WHITE PAPER

AQUION ENERGY

The Advantages of Aqueous Hybrid Ion Batteries Over Lead Acid Batteries

INTRODUCTION

Aquion Energy's Aqueous Hybrid Ion (AHI™) batteries offer many benefits over traditional lead acid batteries, including longer system life in both deep discharge and partial state of charge applications, greater durability, lower maintenance costs, and increased sustainability. The AHI battery chemistry is optimal for any stationary, long-duration, daily cycling application, including off-grid and weak-grid microgrids, telecom systems, and residential solar. AHI products' significant technological advantage relative to lead acid batteries lead to vastly improved lifetime project economics for the end-user.

THE BENEFITS OF AN AHI SYSTEM

Safe and Hassle-Free

AHI batteries are sealed and contain a safe and environmentally-friendly water-based electrolyte, unlike lead acid batteries, which all contain caustic sulfuric acid electrolyte. There's no risk of corrosion to components in close proximity to the battery, no need to maintain fluid level in the batteries or clean the terminals, and no secondary containment system requirement for a battery case leak. AHI chemistry offers increased battery lifetime, reduction in costly and inconvenient maintenance, and prevention of unexpected and often catastrophic failures. In addition, AHI batteries, unlike typical lead acid batteries, do not vent hydrogen gas or require a dedicated fire suppression system.

Figure 1: Example home configuration using 12 Aquion S-Line Battery Stacks

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Better Performance than Lead Acid

AHI batteries offer uncompromised performance in a wide variety of applications. Especially compelling are those applications where traditional lead acid solutions are impractical due to cycle life limitations or maintenance costs. The list below outlines a few of the AHI advantages:

- AHI batteries can handle long stands at a partial state of charge, 100% depth of discharge events, and continuous partial state of charge cycling without reducing cycle life, all of which significantly reduce the life of lead acid batteries.
- AHI products are designed to operate without loss of performance or life at elevated temperatures (up to 40°C on a rolling 24-hour average), and can tolerate even higher temperature excursions for short periods of time. For every 10 degrees greater than 25°C, lead acid battery life is halved.
- AHI batteries are much more abuse tolerant and can handle unexpected charge and discharge events without losing capacity or compromising cycle life.
- Each AHI battery is nominally 48V, meaning that low voltage systems can be easily wired in parallel, decreasing wire size and cost, and increasing system safety and reliability.
- Reliability and redundancy are inherent in systems wired in parallel, meaning that one AHI battery failure does not completely take down an entire installation, unlike lead acid.

Longer Lifetimes and Low Replacement Frequency

AHI batteries will deliver over 3,000 cycles at 100% depth of discharge over a very wide ambient temperature range. Lead acid battery life varies dramatically with depth of discharge and operating temperature. Even the highest performing lead acid batteries can only last a few thousand cycles at 50% depth of discharge and nominal (25°C) ambient temperature. Applications that do not discharge the battery fully will experience extended cycle life with the AHI battery chemistry – 6,000+ cycles at 50% depth of discharge and 12,000+ cycles at 25%. AHI's extended cycle life and temperature independence can significantly reduce the total cost of ownership of the system by simply reducing the replacement frequency relative to lead acid battery products.

Figure 2: Example of lead acid battery corrosion

SAMPLE APPLICATION ANALYSIS: OFF-GRID SOLAR/REMOTE MICROGRID

The application described below is a daily cycling, off-grid solar application that requires a 20 kWh battery system, which is representative of a small residential, telecom, or microgrid application. The system is located in an area that has good solar exposure year-round. As such, the batteries will be primarily charged over 8 daylight hours and then discharged over the remaining 16 hours of the day. The system will use off-the-shelf power control electronics and be designed as robust and simple to maintain as possible.

Application Summary

- Small-scale off-grid solar system
- Usable Energy: 20 kWh
- Nominal Voltage: 48Vdc
- Charge Duration: 8 hours
- Discharge Duration: 16 hours

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PRODUCT SPECIFICATION COMPARISON

The gel lead acid battery chosen for this model is a prevalent and well-regarded 2 volt battery that is often used for this type of small-scale solar system. In addition to the gel battery, an AGM (absorbed glass mat) lead acid 2 volt battery product is also modeled as well as Aquion's S-Line Battery Stack and M-Line Battery Module products.

Product	Voltage	Nominal Ah	Nominal Wh	Height mm (in)	Width mm (in)	Depth mm (in)	Weight kg (lbs)
Gel lead acid	2	1,021	2,042	446 (17.6)	177 (7)	296 (11.7)	54 (119)
AGM lead acid	2	840	1,680	329 (13)	179 (7)	261 (10.3)	42.6 (94)
Aquion S10-0080	48	39.2	1,750	935 (36.8)	310 (12.2)	330 (13)	113 (249)
Aquion M100-L081	48	420	20,000	1,159 (45.6)	1,321 (52)	1,016 (40)	1,440 (3174)

*All capacities and energy ratings normalized to the C/16 discharge rate based on spec sheet data

Table 1: Product Specifications

SYSTEM CONFIGURATION

Lead Acid

A system comprised of 2 volt lead acid batteries must be first sized by the number of cells needed to meet system level voltage. Therefore, batteries must be placed in multiples of 24 to meet system voltage requirements of 48V. In addition, lead acid batteries in this duty cycle are typically sized to 50% depth of discharge to optimize system life. This in effect halves the storage capability of a lead acid system.

AHI

AHI batteries are nominally 48 volts and therefore do not need to be placed in series in order to meet 48V system requirements. AHI batteries can be fully cycled at 100% depth of discharge and deliver a full 3,000 cycles – cycling at lower depths of discharge will proportionally increase cycle life. This means that the AHI system does not need to be oversized for depth of discharge, meaning that the effective energy storage by each S-Line and M-Line product is much higher than that of the equivalent lead acid battery.

Product	Batteries Required	Configuration	Voltage	Nominal kWh	Depth of Discharge	Useable kWh
Gel lead acid	24	Series	48	49.0	50%	24.5
AGM lead acid	24	Series	48	40.3	50%	20.2
Aquion S10-0080	12	Parallel	48	21.0	100%	21.0
Aquion M100-L081	1	Parallel	48	20.0	100%	20.0

Table 2: Each system is arranged in a 2-row, unracked configuration.

Product	Configuration	Height m (ft)	Width m (ft)	Depth m (ft)	Weight tonnes (tons)	Floor Load kg/m2 (psf)
Gel lead acid	2x12	0.45 (1.5)	2.12 (7)	0.59 (1.9)	1.30 (1.4)	1031 (211)
AGM lead acid	2x12	0.33 (1.1)	2.15 (7)	0.52 (1.7)	1.02 (1.1)	912 (187)
Aquion S10-0080	2x7	0.94 (3.1)	1.86 (6.1)	0.66 (2.2)	1.36 (1.5)	1105 (226)
Aquion M100-L081	1x1	1.16 (3.8)	1.32 (4.3)	1.02 (3.3)	1.44 (1.6)	1073 (220)

Table 3: System Footprint

FINANCIAL ANALYSIS

Through their extended cycle life and maintenance-free operational attributes, AHI batteries offer a significantly lower cost of ownership than lead acid batteries, and have a payback period of 3 to 5 years. AHI batteries offer twice the usable energy of lead acid due to their 100% depth of discharge, last 2-3 times longer, reduce balance of system costs and do not require maintenance.

Comparing the costs of these three systems over five years, it becomes clear that AHI batteries offer the best combination of system, maintenance, and replacement costs.

Figure 3: Side-by-side comparison of (from left to right) the AGM lead acid (gray), Gel lead acid (red), and the S10-0080 (green) for a 20 kWh application.

Product	$/kWh (Nominal)	$/kWh (Usable)	System Cost ($/kWh)	Yearly Maintenance Cost ($)	Replacements in 5 Years	5-yr Replacement Cost ($)	Total 5-year Cost ($)
Gel lead acid	$176	$353	$8,640	$150	1	$8,640	$17.430
AGM lead acid	$220	$440	$8,880	$150	1	$8,880	$17,910
Aquion S10-0080	$483	$483	$10,140	$0	0	$0	$10,140
Aquion M100-L081	$550	$550	$11,000	$0	0	$0	$11,000

Table 4: 5-year Cost Comparison

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CONCLUSION

Aquion Energy AHI batteries are a robust, high-performing alternative to lead acid batteries, particularly in applications that require consistent performance, long cycle life, and in locations where consistent maintenance is inconvenient or cost prohibitive. The AHI battery combines the ease of integration of lead acid batteries with the robustness and cycle life of more advanced chemistries. When put into practice, this combination of attributes from Aquion Energy products will deliver better project economics for a number of applications due to longer product life, less maintenance, and better overall system performance than lead acid batteries. The table below outlines the key performance differences between the AHI battery chemistry and typical Gel and AGM lead acid batteries:

	Lead Acid	Aqueous Hybrid Ion (AHI)
100% Depth of Discharge Cycle Life	100 to 1,500 cycles	3,000+ cycles
50% Depth of Discharge Cycle Life	500 to 3,000 cycles	6,000+ cycles
Recommended Temp Range for Optimal Life	25 to 30°C	-5 to 40°C
Maintenance Requirements	Frequent - terminal cleaning, maintenance cycling	None
Performance at Partial States of Charge	Poor - leads to sulfation failure modes	Robust to any partial state of charge or long duration stands
System Redundancy at 48V	No redundancy - single cell failure can bring system to open circuit	Batteries at nominal 48V deliver system redundancy - no single failure can bring string to open circuit
Safety	Caustic sulfuric acid must be contained in event of case breach. Hydrogen must be vented.	Aqueous electrolyte is non-toxic, non-caustic.

DEFINITIONS AND FURTHER INFORMATION

Cycle Life

The cycle life of lead acid batteries is dependent on the product design, chemistry, model, and mode of operation. Typically, the cheaper a lead acid battery, the shorter its lifetime. The cycle life of lead acid batteries is also heavily dependent on depth of discharge, charge profile, and temperature. AHI batteries do not have these same restrictions, and can be operated in a wide variety of conditions while still achieving over 3,000 cycles at a full depth of discharge.

Depth of Discharge

Depth of discharge refers to how much energy is cycled into and out of the battery on a given cycle, as a percentage of the total capacity of the battery. Though this varies cycle to cycle, the maximum depth of discharge typically targeted for lead acid systems is at or below 50%. The cycle life of lead acid batteries is highly dependent on the depth of discharge of the battery. Increasing the depth of discharge of the battery from 50% to 100% will decrease the cycles by two to three times (from close to 1,500 cycles to below 500 cycles).

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Lead acid battery cycle life is highly dependent on the state of charge (SoC) that the battery is cycled at. Cycling that is done between 100% SoC and 50% SoC will last longer than the same depth of discharge cycling that is done between 70% and 20% SoC. This is due to the crystalline structure changes that occur at the various states of charge.

Conversely, due to the nature of the AHI chemistry, the batteries can be cycled between any state of charge and to any depth of discharge without large impacts on the cycle life. This not only reduces the need to oversize the system, it also adds flexibility to system operation.

Efficiency

Lead acid and AHI batteries offer very similar DC-DC round trip efficiencies, ranging from 80% to over 90% depending on the charge rates, operating temperatures, and depth of discharge.

Size/Weight

On an installed basis AHI batteries are typically the same footprint as a standard floor-mounted lead acid system, and anywhere from 1.5-2 times the height. The weights of the two systems are nearly identical. This assumes a 50% depth of discharge for the lead acid batteries--at lower depths of discharge, the lead acid system would need to be much larger.

Temperature Tolerance

Lead acid batteries are highly affected by temperature. The lifetime of lead acid batteries is cut in half for every 10 degrees over 25 degrees C due to rapid increases in the corrosion rate of the internal components of the battery. Higher temperature also affects the power capability of the batteries, reducing charge rates.

AHI batteries are much less temperature-sensitive than lead acid; temperatures below 40°C do not reduce the cycle life of the battery. AHI batteries operate more efficiently at higher temperatures, while not compromising the life of the battery as would happen with lead acid.

Partial State of Charge

One critical difference between AHI and lead acid is performance at a partial state of charge. The fundamental lead acid chemistry contains many side reactions, such as negative plate sulfation and positive plate corrosion, in addition to the regular charge/discharge reaction. One specifically deleterious side reaction is sulfation, which occurs when lead acid batteries are deprived of a full state of charge because they are either held at a partial state of charge or never fully charged. This failure mode causes the formation of large sulfate crystals within the negative plates of the battery that is irreversible and results in permanent capacity loss. AHI batteries are inherently non-corrosive and do not experience any secondary or tertiary reactions which limit lifetime or performance in partial state of charge applications.

Maintenance

AHI batteries require no regular maintenance. They do not need electrolyte refilling, measurement, or any terminal corrosion cleanings as lead acid does in operation.

Safety and Sustainability

AHI batteries are built from non-toxic and environmentally-friendly materials. They are recyclable and will not harm the environment in the case of an installation accident or improper handling. Any leakage of the electrolyte does not pose a safety risk to personnel and damaged batteries can be managed without chemical-grade personal protective equipment.

System Costs

Lead acid batteries create higher system costs than AHI batteries. In most tropic locations lead acid will require HVAC to keep battery temperatures close to 25°C. This both increases the up-front cost of the system and reduces the efficiency of the overall system. Lead acid batteries must also be kept at a full state of charge which means they may often need to be charged by a diesel generator when renewable energy is not available. This not only increases diesel use but also reduces the ability of the lead acid batteries to accept energy from renewable resources.

AHI batteries can be held at a partial state of charge or even fully discharged and therefore can charge completely from the excess renewable energy that is available. This decreases diesel genset runtime and diesel use while increasing the amount of renewable energy that can be used.