Clean energy systems need clean batteries

AQUION ENERGY

Energy Storage.
Clean and Simple.

Aquion Energy Battery Technology
December 2016

Background

The Aspen Battery: What's Inside Matters

Aqueous Hybrid Ion (AHI™) Chemistry

- Poly-ionic system: Na^+, Li^+, and H^+ ions all functional in the system
- Neutral pH water-based electrolyte

+ STAINLESS STEEL

Stainless Steel Current Collector

+ BASE OXIDE

Manganese Oxide Cathode

+ COTTON

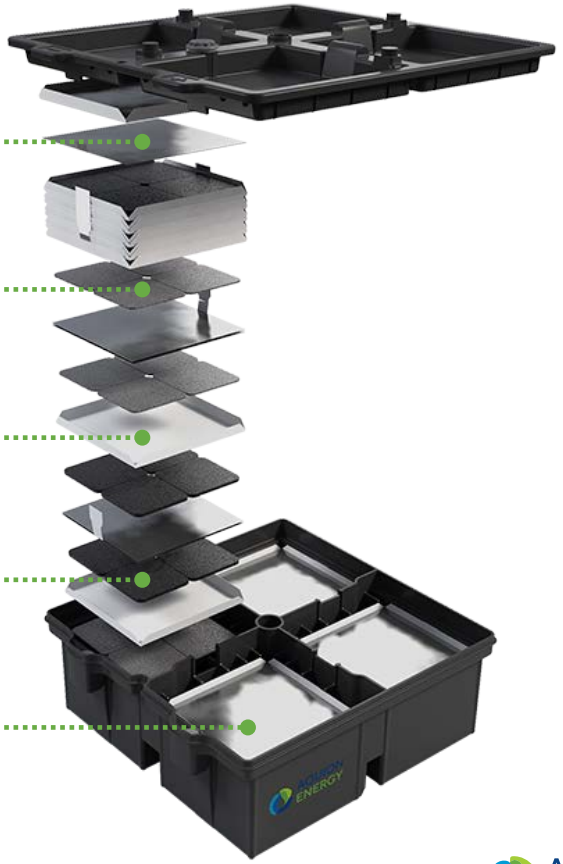
Synthetic Cotton Separator

+ CARBON

Carbon Titanium Phosphate
Composite Anode

+ SALTWATER

Neutral pH Alkali-ion Electrolyte



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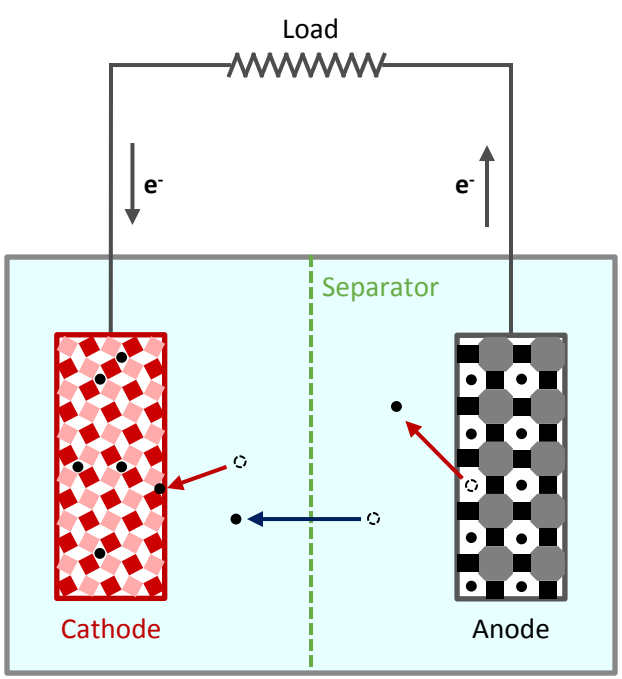
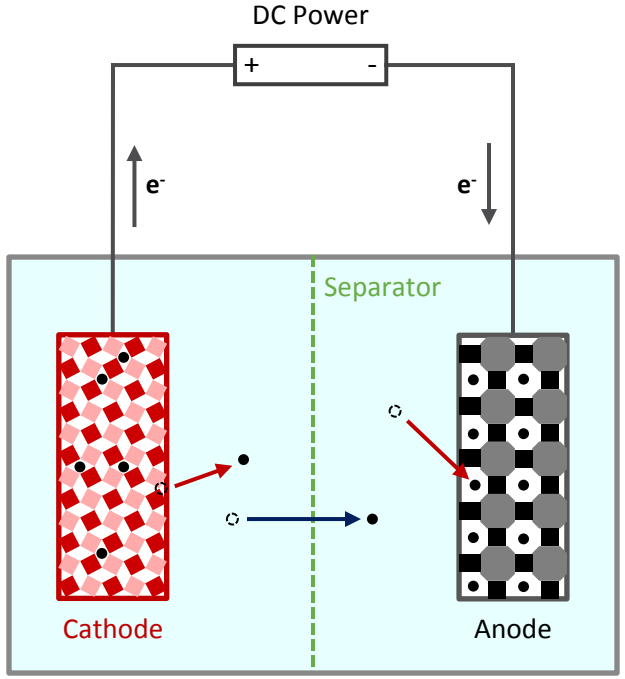
How does it work?

The AHI cathode and anode are bathed in an aqueous electrolyte containing positively charged ions of sodium, lithium, and hydrogen. As negative electrons flow through the external circuit, the electrolyte's positive ions move into and out of the electrodes to balance the charge.



Discharge



Charge

$NaTi_2(PO_4)_3 + 2e^- + X^+ \rightarrow 2\ NaX_2Ti_2(PO_4)_3$ **E° = -1.2 V MSE**

$LiMn_2O_4 \rightarrow 2\ MnO_2 + e^- + X^+$ **E° = +0.45 V MSE**

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Intercalation and Insertion

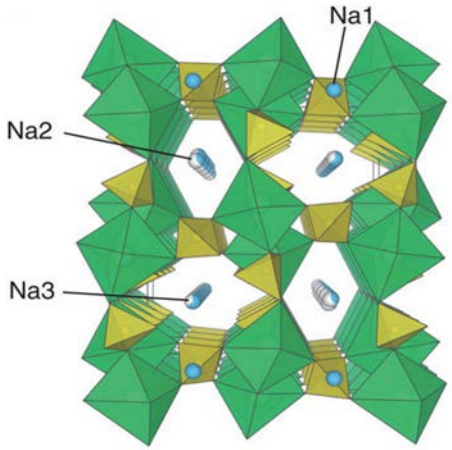
Both cathode and anode integrate and expel the ions present in the electrolyte. An AHI battery uses multiple ions—lithium, sodium, and sometimes hydrogen—reducing the overall cost of the technology.

+ Intercalation: A chemical reaction in which ions participate in the structure of a layered or spinel compound, changing the structure during cycling
+ Insertion: A chemical reaction in which ions are inserted into voids within a crystalline structure

Anode
Sodium Titanium Phosphate and Carbon

Charge: Ions from the electrolyte are inserted into the anode's voids.

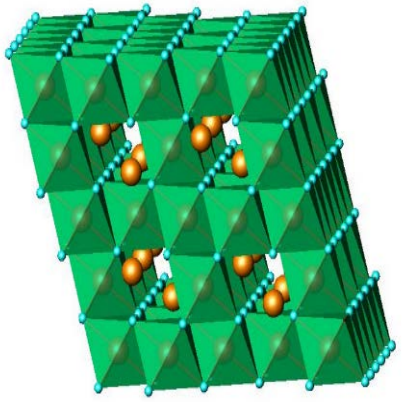
Discharge: Ions leave the voids and re-enter the electrolyte



Cathode
Manganese Dioxide Spinel

Charge: Ions are de-intercalated from the cathode and enter the electrolyte.

Discharge: Ions are intercalated back into the cathode.



Note: Images are representative of the crystal structures used in the anode and cathode.

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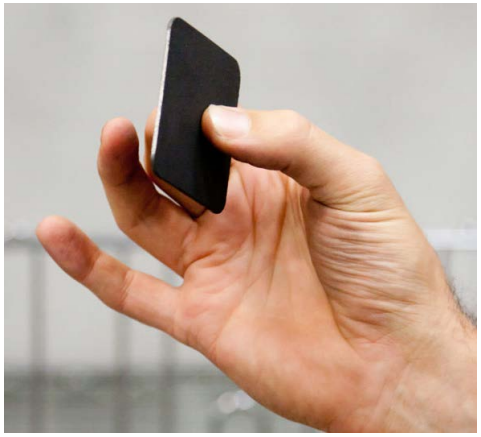
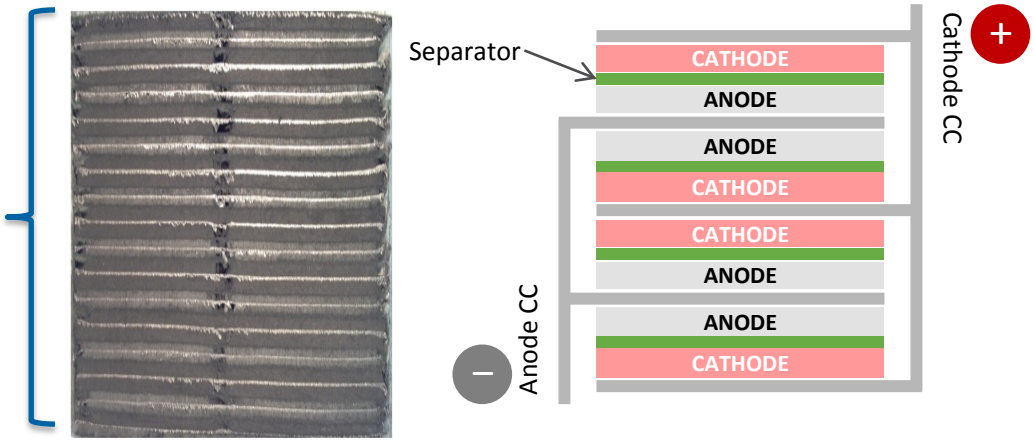
Large Format Energy Storage Device

Electrodes



- Electrodes produced by mixing active material, carbon black, graphite, and a polymeric binder
- Appropriate void space for electrolyte introduction
- Electrolyte is alkali sulfates in water

Electrode stack cross section



- Multi-layer structure within each cell
- 4 pellets per anode layer
- 4 pellets per cathode layer
- Separators oversized to protect against internal shorting

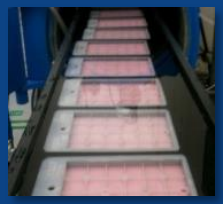
Manufacturing Process

Battery Assembly

Blend | **Granulate** | **Pelletize** | **Electrolyte Infiltration** | **Qualify**

ANODE

CATHODE



Every battery is tested before leaving the factory

+ Container
+ Separator
+ Conductor
+ Lid

AQUION ENERGY

Large Scale Manufacturing Overview - Video

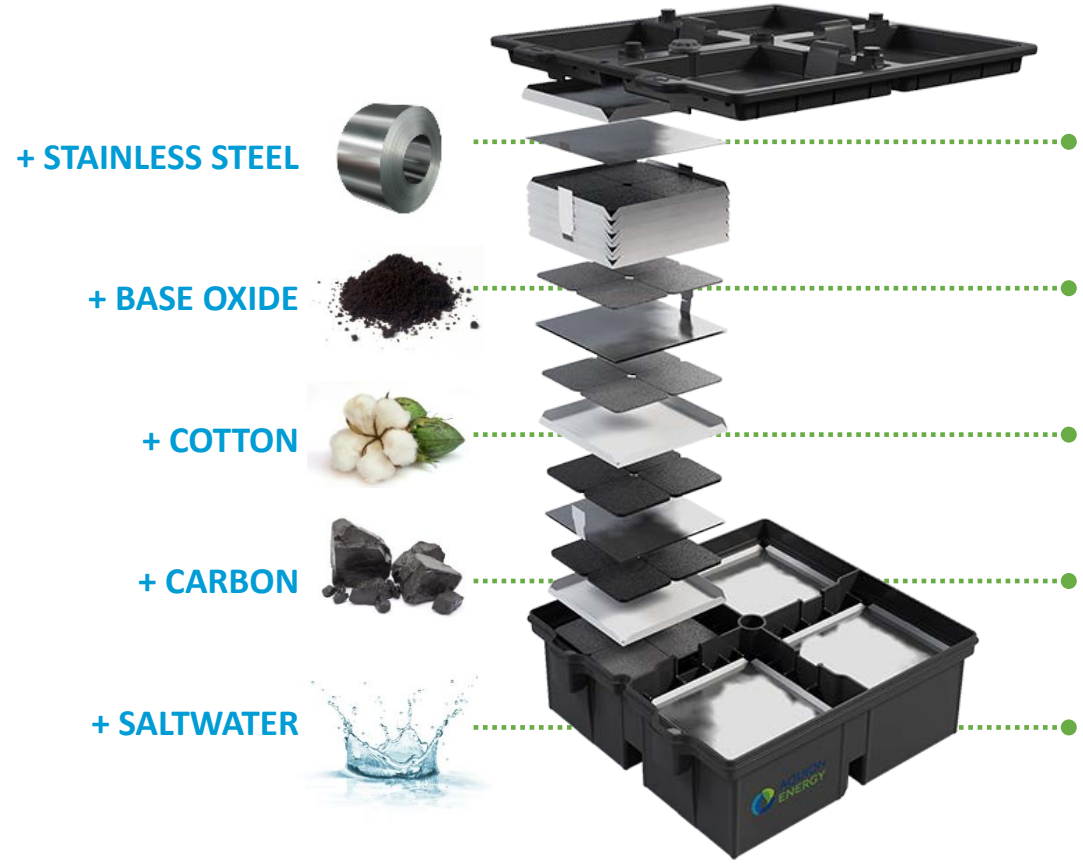
All of our products are manufactured in Pennsylvania

View this video at https://www.youtube.com/watch?v=aANBtotnsLI

Why what's inside matters

Aquion batteries are made of common, safe materials. These features make AHI batteries simple to manufacture, safe, sustainable, inexpensive, robust, and abuse-tolerant.

Aqueous Hybrid Ion (AHI™) Chemistry



PROS	CONS
Low cost, multiple suppliers	Lower conductivity than alternatives
Low cost, multiple suppliers	Lower specific capacity than alternatives
Low cost	None
Proprietary material specific to AHI battery, tolerant to partial state-of-charge cycling	Lower energy density than alternatives
Not flammable, toxic, or caustic, natural overcharge protection, lower cost and greater conductivity than organic solvent alternatives	Lower energy density than alternatives

Technical Specifications

Aspen Battery Specifications

Aspen 48S-2.2

- ~2 kWh
- 48 V nominal
- Standard building block for flexible system design

OPERATION & PERFORMANCE

Nominal Energy	2.2 kWh
Operating Temp Range*	-5°C to 40°C
Round Trip DC Efficiency	~90% at 20-hour discharge, 30°C
Voltage Range	40 to 59.5 V
Charge/Discharge Modes	CC, CP, CV

PHYSICAL CHARACTERISTICS

Height	935 mm	36.8 in
Width	330 mm	13.0 in
Depth	310 mm	12.2 in
Weight	118 kg	260 lbs

Aspen 48M-25.9

- ~26 kWh
- 48 V nominal
- 12 stacks in parallel
- Pre-wired and forklift-ready for easy deployment

OPERATION & PERFORMANCE

Nominal Energy	25.9 kWh
Operating Temp Range*	-5°C to 40°C
Round Trip DC Efficiency	~90% at 20-hour discharge, 30°C
Voltage Range	40 to 59.5 V
Charge/Discharge Modes	CC, CP, CV

PHYSICAL CHARACTERISTICS

Height	1,159 mm	45.6 in
Width	1,321 mm	52.0 in
Depth	1,016 mm	40.0 in
Weight	1,504 kg	3,315 lbs

Aspen 24S-83

- ~83 Ah
- 24 V nominal
- Ideal for small off-grid solar applications, such as LED lighting

OPERATION & PERFORMANCE

Nominal Energy	83 Ah
Operating Temp Range*	-5°C to 40°C
Round Trip DC Efficiency	~90% at 20-hour discharge, 30°C
Voltage Range	20 to 29.7 V
Charge/Discharge Modes	CC, CP, CV

PHYSICAL CHARACTERISTICS

Height	935 mm	36.8 in
Width	330 mm	13.0 in
Depth	310 mm	12.2 in
Weight	118 kg	260 lbs

* 40°C average ambient over 24 hours

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Performance Data

Temperature Tolerance and Daily Cycling

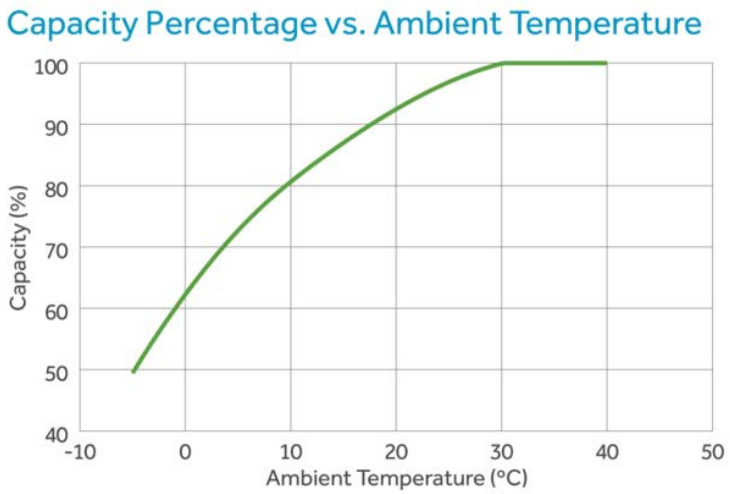
- Applications testing ongoing, both in-house and at third-party test sites
- Data from field installations show excellent stability, and units continue to meet customer expectations
- In second year of applications testing; AHI battery out-performs in key stationary applications

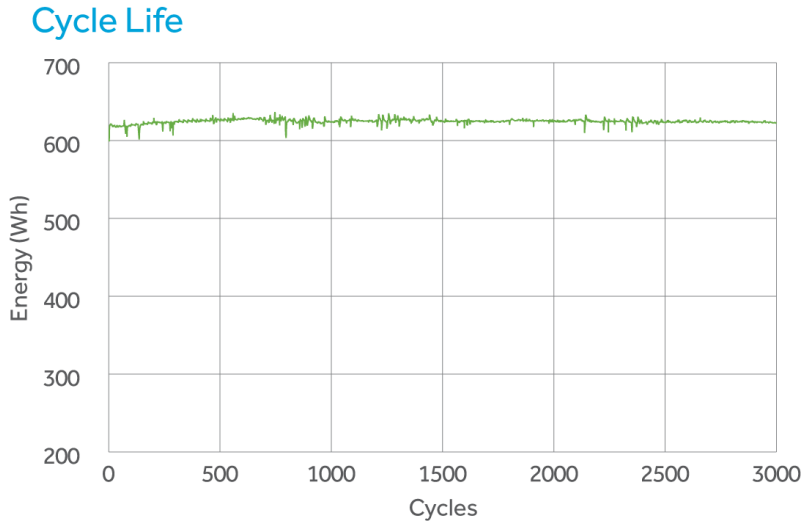
TEMPERATURE TOLERANT

Wide Temperature Operating Range

LONG LIFE

Stable Daily Energy Delivered, 2.5 Years, >3000 Cycles





* Nominal capacity is specified at 30°C

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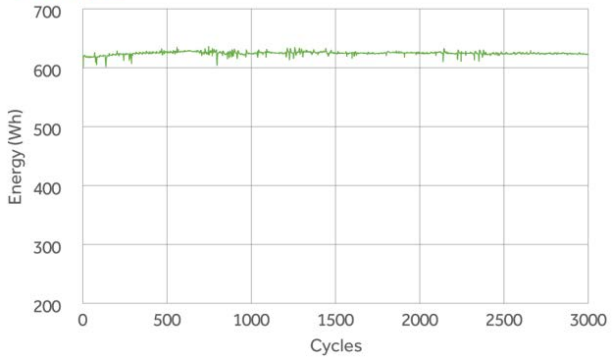
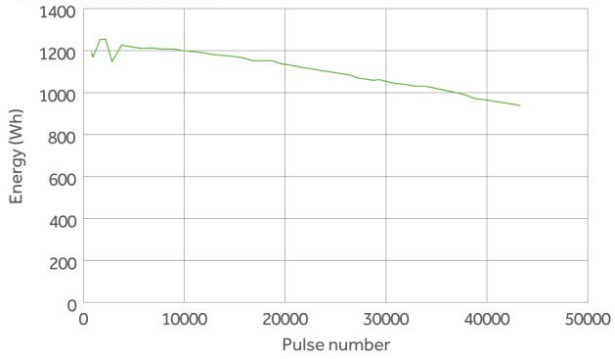
Lab and In-Field Cycle Performance Data

LAB CYCLING

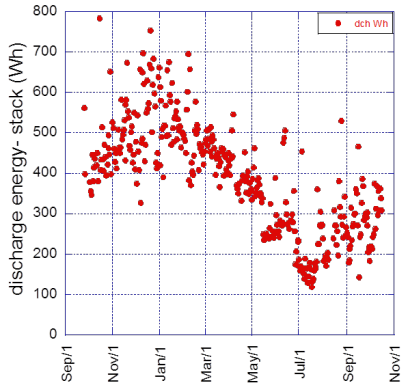
Deep Discharge Testing
70%+ DoD



Partial State of Charge Cycling
10% DoD @ 50% SoC

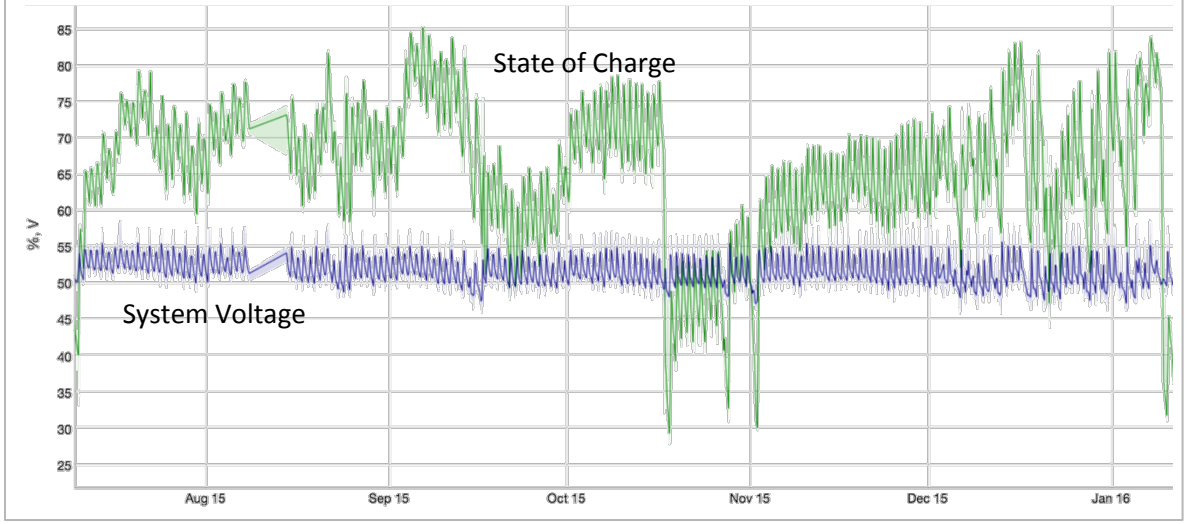


IN-FIELD CYCLING DATA



80 kWh Off-Grid Residence

+ This system has been providing consistent power since installation in September 2014
+ Typical long-duration daily cycle: charge from 14 kW of PV during the day and provide power for nighttime hours



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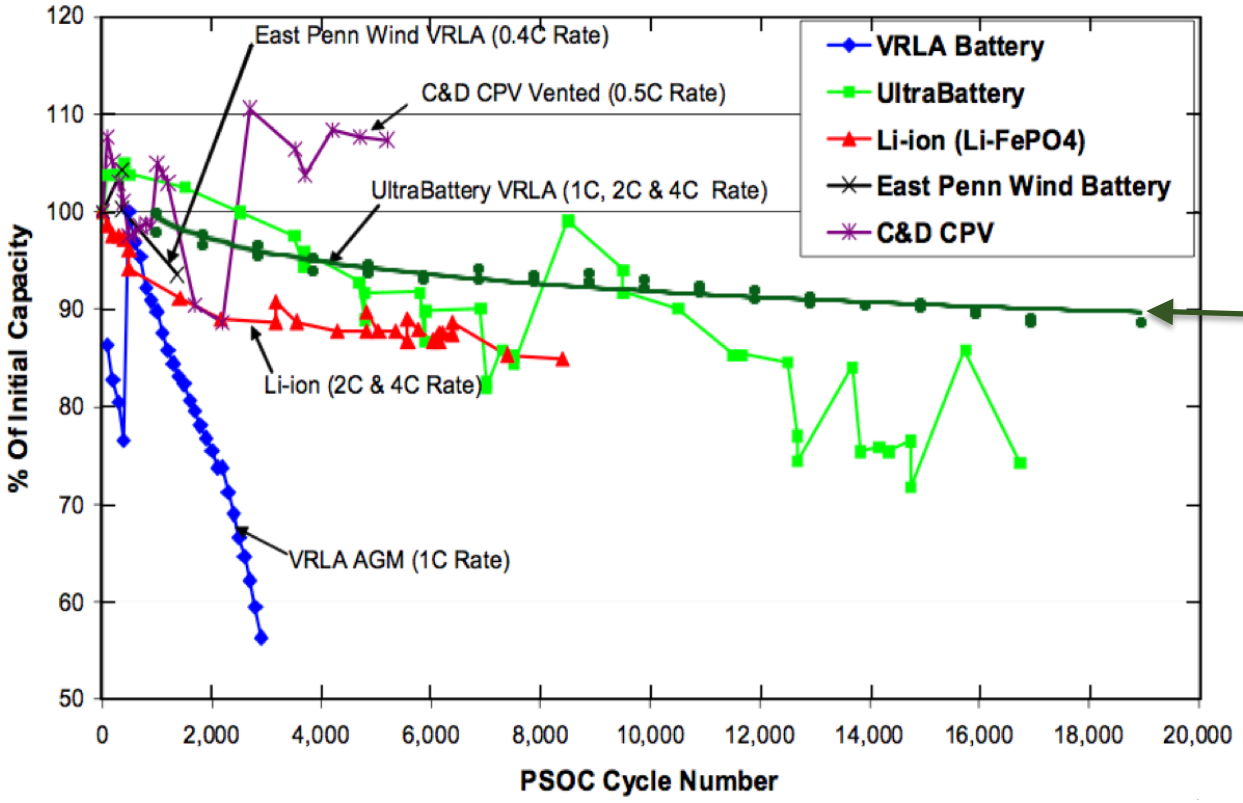
Partial State of Charge Comparison Plot

PSOC
CYCLING TOLERANT

Sandia National Labs Test Data



Sandia National Laboratories

Aquion AHI
(Aquion test data overlaid)

- Aquion AHI battery tested at continuous 40˚C, all other tests at room temperature
- Much faster degradation expected from all competitors at 40˚C
- Charge/discharge rate for AHI battery was ~C/2

AQUION ENERGY

Safety, Third-Party Testing, and Certifications

Aspen Batteries Are Non-flammable and Non-explosive

NON-FLAMMABLE
NON-EXPLOSIVE

+ Inherently safe chemistry: no thermal runaway, non-flammable, non-explosive
+ No toxic or caustic materials
+ CE marked, UL recognized, and Cradle to Cradle™ Certified

UL Recognized

+ Passed UL 1973 flame propagation testing

View this on our YouTube channel - http://bit.ly/1T43QlN

Cradle to Cradle™ Certified

CERTIFIED
cradle to cradle
BRONZE

+ First batteries to be Cradle to Cradle Certified™
+ Cradle to Cradle is an independent certification organization that ensures our batteries contain no toxic components and use only sustainable manufacturing processes

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Thank You

http://aquionenergy.com/where-to-buy-batteries