Evolution: Enabling VRLA AGM Performance with Cost Advantage to a Lead Battery System

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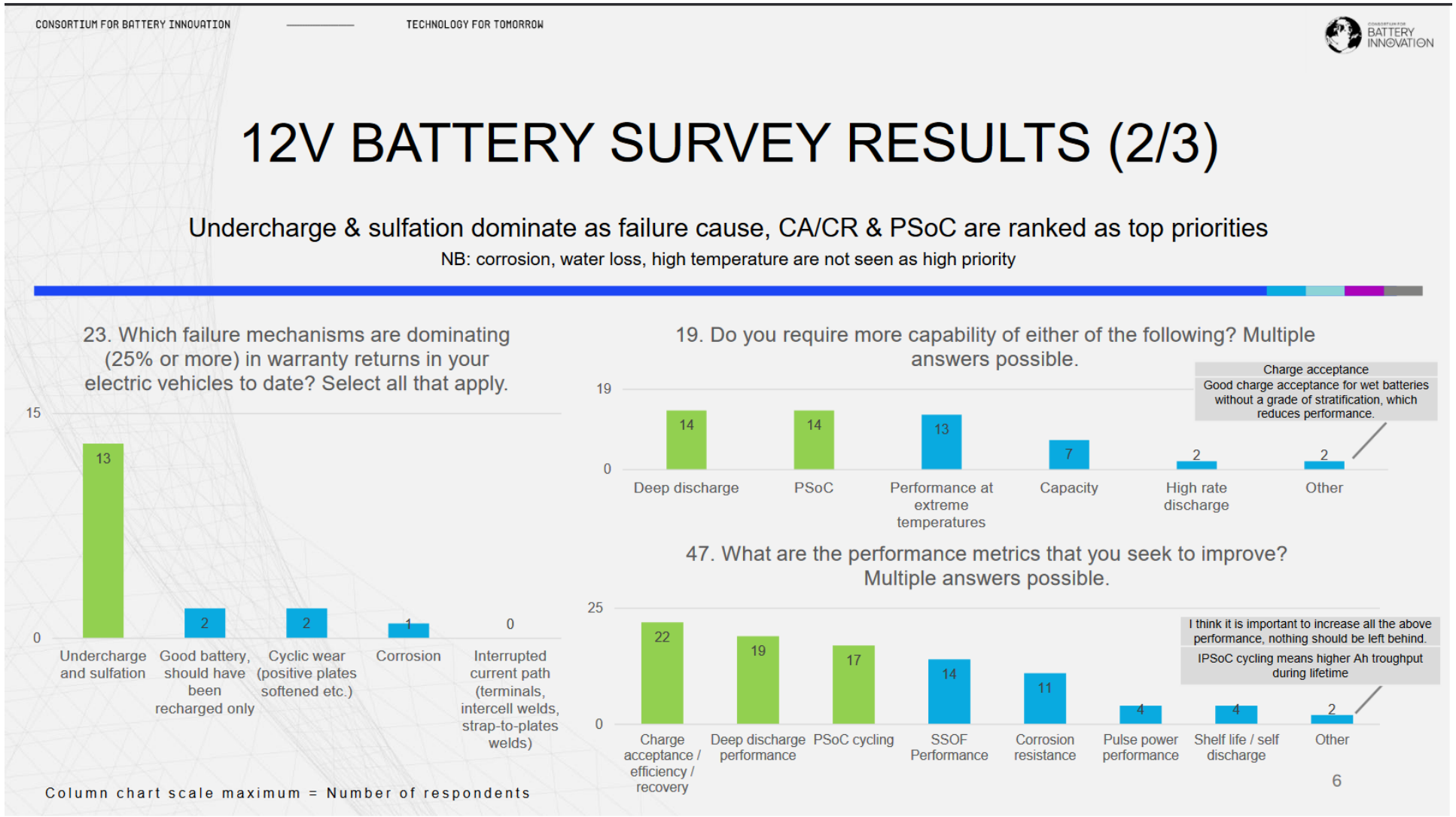
AsahiKASEI

Presentation Outline

- Motivation and Needs: Partial State of Charge (PSoC) Landscape and Challenge
- Traditional Separator Design in Flooded Lead Batteries (FLB)
- Problem Statement in FLB – Acid Stratification Due to PSoC
- Future FLB Separator Design for PSoC
- Concept of Stratosphere™: Solution to Acid Stratification in FLB
- Improved PSoC Cycle Life and its Mechanism in FLB by Stratosphere™
- Improved Battery Management System (BMS) Accuracy in FLB by Stratosphere™
- Other Battery Performances by Using Stratosphere™

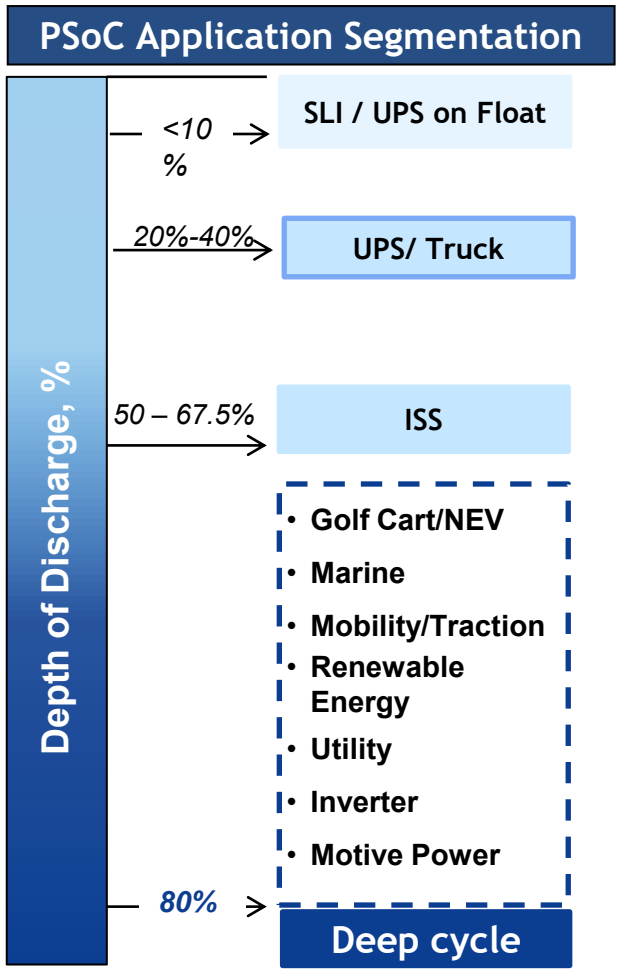
Motivation: Voice of Customers (2024)

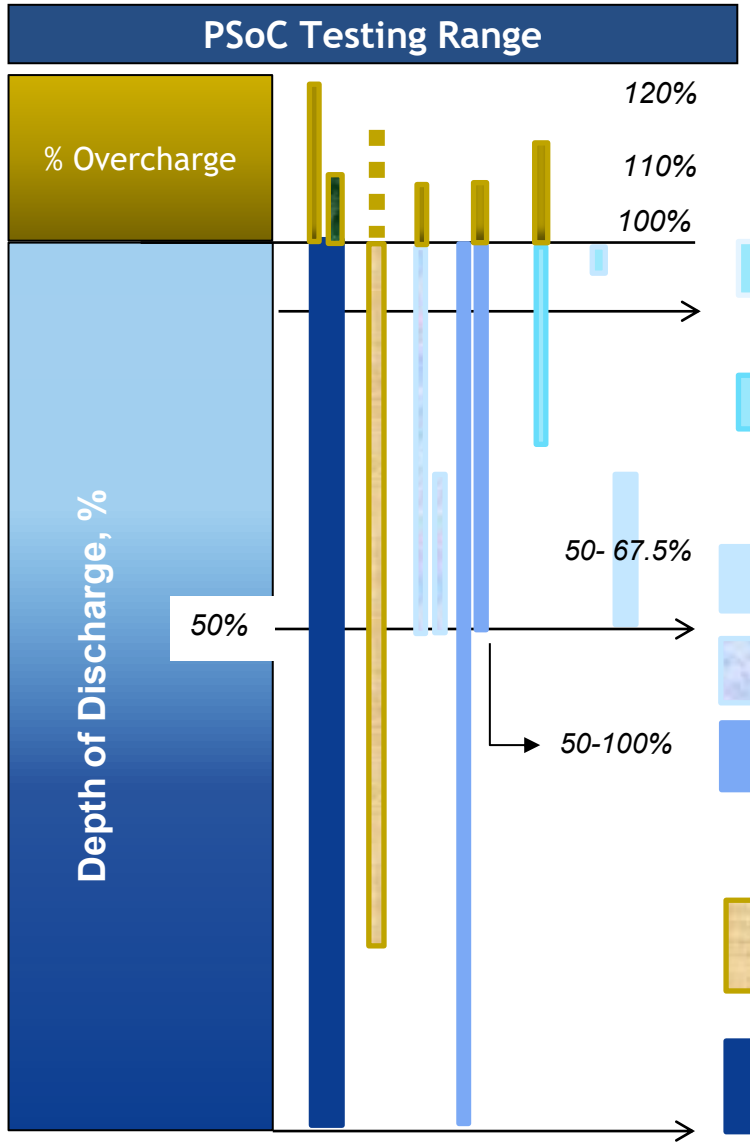


Clear and Present Needs to Improve More Capability: Deep Discharge + Partial State of Charge (PSoC)

[1] CBI (2024) OEM Expert Survey – Overview of Results and Deep Dive

Motivation: PSoC Operation





SBA (Japan EFB) Shallow Cycling <5%

J2185 Truck @ 50c 25% PSoC >110% Overcharge

17.5% @ continuous PSoC 27c: 50% DoD then charge to 67.5% & cycle

EN 17.5% PSoC @27c w/Capacity check & Equalization wkly: 50% DoD then charge to 67.5% & cycle

50% PSoC @40c 100% initial discharge, overcharge 108% & cycle 50-100%

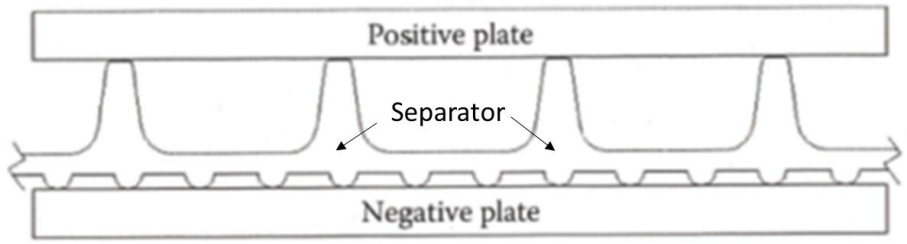
BCIS-15 80 DoD @ 27c
OC 115%/ 110%/108%/ 106%/ 104%/ 103%/ 102%

BCIS-06 100% DoD @ 27c over charge 105% - 120%

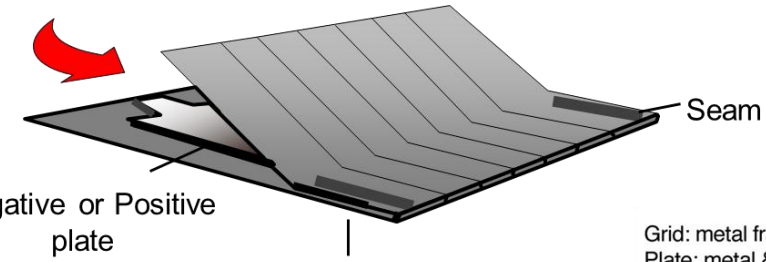
Re-inventing Separators for Longer & Deeper PSoC Cycle Life

Traditional Separator Design in Flooded Lead Batteries (FLB)

- **Major Ribs**
  - Ribs to positive plate for overcharge gassing escape
  - Ribs to Positive plate for acid reservoir and protection of separator backweb from oxidation and shorting
  - More ribs bring more protection from oxidation with <0.8mm plate spacing

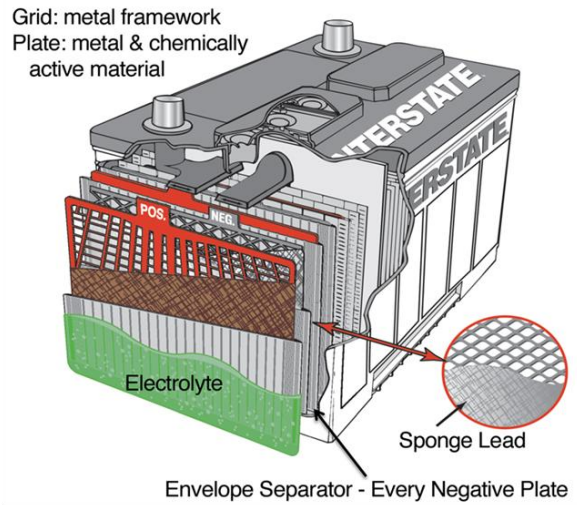


Minor ribs to negative plate
(Flat or Mini-ribs)



Lead Batteries Basic Reaction

$$PbO_2 + Pb^{\circ} + 2\,H_2SO_4 \underset{\text{Charge}}{\overset{\text{Discharge}}{\rightleftharpoons}} 2\,PbSO_4 + 2\,H_2O$$

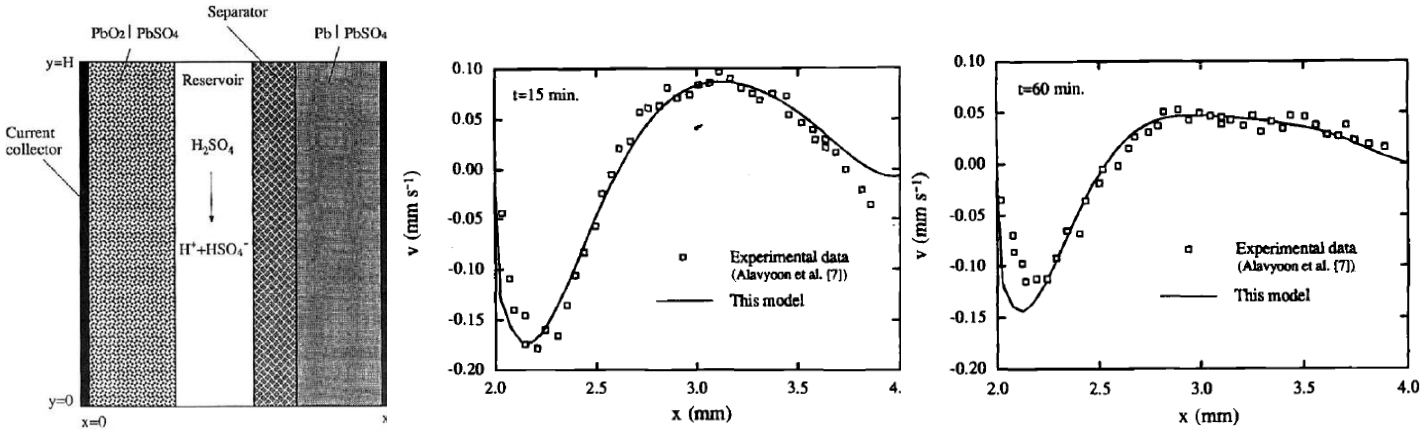


Traditional Separator Plays an Important Role to Deliver Good Battery Performance in FLB

Problem Statement - *Acid Stratification in FLB*

Acid Stratification

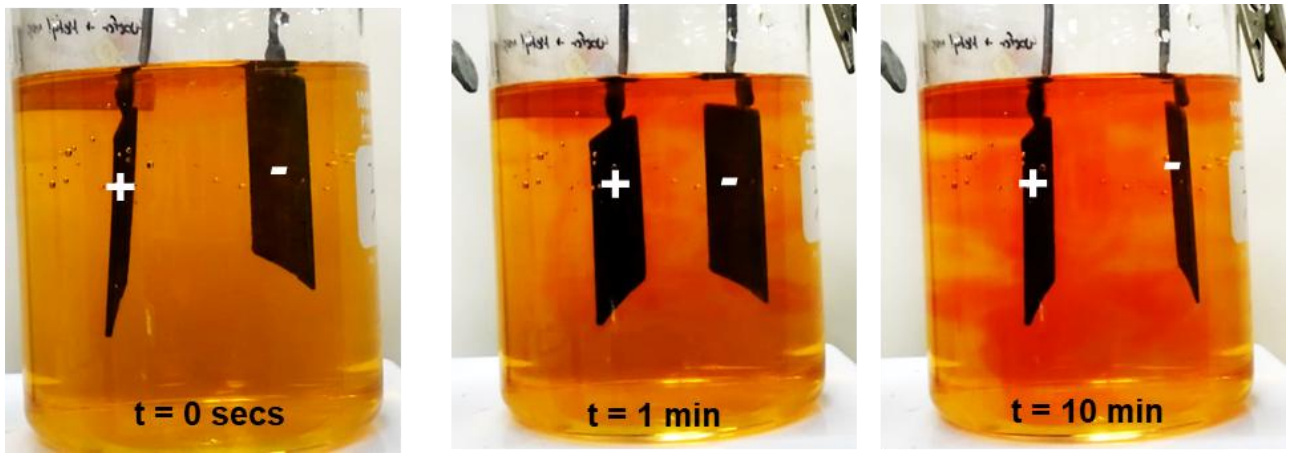
- Concentrated acid is generated at PAM (Positive Active Material) during charging
- Immediate gaps between separator and PAM allows heavy acid to sink and lighter acid to rise
- Deep discharges + recharge accelerate acid stratification



(Normal Orientation) *Comparison of electrolyte velocity profiles during charging at different timestamps [1]*

PSoC Migrating Towards Deeper DoD No Overcharge

- Overcharging generates gas bubbles to rise, which mixes acid
- Lack of overcharge = no more gas mixing



Comparison of plates charging in methyl-orange dyed electrolyte at different timestamps

Deeper DoD and Less Overcharge Means More Acid Stratification

[1] Gu, W. B., Wang, C. Y., & Liaw, B. Y. (1997). Journal of The Electrochemical Society, 144(6), 2053.

Future FLB Separator Design for PSoC

DARAMIC

1970's

Automotive

Less Rib mass: lower IR & Cost

Deep Cycle

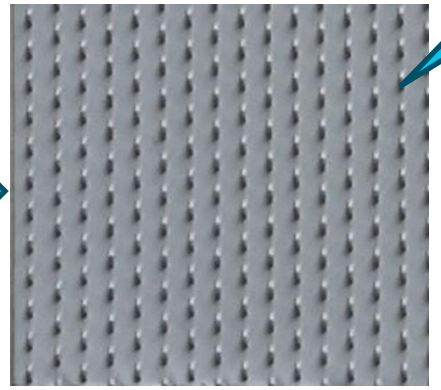
More Ribs: more PAM compression & less shedding

2000's

Combine

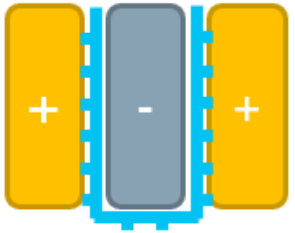
Serrated Rib profile

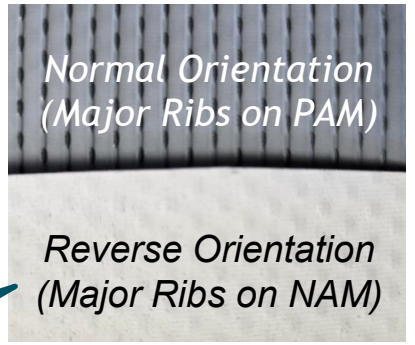
Blend of Deep Cycle with Less Rib Mass & Acid Mixing



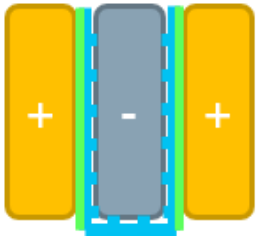
2024

Normal FLB construction Ribs toward PAM





Ribs toward NAM and Stratosphere toward PAM



PAM: 100% intimate contact
NAM: homogenous contact

Thinking Outside the Box: Reverse Orientation of Separator Major / Minor Ribs

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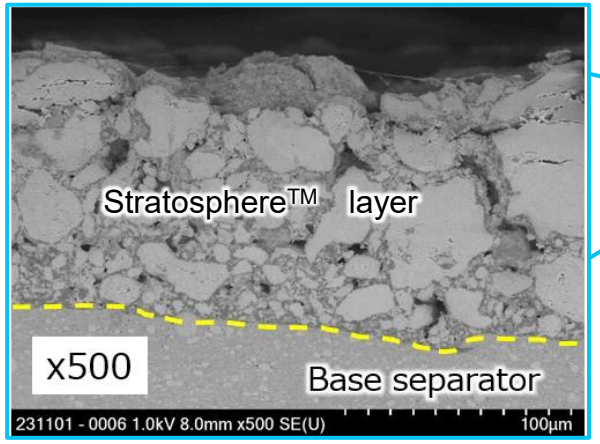
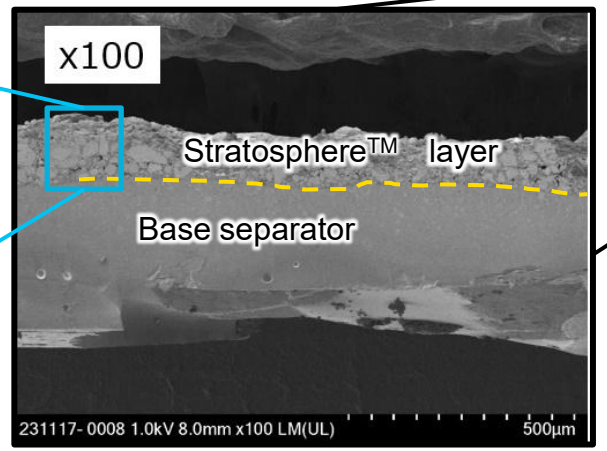
Proposed Solution: Stratosphere™ with Reverse Orientation

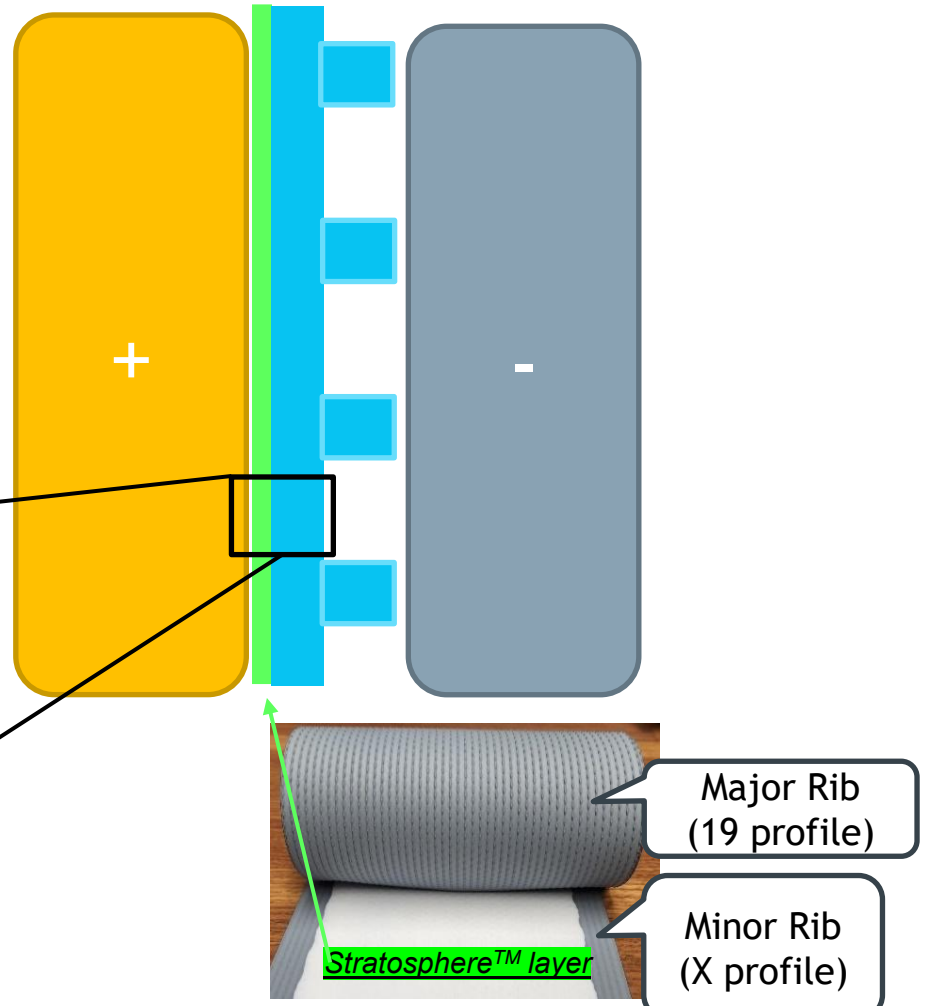
- **Base PE Separator:**
  - Major Rib: Serrated Rib (19 profile)
  - Minor Rib: Cross Mini Rib (X profile) or Flat

- **Composite Stratosphere™ Layer Bound to PE Separator**
  - Intimate contact with the surface of PAM
  - Uniform compression on PAM

*Top view macro view of separator reverse orientation



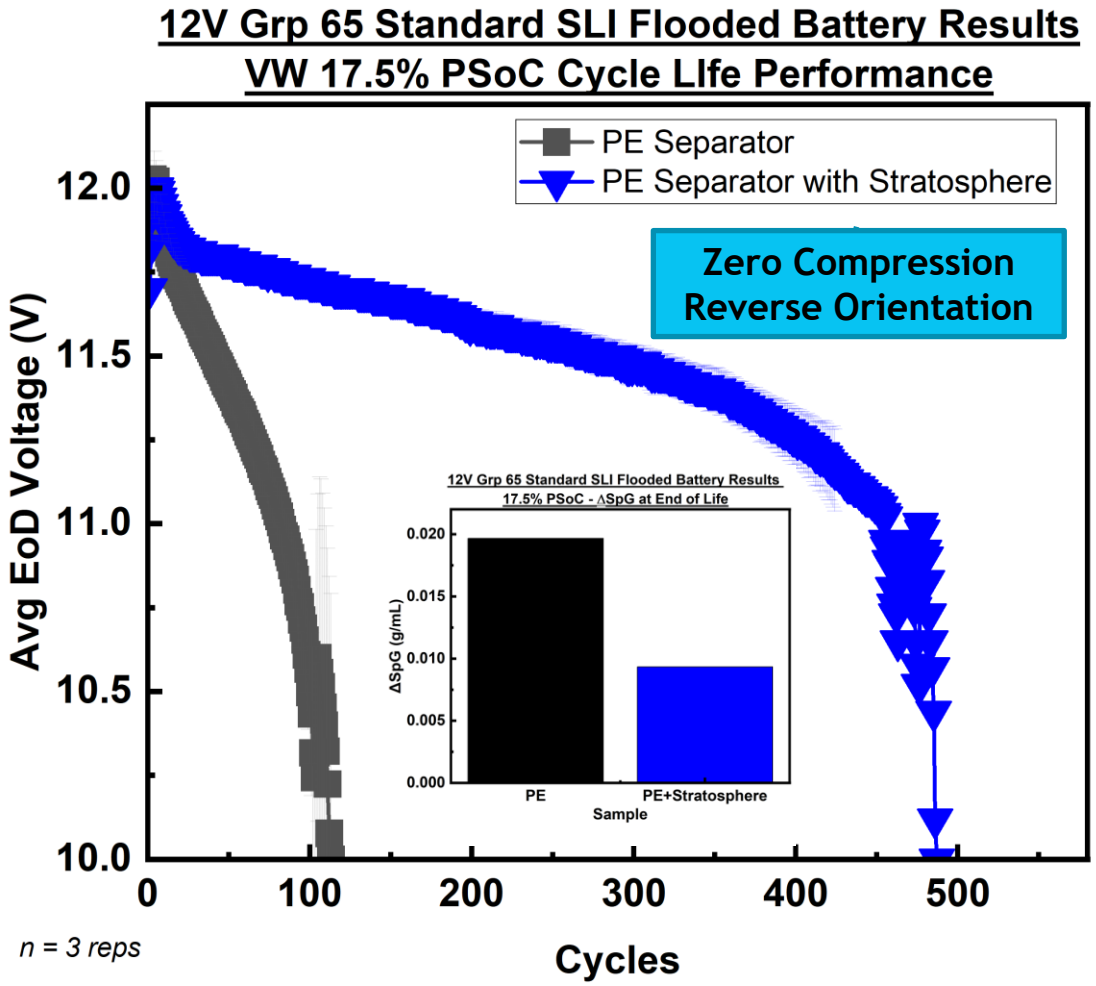




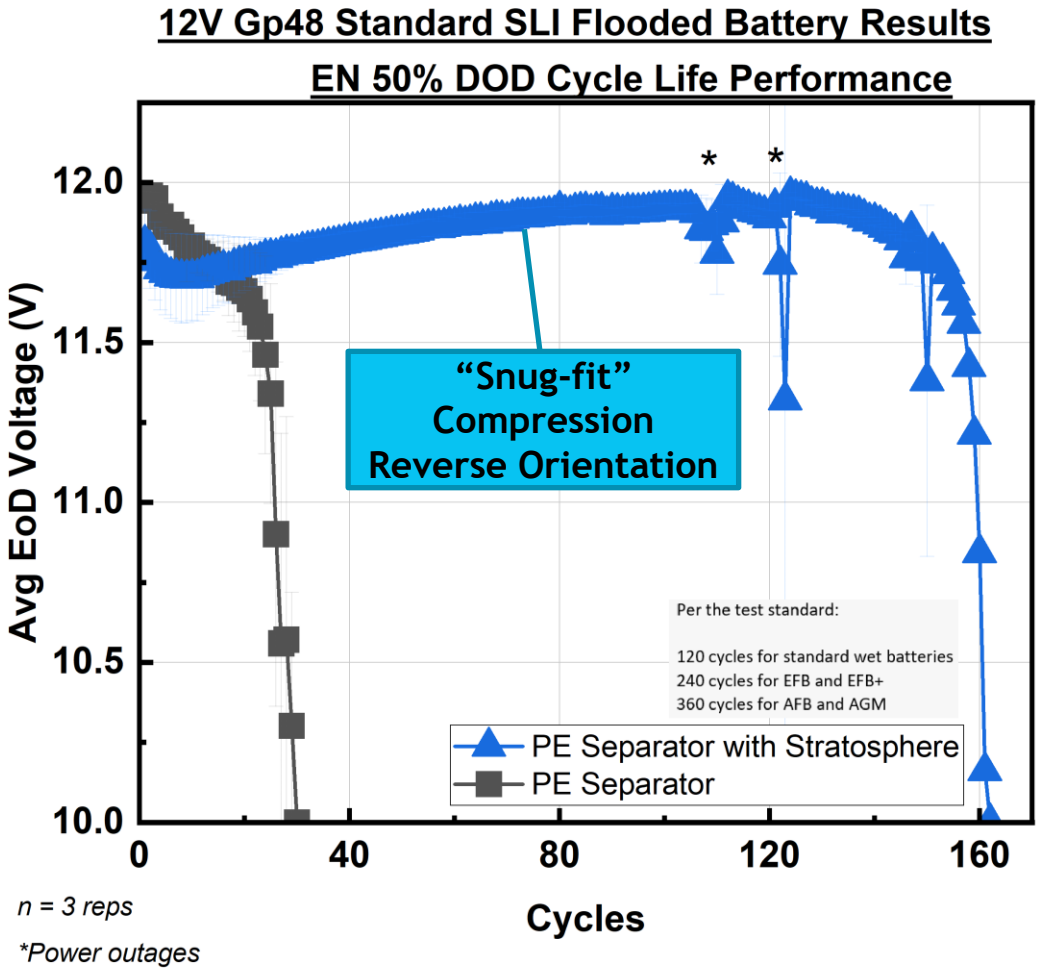
Stratosphere™ Layer Addresses Acid Stratification by Intimate Contact with Uniform Compression of PAM

Improved PSoC Cycle Life in FLB by Stratosphere™

- VW 17.5% (Continuous) PSoC: Cycling 50% - 67.5% DoD

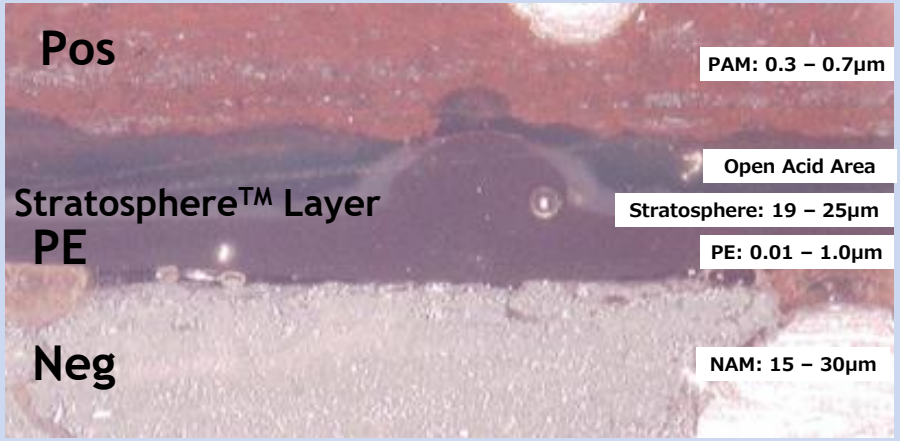
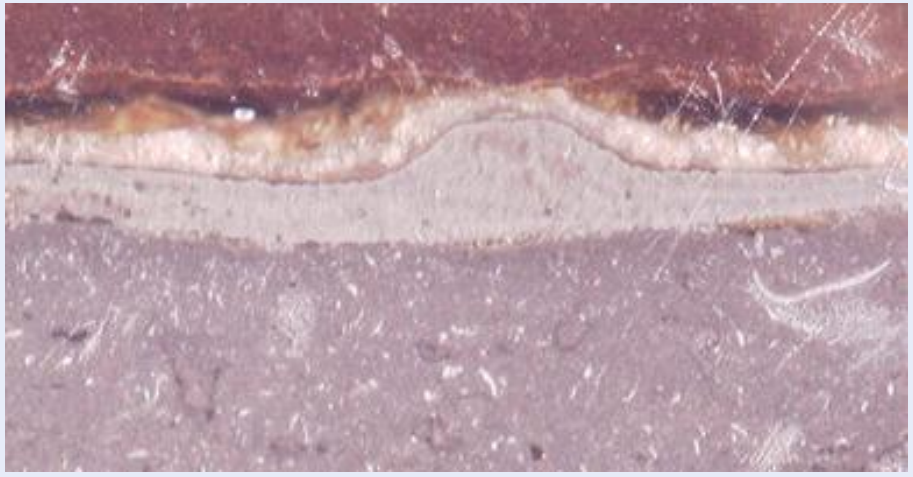


- VW 50% PSoC: Cycling 50% - 100% DoD



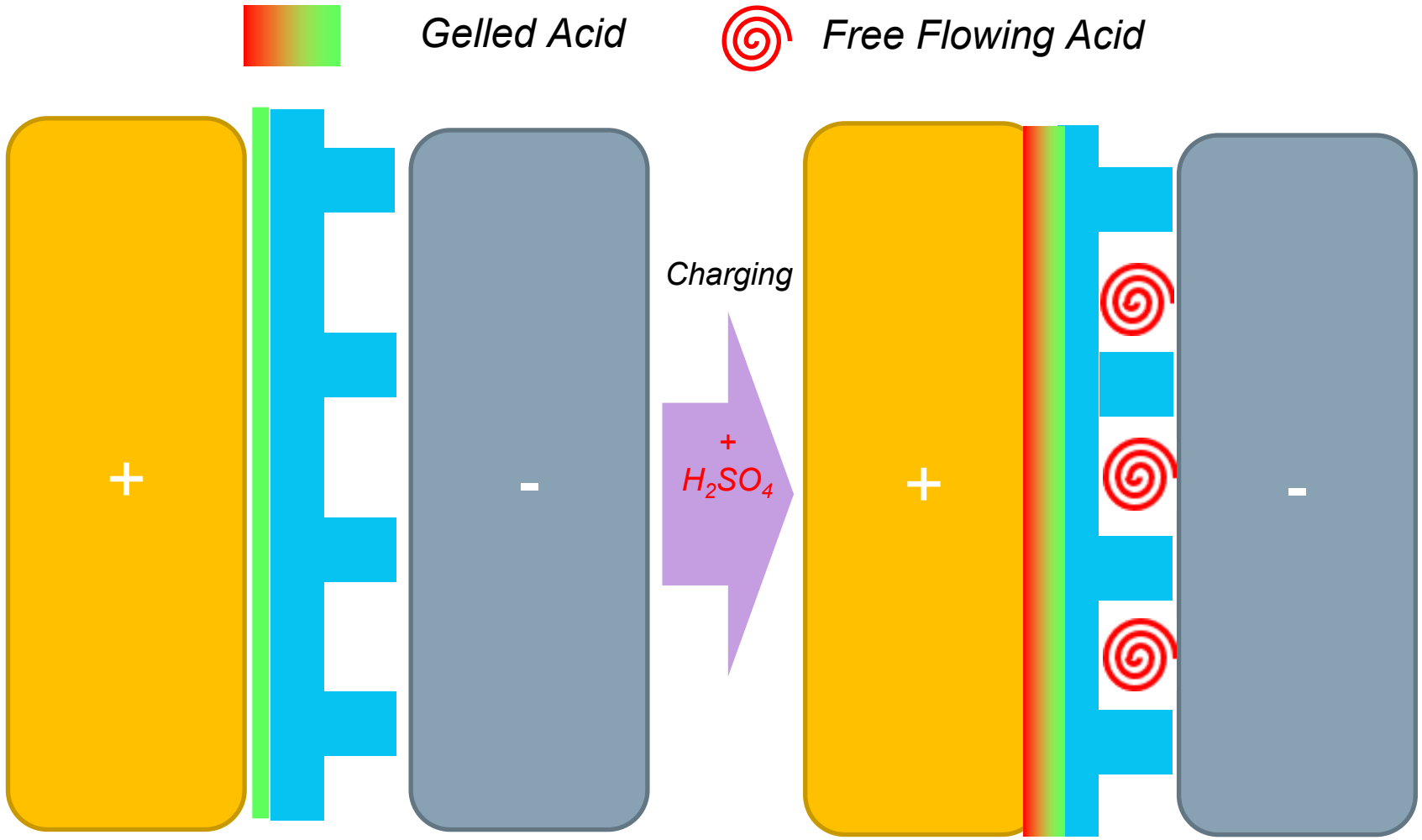
Stratosphere™ with Reverse Orientation Reduces Acid Stratification and Extends PSoC Cycle Life

Stratosphere™ Mechanism (FLB) - Intimate Contact with PAM

	Stratosphere™ - Normal Orientation	Stratosphere™ - Reverse Orientation
Dry cells		
SoC50%		

Proof of Intimate Contact with Uniform Compression of PAM Under Reverse Orientation

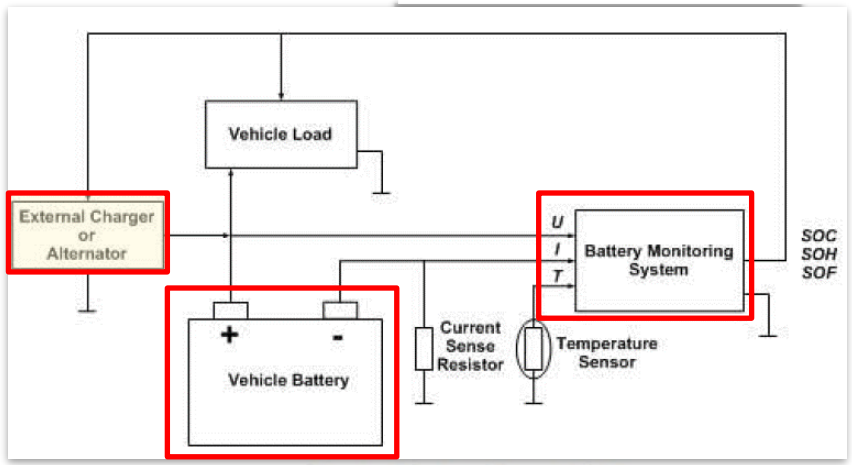
Schematic of Stratosphere™ Mechanism (FLB)

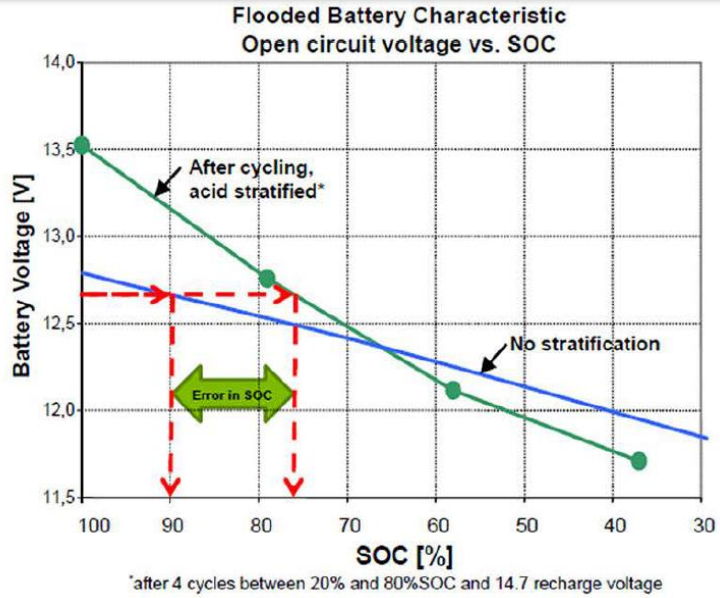


Compression + Stratosphere™ = Homogeneous Utilization of PAM/NAM
Gelation Layer Encases PAM with Concentrated H_2SO_4 and Keeps Free-Flowing Acid for NAM

Motivation: Challenge in Battery Management System

- Most Electric Vehicles (Evs) control the AUX battery by an external Battery Management System (BMS)
- Monitoring systems can have three continuous inputs:
  - **Voltage (V),** Current (I), Temperature (T)
- Open circuit voltage (OCV) depends on electrolyte density
- With stratified acid, highest acid density determines the OCV, *i.e.* overestimates real battery State of Charge (SoC)
- Acid stratification changes Voltage/SoC relationship
  - Error in SOC estimation
- Result: undercharged battery and negative plate sulfation, leading to poor State of Health (SoH)





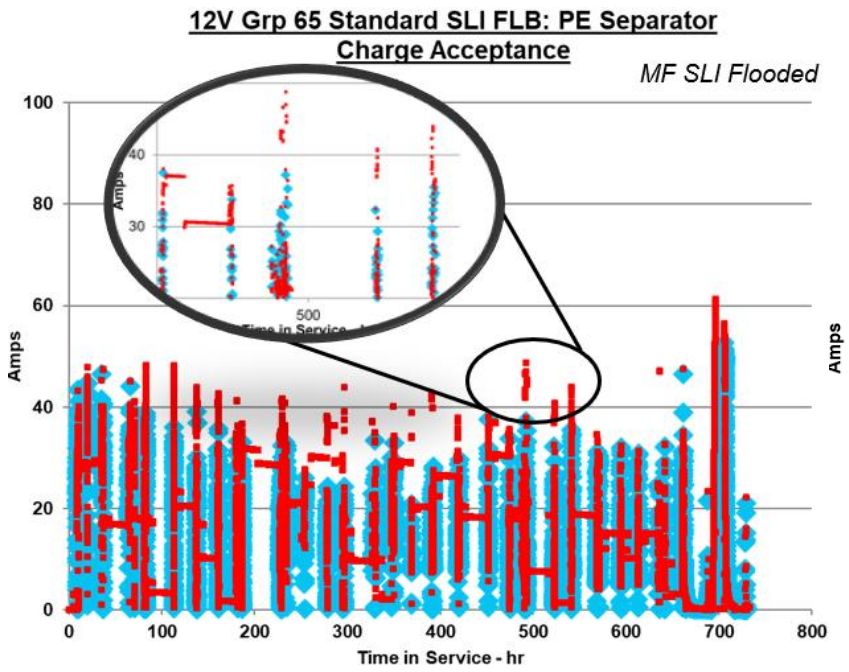
AABC June 20-22, 2012

Acid Stratification Causes BMS to Overestimate Real Battery SoC, Leading to Poor SoH

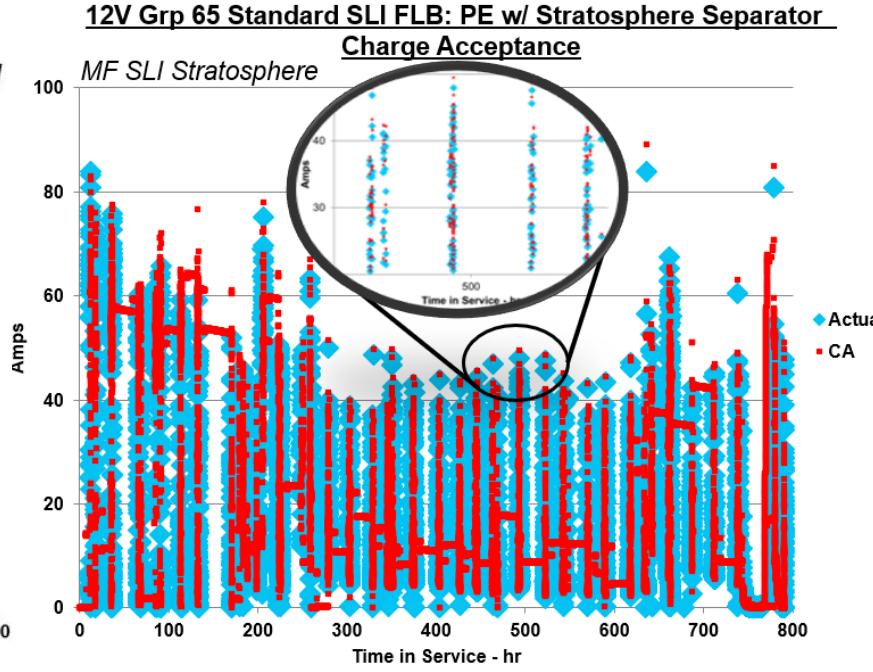
Improved BMS Accuracy in FLB by Stratosphere™

❑ *Tested on: Volvo S90 2019 Start-Stop Diagnostic Data Gp65 80Ah/825CCA*

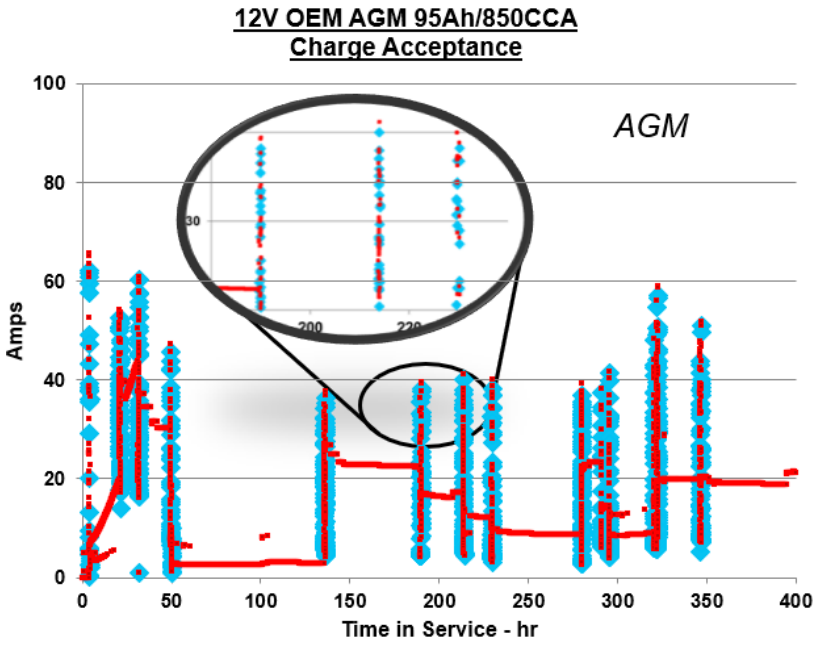
➢ Traditional Separator Design



➢ **Future Separator Design**



➢ **AGM VRLA**



FLB with Stratosphere™ Improves BMS Accuracy to Predict SoH Closer to AGM VRLA Performance

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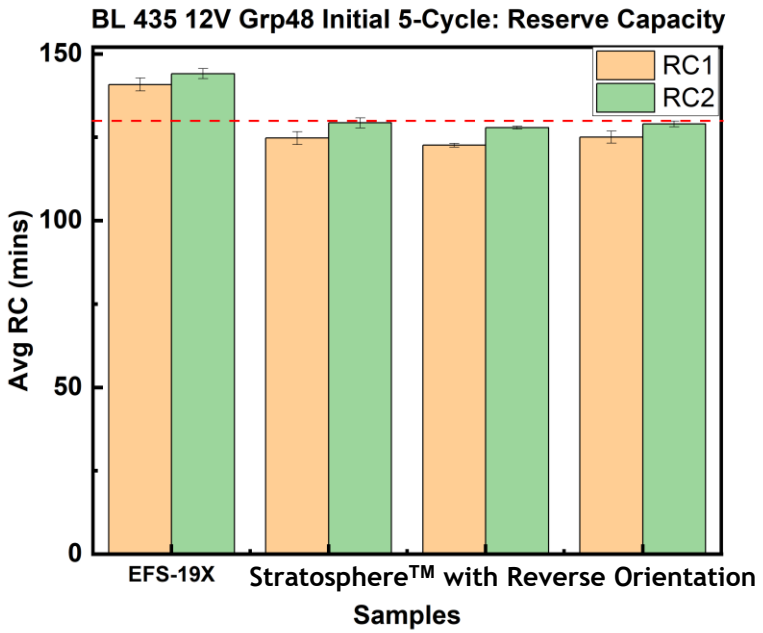
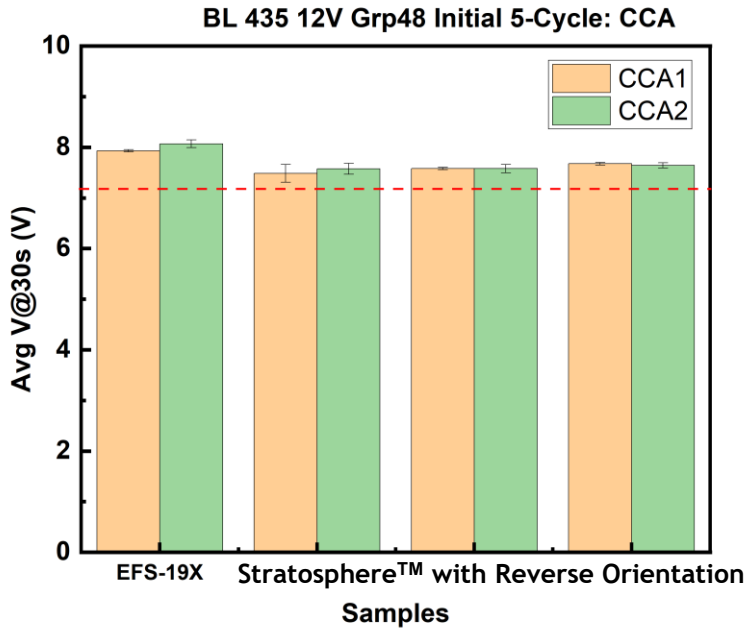
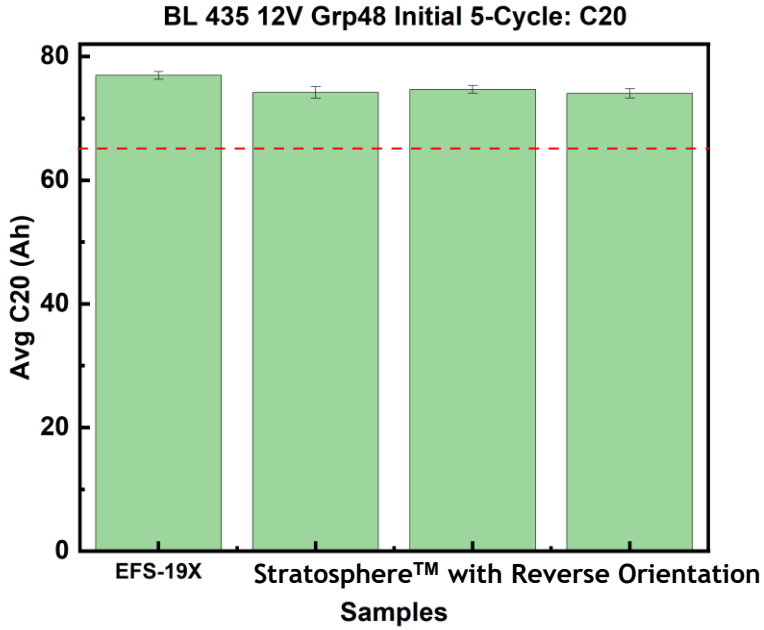
SLI MF Results - BCI-5 Cycle





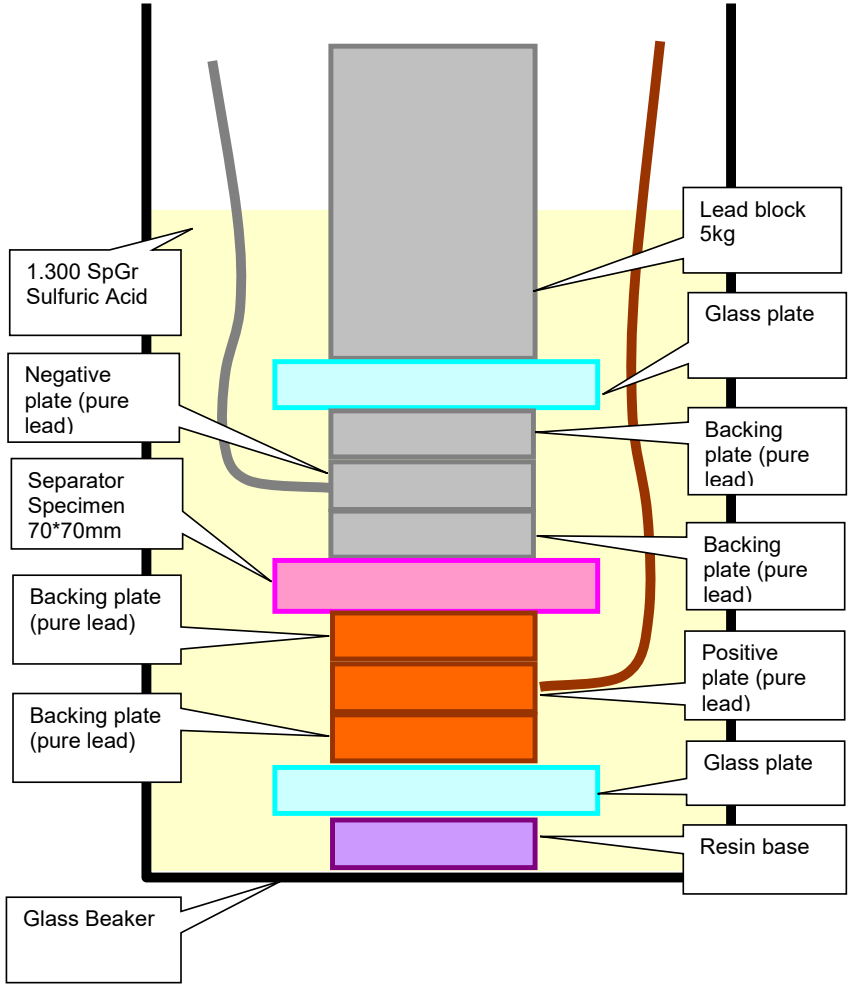


dotted red line denotes manufacturer rating

- RC: RC1 is slightly lower than rating but RC2 hits manufacture rating in the batteries with Stratosphere™
- CCA: Meet manufacture rating in the batteries with Stratosphere™ (all pass)
- C20: Meet manufacture rating in the batteries with Stratosphere™ (all pass)

Not Much Negative Impact on BCI 5-Cycle Battery Performance by Stratosphere™ with Reverse Orientation

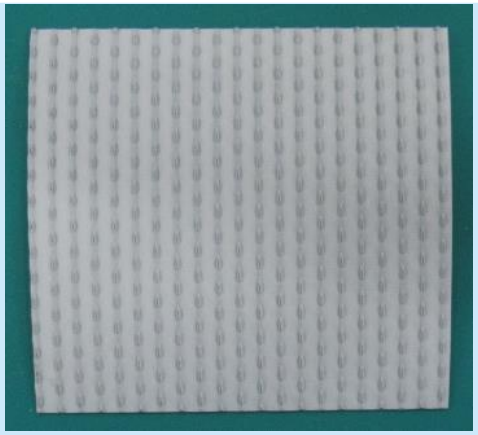
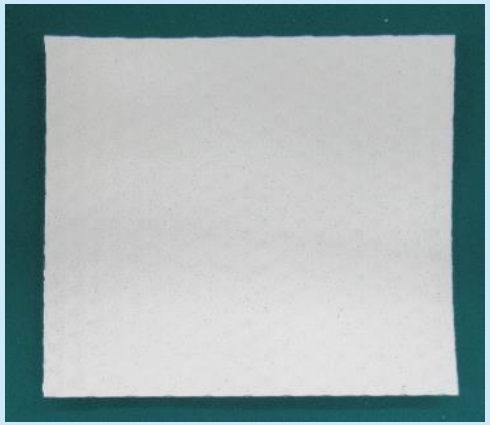
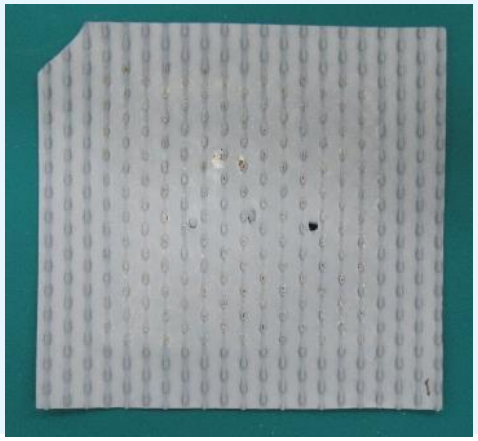
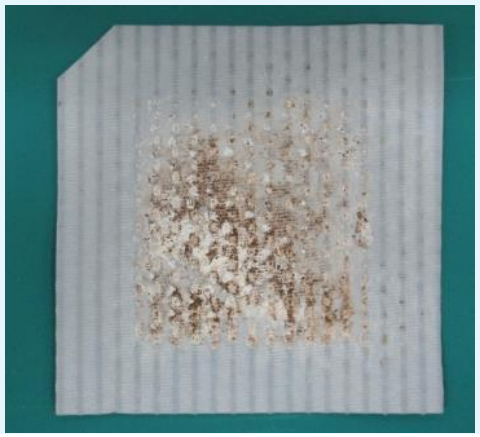
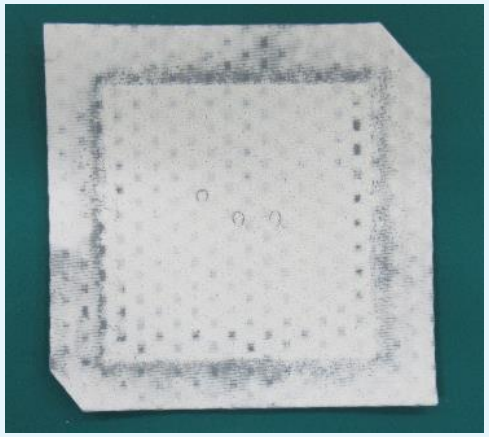
Accelerated Oxidation Test



- **Test Condition**
  - 1000ml of 1.30 Sp.Gravity H_2SO_4 @ 20℃
  - Compress the cell with separator by 5kg lead block
  - Temperature 75℃, Applied current: 5A
  - Stop supplying current when the voltage drops below 2.6V
- **Separator test samples (**L 70MM x W 70MM**)**
  - PE (Normal Orientation)
  - PE (Reverse Orientation)
  - PE + Stratosphere (Reverse Orientation)
- **Running over 100hrs**

Validating Oxidation Resistance of Stratosphere™ with Reverse Orientation

Stratosphere™ Mechanism – *Oxidation Protection vs. PAM*

Oxidation Test	PE (Normal Orientation)	PE (Reverse Orientation)	PE + Stratosphere™ (Reverse Orientation)
Before			
After			

Faced PAM

Stratosphere Layer Protects Separator Against PAM Oxidation

Conclusions

- **Proposed innovative Daramic® Stratosphere™ technology**
  - Featuring a proprietary gelation composite Stratosphere™ layer bound to PE Separator
    - Intimate contact with the surface of PAM under uniform compression
    - Adeptly controls the electrolyte by absorbing and expanding into the void space
    - This evolution in technology retards acid stratification
  - With Separator Reverse Orientation design under compression enables
    - Homogeneous utilization of PAM/NAM
      - Gelation Stratosphere™ layer encases PAM with concentrated acid and makes free-flowing acid for NAM

- **This evolution in technology by Daramic® Stratosphere™ technology can**
  - Extend at least 2x the battery's PSoC cycle life in flooded lead batteries (FLB)
    - Improve PAM utilization by applying homogeneous compression over the electrode surface
    - All while maintaining affordability of FLB
  - Ensure reliable sulfate ion transport and communication with the battery management system

- **Daramic® Stratosphere™ technology**
  - Combines the best aspects of FLB, VRLA and AGM lead battery separator technologies
    - Like no other separator developed to date
  - Represents a significant advancement and evolution in the field of lead batteries
    - Reinforcing their position as one of the most cost-effective battery technologies available today

Thank You!

Naoto Miyake

Asia Technical Director