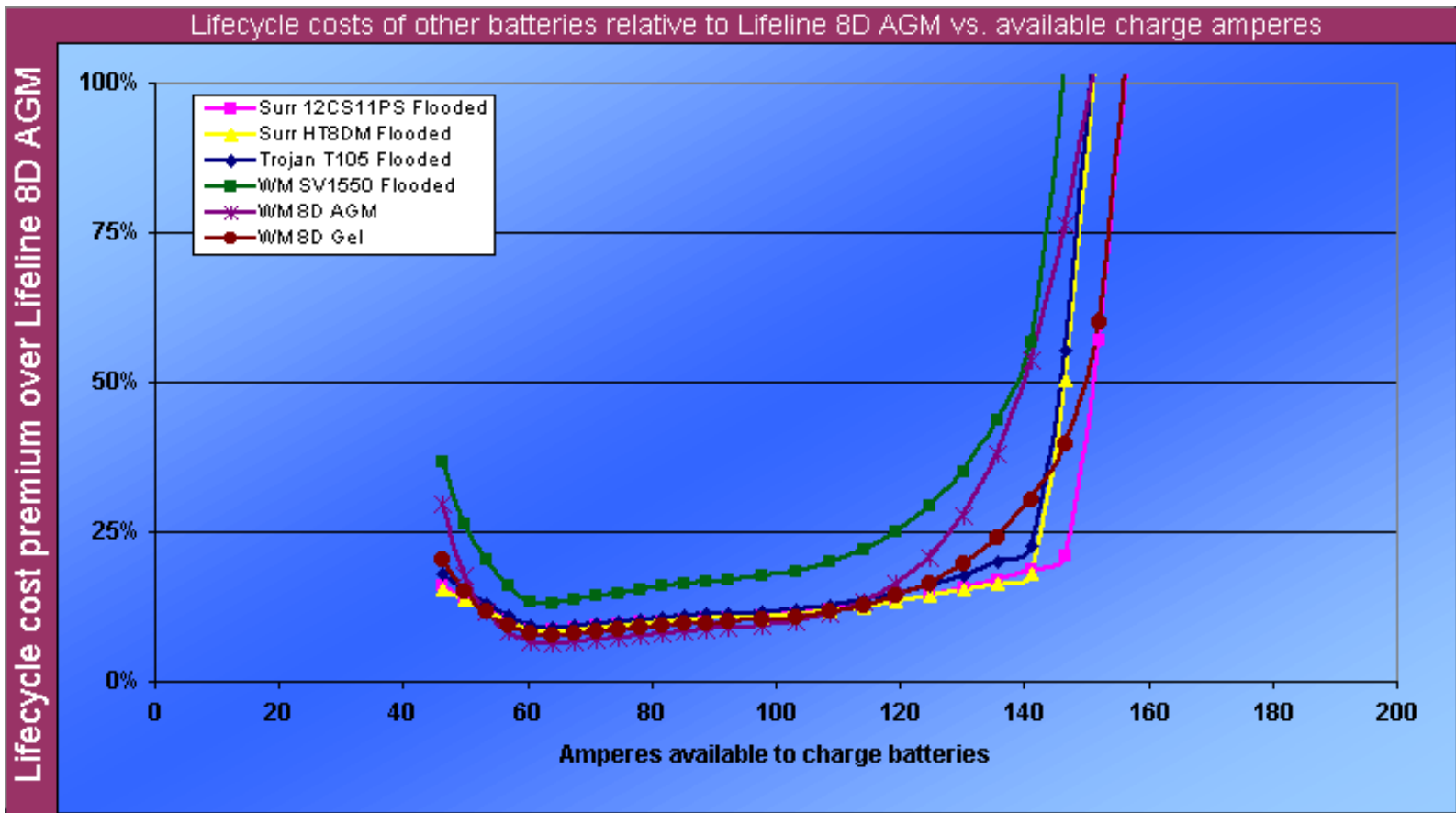


Comparing Life-Cycle Costs By Battery Technology

Assuming you use your engine to recharge your batteries, how much savings does the use of AGMs translate into? I created a spreadsheet that calculated the results below. This spreadsheet accounts for just about everything: Starting with the loads on board, you arrive at a bank capacity recommendation. This battery bank can then be recharged by a variety of means: Solar, Wind/Water, Gen-Set, and engine. Each of these charge sources is properly "costed" (depreciation, maintenance, fuel costs). Using other information, such as how many days you spend on board per year (to enjoy the fruits of your labor) you can then compare system costs.

The default settings in the cost model reflect the loads on our boat, the [Cat's Pyjamas](#). Using a 4x multiplier, we need about 400 amp-hours of capacity in the house bank. We currently have no means to charge the system save for our engine (although solar panels look pretty attractive) and after a few inputs the model goes to work. Battery parameters are based on published manufactured specifications and costs are extrapolated for a given house bank capacity. I assume year-round occupation (i.e. 1 cycle per day) and tried to keep things even by trying to standardize on group 8D batteries.

In the below comparison are Lifeline AGMs (8D) as a baseline, premium Surrette flooded cells (the 400 series model HT8DM and the 500 series model 12CS11PS - they don't make a 500 series 8D marine battery), inexpensive Trojan flooded cells (model T105 - also non 8D), and West Marine AGM and gel cells (8D). More batteries can be chosen from or added to the small database in the model.

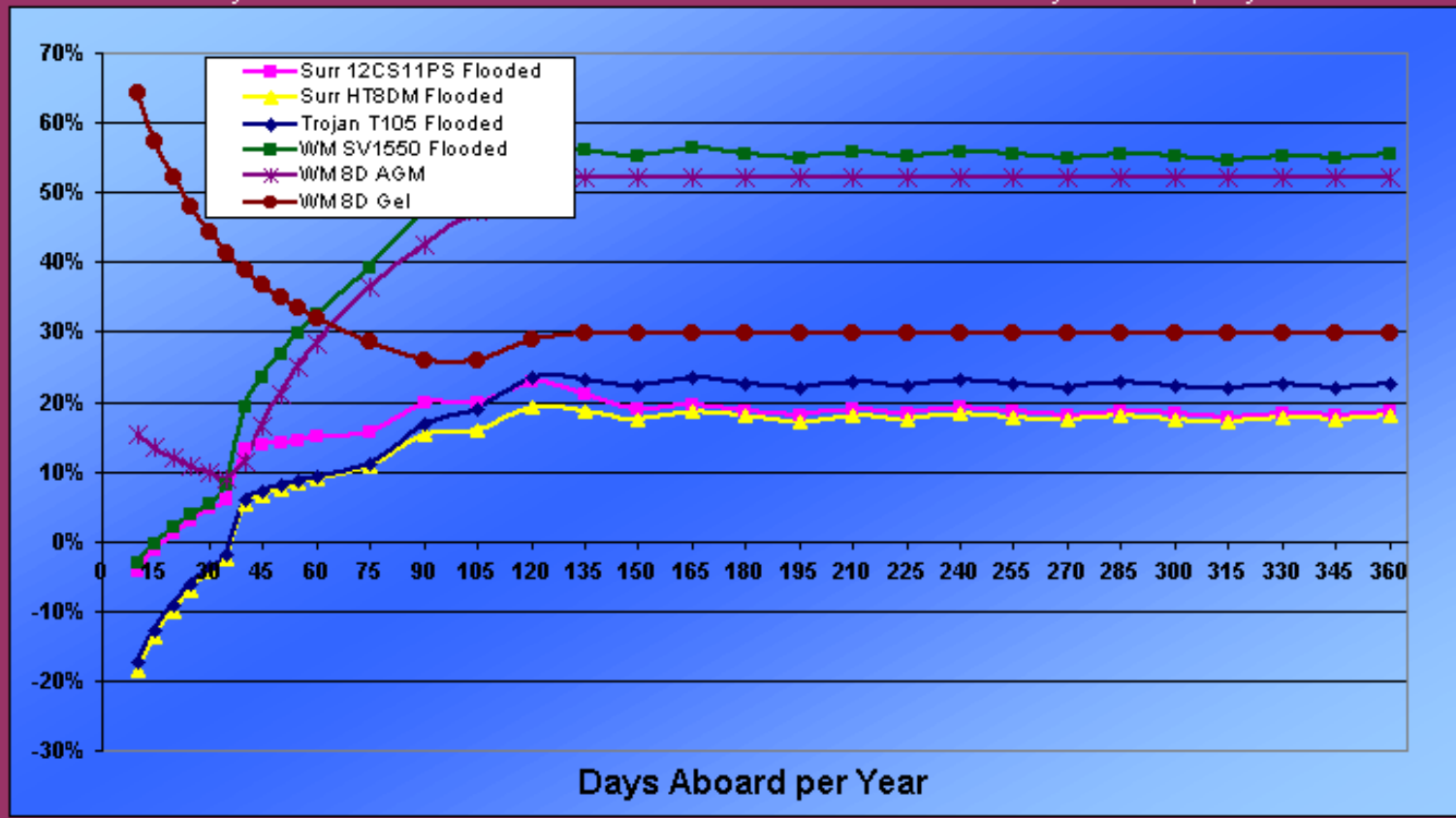


As expected, the flooded cells do best when the available charge amperage is at 25% of the amp hour capacity of the battery bank. Gels hit the same kind of pivot point at 50% of Ah capacity. But all costs considered, Lifeline AGMs are cheaper to use. Note: I am not accounting for self-discharge losses, AGM ampere charge acceptance has been limited to 100% of battery bank amp-hour capacity.

The much lower cycle life of West Marine AGMs make them progressively more expensive as charge capacity is increased. In order to allow fair comparisons the cost model allows you to switch batteries. However, the model levels the playing field in terms of cost by using \$/Ah figures. Thus, larger batteries will always have an advantage - but they may not be applicable. Ideally, you should use batteries that are close to or a multiple of the desired Ah capacity. For example, if Lifeline Group 8D's offer 255Ah and I need a 500Ah bank, that is a perfect match while the 360 Ah offered by the Trojan L16 would be too low or too high (i.e. 360 Ah vs. 720 Ah).

Lifecycle costs of other batteries relative to Lifeline 8D AGM vs. days aboard per year

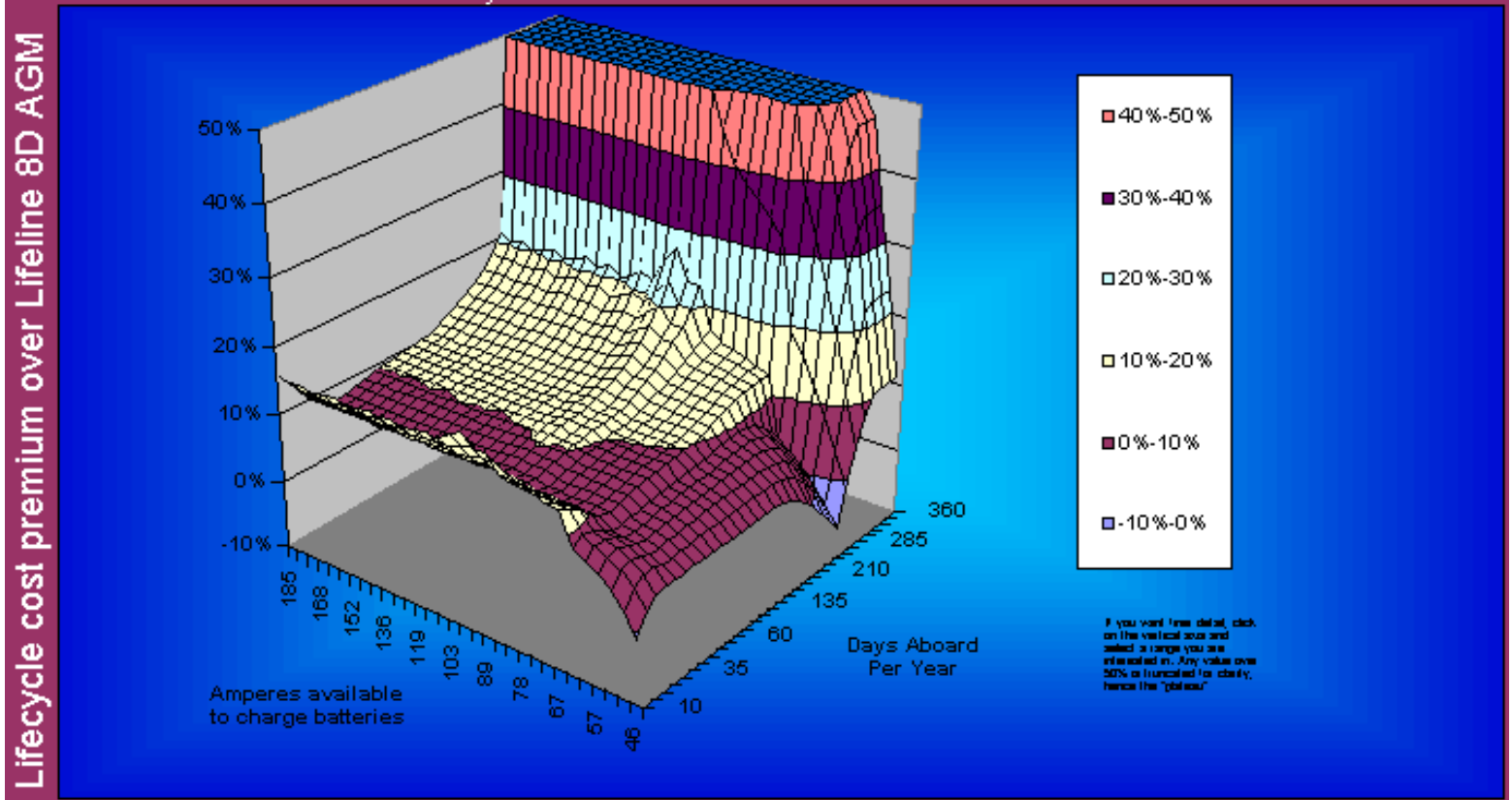
Lifecycle cost premium over Lifeline 8D AGM



Well, but how do my sailing/cruising habits influence the outcome? To answer that question, you can adjust how many days per year you expect to use your boat. Given our assumptions, someone who spends more than 3 months aboard can save at least 15% by using Lifeline AGM battery storage technology.

Then you can combine the two variables and see how and when it becomes less expensive to use a Rolls CS series battery instead of an Lifeline AGM. For example, for the given loads and the size of the battery system, a small alternator / low occupancy rate results in no advantage of AGM system costs over flooded technology. However, even moderately powerful charging system and occupancy rates clearly benefit the cost effectiveness of AGM batteries.

Lifecycle costs of Surr 12CS11PS relative to Lifeline 8D



The cost premium is expressed in percent. The brown and blue spot in the lower right hand corner is the area where AGMs are less cost effective than Surrette CS series flooded cells (by up to 11%). All other areas suggest that the AGM is more cost effective. Each color "step" denotes a ten percent change, much like a topographical map shows elevation rings. The map tops out at 50% in order to increase resolution - the peaks go higher in those regions.



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How the Model Calculates Life-Cycle Costs

Throughout the model, all white fields are for you to modify. The shaded sections contain calculations... any modification to them would invalidate the results.

The loads input page collects all the items that you may have on board. You enter amp draws and duration, the model then calculates your daily amp-hour needs. The runtime load influences the amount of current that can be used to refill your batteries. This benefits flooded battery users in particular, since their batteries tend to absorb less energy than AGM or Gel batteries. The assumption is that run-time loads are satisfied before charging can take place.

Naturally, the model compensates for reduced charge requirements if house loads on batteries are "avoided" during recharge. More on this in the ReadMe file that accompanies the cost model. Also, keep in mind that these results are for BULK charging **only**. All lead-acid battery types revert to much lower charging rates during absorption and float. I also built a model to deal with this, although it is much more involved than the simple bulk charging model shown here. Send me an e-mail if interested (see link below)

Loads that turn on and off regardless of the engine. Estimate time on a per day basis.		Standby Current (Amps)	Standby Time (Hours)	High Current (Amps)	HC Time (Hours)	Ah/Day	Loads that turn on with the engine	Current Draw (Amperes)
Nav	Instruments			0.5	10.0	5.0	Paralell Solenoid	0.9
	GPS			0.5	10.0	5.0	Isolator/Eliminator	
	DGPS			0.5	10.0	5.0	Water maker	
	Autopilot	0.1	8.0	5.0	1.5	8.3	Refrigerator	
	Radar	2.3	4.0	3.9	2.0	16.8	Freezer	
	VHF	0.8	8.0	5.0	0.2	7.2	Blowers	8.8
						0.0		
					0.0			
Lights	Cabin			5.0	3.0	15.0	Avg. Runtime Load	13.7
	Navigation			1.0	3.0	3.0	Estimated House Load during recharge (amps)	4
	Anchor			1.0	8.0	8.0	Enter Data to the right to determine the required battery capacity. Also fill in the chart above to determine how much current is drawn from the alternator while it is running. For greater accuracy, add a house load during recharge (however, it is NOT required).	
						0.0	Be conservative. Make your estimates for average days. The required battery capacity is set at 4x of daily needs calculated here.	
Amenities	Refrigerator					0.0	The data I have entered is representative of the equipment we have on board. Your equipment may be different. Consult manuals for ampere draws and estimate daily hours based on experience.	
	Stereo					0.0	Copyright by Constantin von Wentzel battery@vonwentzel.net Use at your own Risk	
	Inverter					0.0		
	Air Conditioning					0.0		
Misc.	Battery Monitoring	0.1	24.0			2.4		
	Bilge Pumps					0.0		
	Waste System					0.0		
	Windlass			70.0	0.1	5.8		
	Heater System	1.0	2.0	4.0	4.0	18.0		
	LP System			0.5	2.0	1.0		
	Washdown Pump			12.0	0.0	0.4		
	Freshwater Pump			12.0	0.1	1.0		
					0.0			
					0.0			
Total						102.0		

Charge System:		
Daily Charge Needs	102	Ah
System Voltage	12	Volts
Battery Capacity Multiplier	4	
Desired Battery Bank Capacity (Ah)	408	Ah
Non-battery load on alternator (see Household page)	13.7	Amperes
Charge Capacity available to recharge battery	92.3	Amperes
Days Boat is used per Year	365	days/year
Electrolyte & Sulphation Maintenance		
Cost of Electrolyte Water	1	USD/qt
Quarts of water per cell/maintenance	0.25	qt/cell
Days between electrolyte maintenance	31	Days
Days between equalization charges	40	Days
Labor Cost	\$15	USD/hr
Labor hrs to service a 12V Battery set for electrolyte	0.25	hrs

Amp-hour Requirements

The first section of the second page calculates the number of amp-hours needed per day. Then it is up to you to specify the voltage of your system and what kind of capacity multiplier factor you want to use.

The capacity multiplier is a measure of how much larger the battery bank is supposed to be than your daily needs. The most commonly advocated factor is 4x though some practioners go as low as 3x. The question is how much battery reserve you want to or can carry.

Labor hrs to equalize a bank of batteries 1 hrs

Then the model queries how many days a year you intend to use the boat, as well as maintenance costs associated with your batteries. Sulphation and electrolyte maintenance only applies to flooded cells since VRLAs don't require such maintenance.

Solar Cell	
Combined Wattage of panels	W
Avg Hrs. of sunshine/day	hrs/Day
Avg. Amp-Hours produced per Day	Ah/Day
Cost to Buy and install panels and charger	USD
Expected Life	Years
Wind/Water based electrical generator	
Avg. Amp-hours produced per day	Ah/day
Cost to Buy and install	USD
Maintenance Costs USD per Year	USD/Year
Expected Life	Years

The Renewable Energy Section:

The renewable energy section allows you to enter the parameters of your renewable energy sources. We don't have any so our sections are blank. However, you can use this section to see if your net USD/day cost goes down should you install a renewable energy system. Particularly liveaboards can benefit from a relatively low life cycle cost of a renewable energy system.

Gen-Set	
Max Amps	A
Cost w/Installation	USD
Gen-Set Life	hrs
Fuel Consumption	US Gal/hr
Fuel Cost	USD/US Gal
Maintenance \$/1000 hrs runtime (incl labor)	USD

Producing Power with Combustion Engines:

The next section busies itself with combustive ways to generate electricity. Here each source of charge is characterized by life, maintenance costs, etc. As applicable, you should change the parameters to reflect the situation on your boat. At the very bottom you can set the various charge efficiencies by battery type.

Main Engine costs	
Alternator output (hot) during charge	106 Amperes
Engine Cost (w/Installation)	10,000 USD
Engine Life	6,000 hrs
Fuel Consumption	0.5 US Gal/hr
Fuel Cost	1.5 USD/US Gal
Maintenance \$/1000 hrs engine runtime (incl labor)	\$947 USD
Charge Efficiency	
Flooded Cells	83% Percent
Absorbed Glass Mat (AGM)	95% Percent
Gel Cell	87% Percent

Battery #	1	2	3	4	5	6	7	
Battery Used for Comparison	Lifeline 8D	Surr 12CS11	Surr HT8D	Trojan T105	WM SV1550	WM 8D	WM 8D	Make/Model
Battery Type	AGM	Flooded	Flooded	Flooded	Flooded	AGM	Gel	
# of batteries to achieve 12V @ ~408Ah	2	2	2	4	2	2	2	
Amp-hours per set (20 hr rate)	510	684	442	450	446	490	450	Ah
Suitability (the closer to zero the better)	25%	68%	8%	10%	9%	20%	10%	Over/Under desired Ah
Battery Cost (USD)	774	1366	493	304	418	938	898	USD/set
Expected Cycle Life @ 50% DOD	1000	3200	1250	500	200	300	500	cycles
Maximum Battery Life (est)	8	20	10	6	6	8	5	Years
Individual Battery Length	20.62	22	20.75	10.38	20.62	20.62	20.62	in
Individual Battery Width	10.95	11.25	11	7.13	10.95	10.95	10.95	in
Individual Battery Height	10.17	18.25	10	11.2	10.17	10.17	10.17	in
Battery Bank Weight (lb)	316	544	328	248	262	322	316	lb total
Bank Initial Purchase Cost (USD/Ah)	1.52	2.00	1.11	0.68	0.94	1.91	2.00	USD per amp-hour
Volumetric Amp-hour Capacity	0.111	0.076	0.097	0.136	0.097	0.107	0.098	Ah/in^3 at 12V
Weight Factor	1.614	1.257	1.348	1.815	1.702	1.522	1.424	Ah/lb at 12V
Purchase Cost by cycles	0.77400	0.42688	0.39401	0.60800	2.09000	3.12667	1.79600	USD/cycle

The battery properties section allows you to chose batteries by number (the data is on another page). The left-most column is the baseline, the column to the right holds the data for the 3D comparison. In this example, the Lifeline AGM is the baseline, which is compared to a Surrrette 12CS11 on the 3D page.

	Lifeline 8D	Tr 12CS11	Surr HT8D	Trojan T105	WM SV1550	WM 8D	WM 8D	
Max Charge Acceptance	92.30	92.30	92.30	92.30	92.30	92.30	92.30	Amperes
Charge Efficiency (percent converted)	95%	83%	83%	83%	83%	95%	87%	Percent
Bulk Charge Rate	87.685	76.609	76.609	76.609	76.609	87.685	80.301	Amperes
Daily charge time to Bulk Charge	1.113	1.265	1.265	1.265	1.265	1.113	1.210	hrs/Day
Battery Purchase Costs	0.774	0.427	0.394	0.608	2.090	3.127	1.796	USD/Day
E&E Maintenance	0.000	0.669	0.669	0.669	0.669	0.000	0.000	USD/Day
Solar Cell Depreciation	none	none	none	none	none	none	none	USD/Day
Wind/Water Gen Depreciation	none	none	none	none	none	none	none	USD/Day
Wind/Water Gen Maintenance	none	none	none	none	none	none	none	USD/Day
Generator Depreciation	none	none	none	none	none	none	none	USD/Day
Generator Fuel Costs	none	none	none	none	none	none	none	USD/Day
Generator Maintenance	none	none	none	none	none	none	none	USD/Day
Engine Depreciation	1.854	2.109	2.109	2.109	2.109	1.854	2.017	USD/Day
Engine Fuel Costs	0.834	0.949	0.949	0.949	0.949	0.834	0.907	USD/Day
Engine Maintenance	1.053	1.198	1.198	1.198	1.198	1.053	1.145	USD/Day
Totals	4.516	5.352	5.319	5.533	7.015	6.868	5.865	USD/Day
Cost Premium relative to Lifeline 8D	0.044	0.052	0.052	0.054	0.069	0.067	0.058	USD/(Useable Ah Cycle) Premium over Lifeline 8D
		19%	18%	23%	55%	52%	30%	

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I assume you bulk charge and cycle your batteries from 80%full to 55%full. Max AGM charge amps now 4*Ah capacity.

You want to fully charge your batteries at least once a month in order to prevent sulphation

The last section calculates the net cost per day by category and battery type. It also calculates the relative cost premium of each battery technology relative to the Lifeline AGM baseline battery. If a cost does not apply (for example, you don't use a wind generator) the model returns "none".

Downloading the Cost Model:

Properly sizing a battery system to match a load is pretty simple, if tedious. The spreadsheet allows you to input the values from your equipment manuals and see just how much battery capacity you will need. Furthermore, you can compare system costs from battery to battery depending on how much time you spend on board, battery parameters, and charging options. This is the kind of information that magazines should publish because as we consultants like to say: "it all depends".

You can now download two versions of the Bulk Charging Model along with a read me file describing its use in depth. One version is meant for PC users and comes in the .ZIP format. Macintosh users can download a smaller .sit archive.

- [Bulk Charging Model for Macintosh \(Stuffit format\)](#)
- [Bulk Charging Model for PCs \(ZIP Format\)](#)

Naturally, I'd love to hear about your impressions and suggestions for improvements. Many thanks for your interest and I hope this tiny model will help you make an informed decision.

Sizing Wiring the ABYC Way:

Another fun project was creating a automatic lookup table for ABYC electrical wire size requirements. This Excel file will basically translate voltage drop requirements and ampere draws into American Wire Gauge (AWG) wire sizes. I make no guarantees about accuracy, but it seems to work.

- [AWG Wire Sizer](#)

This Excel spreadsheet was very useful for [rewiring our boat](#) as it allowed me to order wiring in bulk and in advance.



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Conclusion:

While I learned that some flooded cells have a superior cycle life, AGMs are still the battery in my future. I do not enjoy battery maintenance - I prefer to sail - and there are so many additional benefits to using AGMs over flooded cells. Since our boat already has a [powerful charging system](#), the next logical step is to install better batteries to take advantage of it.

Thus, our battery compartment saw a refit and expansion in order to house 6 group GPL4C AGMs by Lifeline to replace the 3 group 30H batteries there before. The diesel engine is now totally "over-battered" with over 900CCA while the house bank grew from 260 to 400 Ah of capacity.

The new AGM battery banks consist of a series configured starter bank (2x6 Volt Cells) and a series-parallel configured house bank (2 sets of 2x6V cells). While the boat is fused with 2 sets of 200A Class T fuses, and the connectors that put the house bank batteries into series also feature 200A fuses. Thus, I can safely combine maximum battery life and performance with much less maintenance.

Remember, battery and charge systems can be very powerful and dangerous. If you are competent enough to read, understand, and follow the guidelines found in marine electrical manuals, you can do much of the work yourself. However, don't blame me if something goes wrong!

Even if you want someone else to do the work, it is always better to understand and know what to look for when inspecting the system. The entire electrical system on board will have to be sized to accommodate the intended loads and charge systems. It is up to you to ensure that whatever changes are made to your system meet [ABYC](#) and other marine electrical standards. Good luck on your journey and happy sailing.

Constantin von Wentzel



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Appendix: The mini-drama with Chuck Husick

The origin of this battery research can be traced back to an article I read in an "Annual" issue of Ocean Navigator written by Chuck Husick. What bothered me initially about Chuck Husick's article was the omission of VRLA battery technology: He did not want to cover their @qout;virtues and liabilities@qout;. But as I kept reading, more and more red flags kept popping up. Here a couple of the big ones that stuck out like sore thumbs.

Funny Battery Bank Sizing Ideas:

Chuck Husick started a boat energy exercise with a constant 20 ampere load. Common sense would dictate some beefy battery banks and charging systems as a "constant" 20A draw is usually the result of many loads on board. Furthermore, energy draws typically ebb and flow over the course of the day. For example, on our boat, the highest continual draw is at night when the lights and the cabin heat are on. As a rule, the battery bank should be capable of supplying the maximum required current with some safety margin on top of that.

For the sake of argument, let us assume that a boat with a constant 20A draw exists. Using standard guidelines, a 20A load would call for up to 1920 Ah of battery capacity ($20A \times 24 \text{ hrs} \times 4 = \sim 650\text{lb}$ of battery). Chuck Husick however decided to use one 275 Ah battery, since his undersized charging system was only capable of delivering 55 amps to the batteries. Why someone would match a battery bank capacity to an alternator instead of the anticipated load is a mystery to me. I have yet to find another resource that advocates such potential battery abuse.

Continuing Mr. Husick's hypothetical exercise, the passage makers were expected to run their diesel engine for 8 hours (!!!) per day. Naturally, given the very low capacity of the battery, these recharges had to be distributed across the day and the night. You know, nothing warms my heart more than the idea of having to treat my diesel engine like a newborn infant and "feed it" four times a day, including when people want to sleep. Furthermore, most auxiliary diesels suffer when run without a significant load - it can cause cylinder glazing and other expensive problems. Even a 120A alternator only draws 5-6hp off your engine.

So, do such "results" have any kind of basis in the real world? Why wouldn't an article for passage makers (the supposed target audience of Ocean Navigator) contain a "real world" exercise with "real" loads (broken down by item) and "real" battery, charging system sizing? There are plenty of resources out there that Chuck Husick without doubt is aware of.

Better yet, he could have created three scenarios for passage makers with boats of differing sizes and luxury levels. Let's face it: Not all of us carry a air conditioner, water maker, or sub-zero refrigerator on board.

Hilarious Battery Charging Ideas:

While every source I have consulted so far recommends minimizing the number of banks to maximize bank capacity (to enhance cycle life by limiting the depth of discharge), Chuck Husick takes a very different tack. He recommends discharging batteries individually and recharging them collectively, even though this will result in lower effective battery capacity.

High discharge rates relative to battery capacity will make the battery go "flat" faster because the available capacity of lead acid cells decreases as a function of amperage draw (i.e. the chemistry in the battery cannot keep up with the current draw). Some types of lead acid batteries are better at overcoming this problem than others. It depends on the lead plate thickness (starter vs. deep cycle), construction (AGM, Gel, flooded/wet cell), and chemistry (alloys, buffers, and so on). Keep in mind that while a flooded starter battery will allow high rates of discharge, it will not tolerate deep discharges at all.

Once a charging source is available, Mr. Husick recommends paralleling the batteries for recharge. But how can you ensure that individually discharged batteries have the same charge level prior to recharge? Inevitably, some cells will be over-charged and others undercharged, as the collective bank is worked to float (the last stage of charging). While small charge differences may not result in immediate and drastic plate damage, the real question is why to discharge individual batteries from a bank in the first place.

Better Performance from Individual Batteries than from a Bank?

Chuck Husick claims that his battery management philosophy will lead to "better performance". Unfortunately, this philosophy runs counter to accepted physical laws and published industry resources. For example, Peukerts equation is used by every battery manufacturer to characterize the load characteristics of their batteries. If Chuck Husick has found a way to get better performance out of individual batteries in a bank rather than the bank as a whole (and therefore bypass Peukerts Effect), I (and the rest of the battery industry) would want to know how.

Furthermore, a properly fused bank will continue to function after a partial failure (i.e. a battery shorting out, causing its fuse to trip) while a cell shorting out in an individual battery will leave you with insufficient voltage to run most electronics on board. In certain situations (storms, harbor entries at night, etc.) this could be pretty disastrous as the crew struggles to diagnose the problem, then to switch the batteries around.

To summarize, Chuck Husick

- *ignored very relevant battery technologies*
- *came up with a battery discharge scenario/charge plan that had no basis in the real world*
- *ignored physical laws that clash with his battery philosophy*

This is why I believe his technical writing should be taken with a grain of salt. He has lived a very interesting life, has earned many certifications, and even has an impressive sounding position at US/Boat. However, I am unsure how any of these qualify Mr. Husick to write competently about marine batteries and how to best utilize them.

What is worse, he has refused to reconcile the inconsistencies between his views and generally accepted theories on optimal battery charging, utilization, etc. Not one shred of evidence has been submitted by

him to refute Peukerts Law (which is the only way that his discharging/recharging advice could actually lead to *equivalent* performance of individual batteries vs. a battery bank), nevermind superior performance as he claimed.

His ignorance regarding objective comparisons between various lead-acid battery technologies is even more appalling. For example, he compares AGM batteries on cycle life to super-premium Surrrette/Rolls batteries while also comparing them to entry-level batteries on price. This is a great way to rig a contest. When pressed where to find the Rolls-Royce of marine flooded batteries at a Ford Pinto price, he couldn't.

So what was the point of publishing his original article in Ocean Navigator? Where was the objective editing that most of us depend on when we seek advice? **From my discussions with the editorial staff, it became clear that Ocean Navigator does not review articles for technical accuracy.** So if something looks funny to you in one of their publications, it probably is. How hard is it to sell snake oil to the gullible?

Time for Letters to the Editor!

Being the engineer I am, I decided to hunker down and write [my first letter to the editor](#). Surprisingly, Ocean Navigator published it (though truncated) along with a reply from Mr. Husick. His replies made me scratch my head in wonderment and [I have assembled them on this page](#).

Thus, my need for [Letter II](#). Admittedly, I had a bit of fun poking at his explanations and Ocean Navigator decided not to print it. Chuck Husick decided to ignore the points he could not argue and wrote a rambling response (included in [Letter III](#)).

Most galling was Chuck Husick's cavalier dismissal of Nigel Calder's excellent and clear arguments as mere "opinions" without offering any proof whatsoever that his own views were better. I suppose that would have been difficult since he has yet to find a way to refute Peukerts Law or to find a new Rolls-CS series battery for the price of a budget Trojan cell.

Despite the very real threat of sending my letter straight to the roundfile, I replied with a point-by-point rebuttal in my [third Letter to the Editor](#). As expected, it was not answered or printed either.

Epilogue

The most unfortunate aspect of this dialogue was the lack of specific references to support Chuck Husick's views. Where was the scientific evidence that his proposed battery management is superior? I'm not against exploring new ideas... but the responses he submitted to my queries indicate that he did not follow or understand the links I provided. As threatened in his response to letter II, Chuck Husick has chosen to "withdraw from the discussion" we were having. His qualifications are impressive, but I continue to question a number of his assertions.

His unwillingness to form real arguments by offering scientific proof, relevant personal experience, or even just a bibliography that supports his thoughts is telling. If you attend any seminars that are taught by Chuck Husick you may want to take what he says about batteries with a grain of salt. Considering his

inflexibility when presented with overwhelming evidence to the contrary of his views, I'm not sure what value the rest of his presentation might have either. After all, you're there to be educated, not to sift through what may or may not be true.

The resume of Chuck Husick certainly sounds impressive. Not everyone was the president of Chris Craft or sits on the board of US Boat. However, when it comes to practical aspects of a boat and its maintenance, I prefer to stick to someone like Nigel Calder who has made a career or successfully fixing and specifying boats. Please keep in mind: I do not claim to be an lead-acid battery expert - I just happened to build cost models for a living, read a couple of books, and surfed the net for a while to come to a diametrically opposed opinion to the assertions by Chuck Husick.

If someone can enlighten me further, please do not hesitate to [contact me](#). I'll do my best to post the information as quickly as possible.

Cheers!
Constantin von Wentzel

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Welcome to the von Wentzel family site!

Enjoy photos from my life, Apple Airport Base Station tutorials, the saga of our Prout Escale catamaran, or lead-acid battery information... there is something for everyone. Click on any image to open that part of the web-site - just below are links to recent additions:

[Three Days, Three Birthdays in London](#) [Leo and Carisa Marry!](#)

Photos:



See my small but growing collection of [family photos here](#).



A ever-growing [picture archive](#) awaits you [here](#). Covering travel, weddings, and other fun events

Sailing:



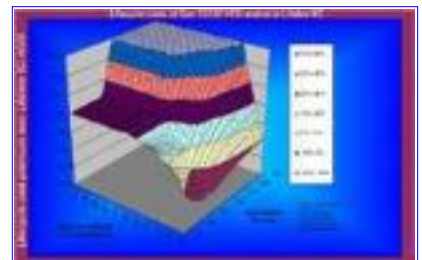
Voyages on the Cats Pyjamas, the family catamaran, [chronicles past trips...](#) sailing is in my blood - I love it. You'll get an idea just how much fun we have sailing her when we can.



Technical:



[Learn more about Apple Airport Base Stations!](#) Initially conceived as a guide to repair a common internal power supply problem, this section has expanded, covering external antennas, improving cooling, and other diversions.



In the lead-acid battery section of

the archive features images from around the world.

INSEAD

INSEAD students are renowned for their demoralizing teacher evaluations, tough questions, and [excellent party spirit](#). Though the one year MBA program is intense, I wouldn't have had it any other way.



We're married! [See pictures from the wedding & the honeymoon...](#) Shoma and I spent the whole day giggling and our happiness has continued to the present day.

Unfortunately, [we have had to repair many OEM defects on our Prout Escal](#)... some of them were life-threatening. If you own or are considering the purchase of a Prout catamaran, you might want to have a look. No matter how much fun our Prout has been to sail, it's pretty scary how much time and money we have spent on repairs on what was a new boat.



Our Pischel rigid inflatable dinghy has been a roaring success. Despite many seasons in the sun, marine growth encrustations, and the rocks of Maine "beaches", it has been holding up great. We decided to adapt it a bit to its nonnative working environment. [This section tells you how we did it.](#)

my web-site, [I go into some depth about marine battery choices](#). Discover how to size and configure your system, and what battery (AGM, Gel, Flooded) makes the most sense for you. I even offer a free cost model!



Ever wondered what it is like to simulate a factory in MS Excel®? Here are links to three reports I co-authored for energy efficiency issues of [washing machines](#), [air conditioners](#), and [water heaters](#) on the DoE web-site. A paper [on disruptive technologies \(GPS versus LORAN\)](#) can be found at INSEAD.



I've learned some funny things over the years. [Here is a budding archive.](#)

And now for a word from your friendly webmaster, Constantin von Wentzel

Hi! Well, the year in France went by quicker than I thought possible! Now that I have finished my MBA studies at INSEAD and Wharton, it's time to find a job. Ideally, it would allow me to use my strategy, modeling, product development and/or operations management skills.

Prior to business school I was a consultant for Arthur D. Little, Inc. in Cambridge, MA. Besides developing new and exciting products for clients, I helped build new production facilities, improve operations, and even helped US consumers save a net present value of \$12 billion or so (see DoE links above). My primary specialty was the evaluation of products and technology business plans, usually via customized activities based cost models. These bottoms-up models predicted product costs, facility requirements, optimal layouts, etc. I also helped build a factory, transitioned several product families from design to the manufacturing line, and participated on a number of operations management assignments.

Naturally, this work required a great deal of client interaction which I enjoyed immensely. Furthermore, I am very grateful for all the opportunities that consulting at ADL gave me to explore a eclectic bunch of industries, cutting edge technologies, and the creativity I was allowed to bring to the job. If you're interested in finding out more about me, please don't hesitate to click on the link below and send me a message.

Cheers, [Constantin](#)

For those that care, this site was built primarily using [BBEdit](#) on a [Macintosh](#). It is [HTML 4.01](#) and [CSS](#) compliant. [Privacy Notice](#)