
MOLECULAR REBAR[®]: Advanced Pb-Acid Batteries Enabled

Next Generation Solutions for EFB Batteries and Beyond

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**BLACK DIAMOND
STRUCTURES™**

Who We Are

Black Diamond Structures™ is a global nanotechnology leader with the mission to help manufacturers create the next generation of world-class batteries.

Our unique products, based on proprietary **MOLECULAR REBAR®** technology, together with our team of world-class nanomaterial experts alter your battery's "DNA", unlocking its full potential... fast.

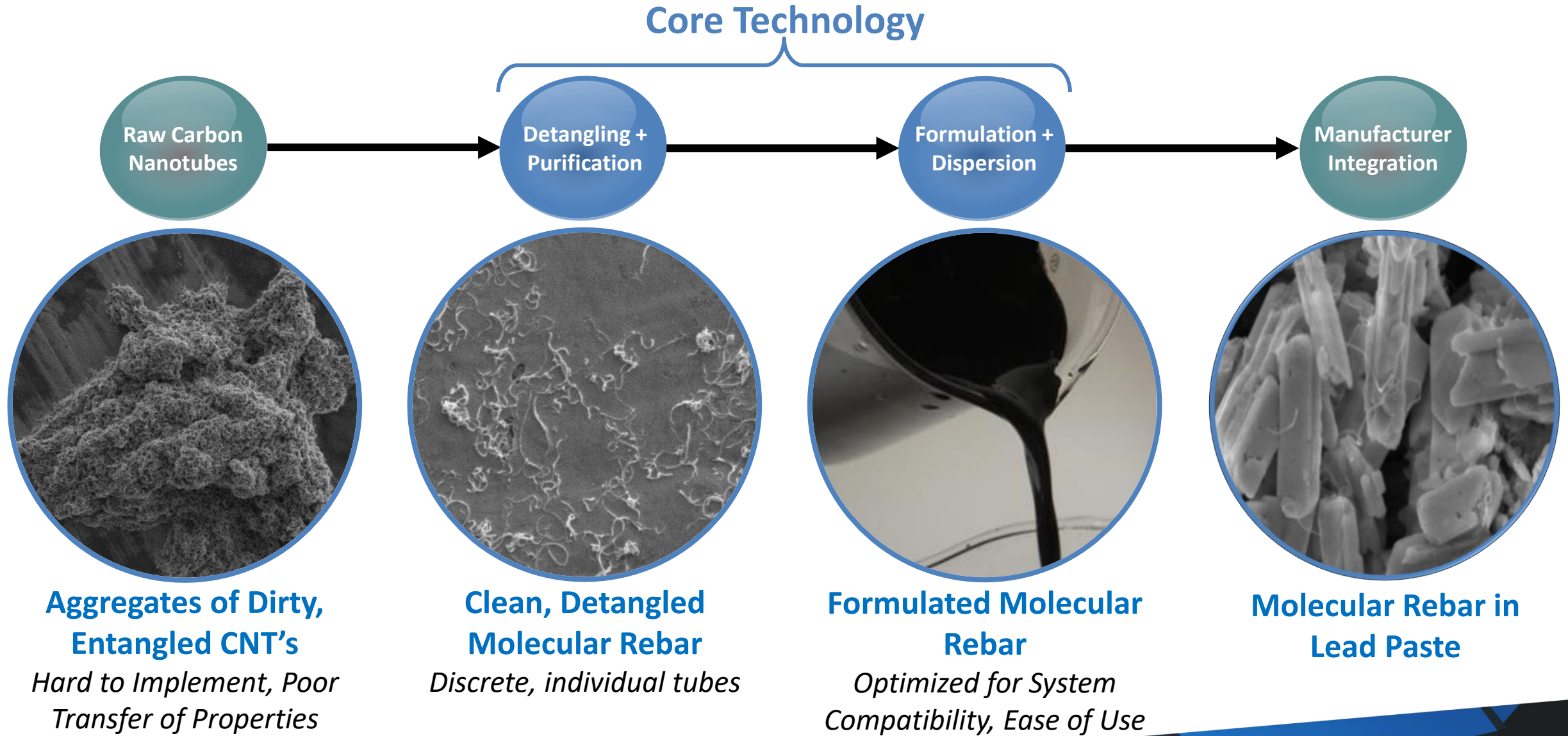
Our teams work directly with our customers to find solutions that enhance your battery's mechanical and electrochemical properties to meet market challenges for decades to come.



**YOUR
NANO
CONNECTION**

**BLACK DIAMOND
STRUCTURES™**

MOLECULAR REBAR[®] Technology



Providing Innovation for Three Distinct Applications

Lead-Acid Batteries

Charge Acceptance
>25%



Cycle Life
>25-300%



Enables Partial State
of Charge Operation



Improved Thermal
Operations Range



Silicon Graphite Anodes

Higher Energy Density
>20-45%



Longer Cycle Life
>20-100%



Increased Electrode
Strength >30-100%

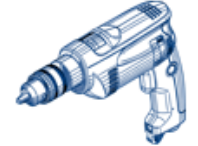


NMC Cathodes

>15 min Fast Charging
Enablement (4C Rate)



Enhanced High-Power
Discharge Capability



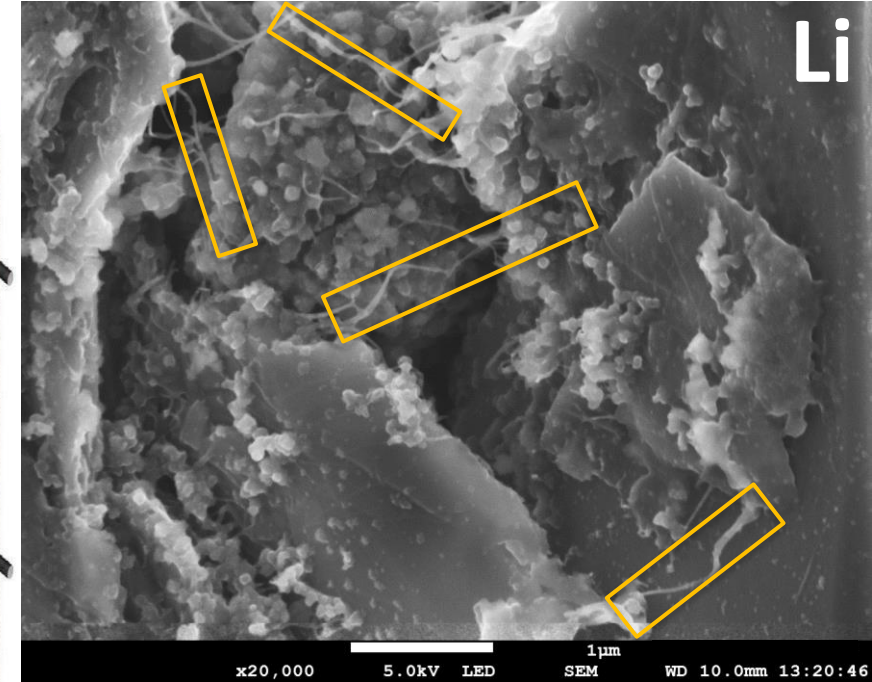
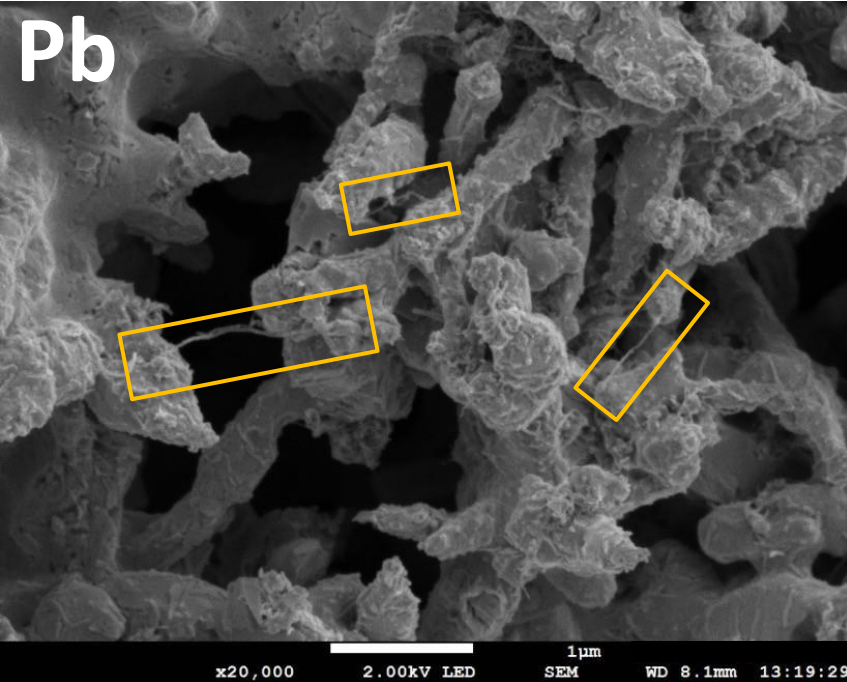
>5-10% Longer Cycle
Life



Our tailor-made MOLECULAR REBAR[®]-based formulations provide solutions for today's energy storage challenges

Augmenting Battery Material with Molecular Rebar

- **MOLECULAR REBAR®-based products provide nanoscale, electroactive reinforcements which:**
 - Act to bring the active material together, reinforcing electrode structure → **Enhanced robustness and durability**
 - Alter interparticle connectivity and morphology to enhance active material structure → **Improved electrical performance**
 - Overcome structural and chemical limitations that induce failure → **Consistency of performance**



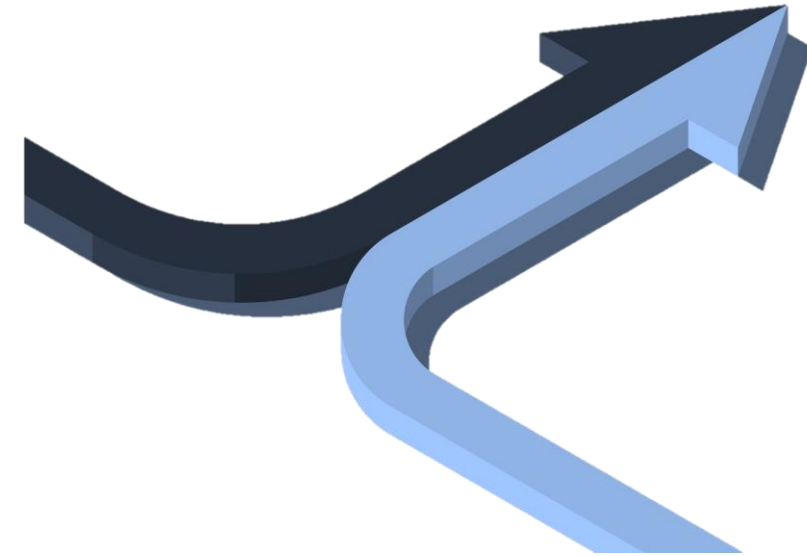
Molecular Rebar Products Change the “DNA” of Your Battery

**BLACK DIAMOND
STRUCTURES™**

Pb1200 Series: Our Harmonized Lead-Acid Solutions

Advanced MOLECULAR REBAR® technology can now be combined with custom-tailored expander components for ultimate synergy and performance

- **Our New Solutions enable you to:**
 - Take dramatic steps towards meeting challenging OEM requirements
 - Replace costly or poorly balanced expander/carbon mixtures
 - Reduce costs by eliminating the need for excessive material or components
- **Breakthrough made possible through strong partnership with Addenda:**
 - Access to unique, alternative components
 - Scale production and global distribution of co-developed additive packages
 - Strong product uniformity and quality



The Demands of Modern Automobiles

Rapid adoption of eVehicles is challenging the micro/mild-hybrid ICE market, and the batteries which support it, to do more, for less cost

- To remain competitive, the lead-acid battery market must embrace these challenges, and drive innovation
 - The Consortium for Battery Innovation (CBI) released a technical roadmap steering the community towards success:

| Performance Metrics | | Unit | Common Values | 2025 | 2030 |
|---------------------------------|---------------------|-------|---------------|---------------|---------------|
| Dynamic Charge Acceptance (DCA) | EN-50342-6 | A/Ah | 0.25-0.85 | 2.00 | 2.00 |
| Run-In DCA | Ford Test B | A/Ah | 0.50-1.00 | 1.50 | 2.00 |
| High Temperature Durability | IEC, CENELEC | Units | 6-16 | 20 | 20 |
| Water Loss | EN-50342-1, CENELEC | g/Ah | 1.5-6.0 | <3 | <3 |
| Cold Crank / Reserve Capacity | EN, IEC, SAE | - | No Compromise | No Compromise | No Compromise |

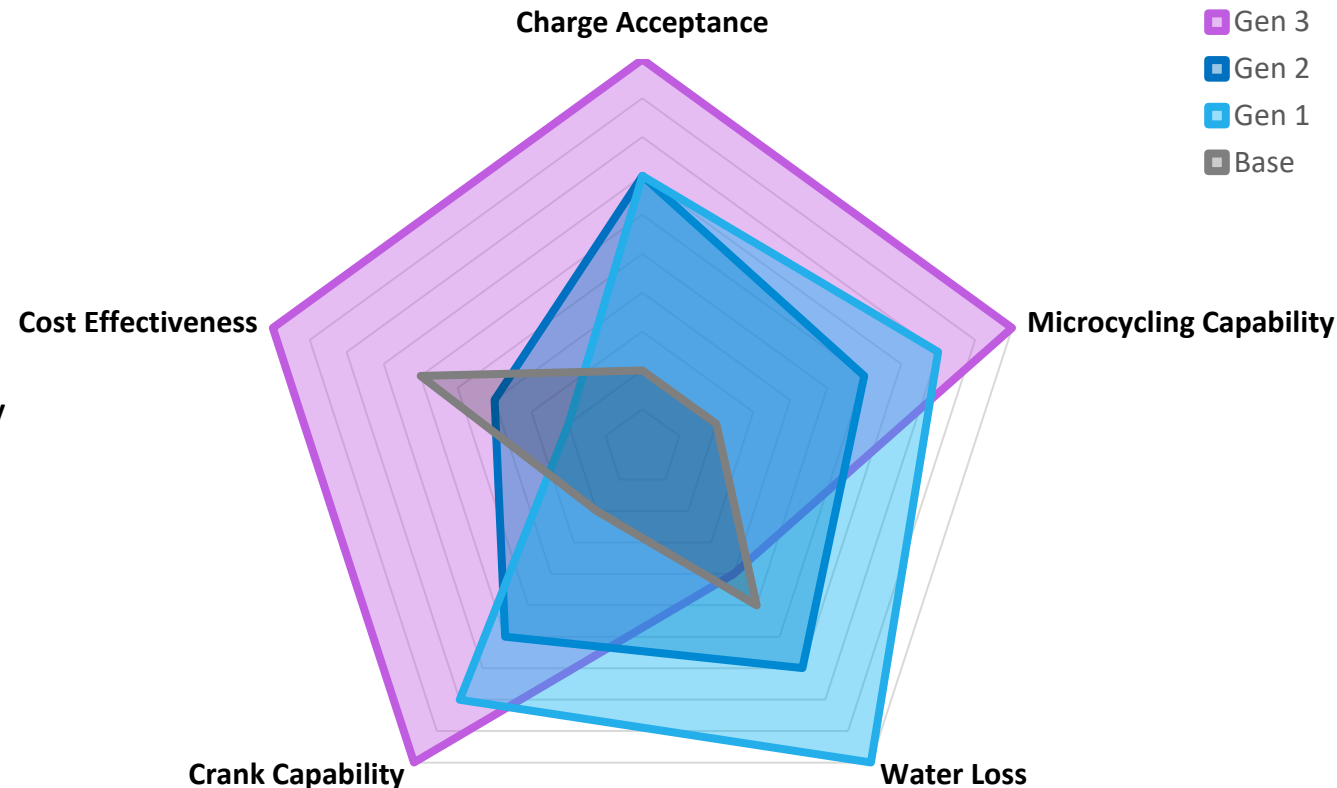
Ref: Sep 2021 CBI Technical Roadmap

- Inherent to these Performance Metrics is the need to maintain balance; a principle Black Diamond strives towards
 - Charge Acceptance vs. Water Loss / CCA
 - Performance vs. Cost

MOLECULAR REBAR® Addresses These Demands

Since their unveiling at 14ELBC, MOLECULAR REBAR® products have continuously evolved to address the market need

- **1st Generation EFB Products (<2016)**
 - MOLECULAR REBAR® added to existing designs
 - High chargeability and micro-cycling performance, offset with high water loss and cost
- **2nd Generation EFB Products (2017-2019)**
 - MOLECULAR REBAR® added alongside a commercially available expander, augmented by Advanced Carbon
 - More balanced charge acceptance / water loss
- **3rd Generation EFB Products (>2020)**
 - MOLECULAR REBAR® tuned and unified with custom-tailored expander for maximum component synergy
 - Next level of balanced performance, adjustable to the customer need



1st Generation Commercial Customer Testimonial

| Performance Metrics | | Unit | Existing Design | 1 st Gen MR Solution |
|---|------------------|-------|-----------------|---------------------------------|
| Capacity | EN-50342-1 | Ah | 59 | 60 |
| Cold Crank Performance (V_{10s} / t_{6V}) | EN-50342-1 | V / s | 7.25 / 120 | 7.60 / 142 |
| Dynamic Charge Acceptance (DCA) | EN 50342-6 | A/Ah | 0.26 | 0.42 |
| Regenerative Ability | Toyota | As | 400 | 540 |
| Micro-cyclability | EN-50342-6 17.5% | Units | 4 | 7 |
| High Temperature Durability | SAE-J2801 | g/Ah | 13 | 12 |

- **Latin American Customer:**
 - Made an SLI perform like an EFB:
 - +62% DCA without CCA detriment
 - +35% regenerative ability
 - +75% micro-cyclability
 - Almost no change to water-loss sensitive test (SAE-J2801)

| Performance Metrics | | Unit | Existing Design | 1 st Gen MR Solution |
|---|------------|--------|-----------------|---------------------------------|
| Reserve Capacity | SAE-J537 | mins | 54 | 56 |
| Static Charge Acceptance (SCA) | SAE-J537 | A | 6.75 | 8.00 |
| Cold Crank Performance (V_{10s} / t_{6V}) | EN-50342-1 | V / s | 7.60 / 76 | 7.80 / 82.5 |
| Micro-cyclability | SBA-S0101 | Cycles | 5,883 | 35,300 |
| Gassing Rate Characteristic | SAE-J537 | mL/min | 8.6 | 15.8 |

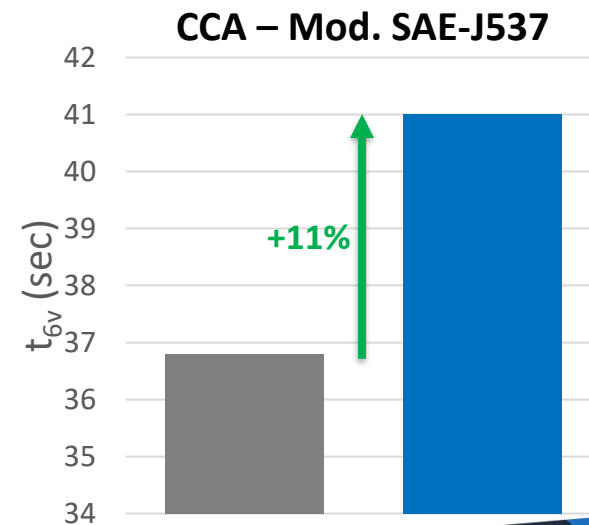
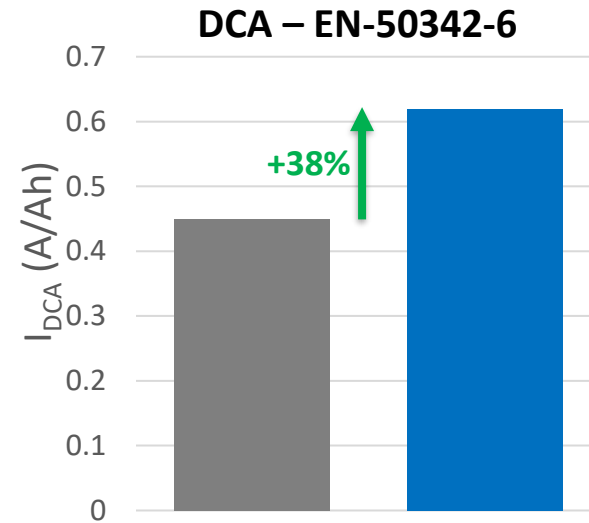
- **Asian Customer:**
 - Made an SLI perform like an EFB:
 - +18% SCA without CCA detriment
 - +500% micro-cyclability
 - Significant increase in gassing rate

Full-scale, 12 V Automotive Battery Data

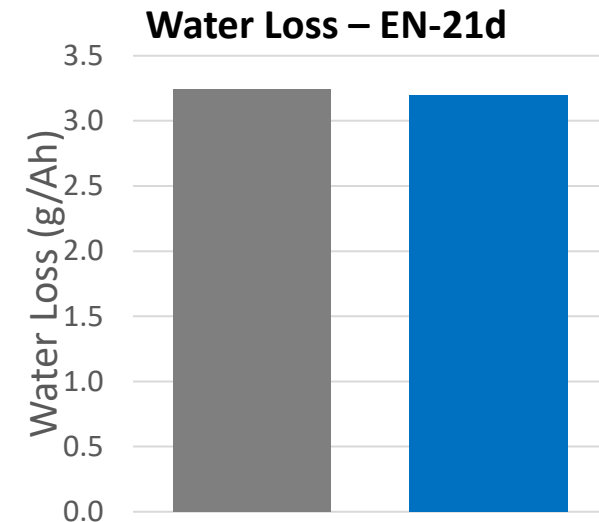
2nd Generation Commercial Customer Testimonial

- **Tier 2 Manufacturer:**

- Improved / Rebalanced an existing 70 Ah / L3 EFB design
 - 38% improvement in Dynamic Charge Acceptance
 - *Market leading, versus store-bought Tier 1 batteries*
 - 11% increase in CCA duration (SAE-J537 to t_{6V})
 - Comparable water consumption (W3 Rating)
- Achieved through:
 - Customer-specific prescription of MOLECULAR REBAR®
 - *15 L Pb1210N / 1000 kg PbO*
 - 60% reduction of incumbent Advanced Carbon
 - Use of basic, pre-mixed expander components
- Results duplicated in additional models, inc. L1 design



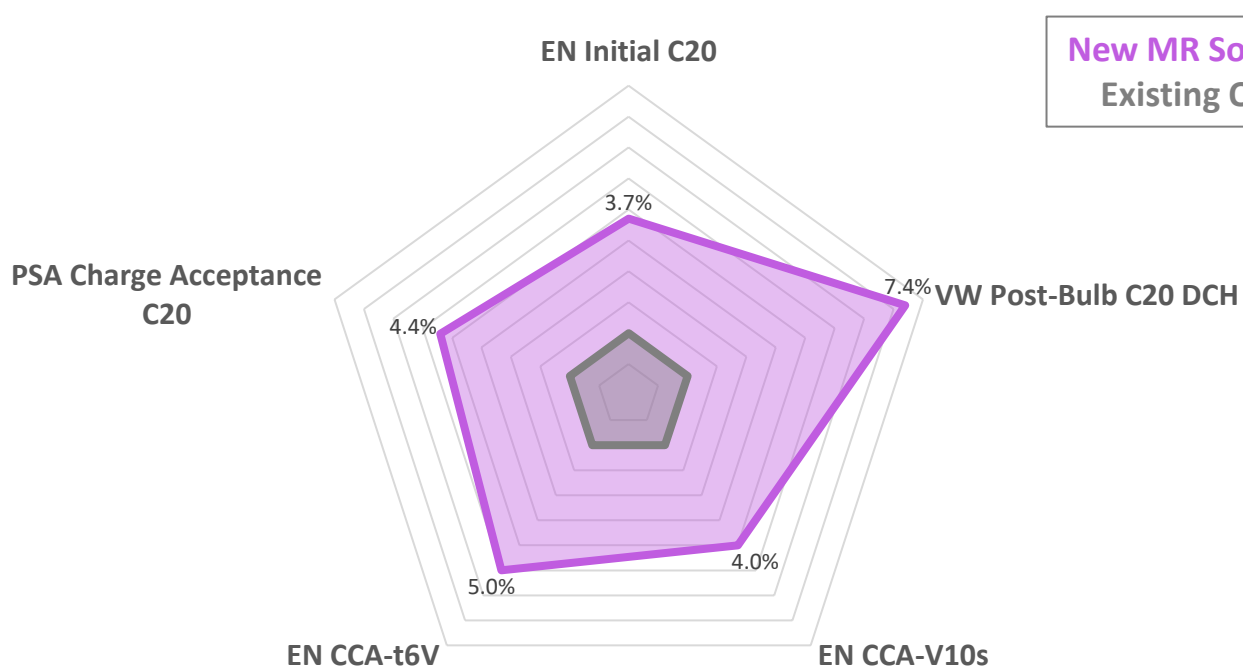
*Full-scale, 12 V
Automotive
Battery Data from
a 3rd Party Lab*



3rd Generation Manufacturer Testimonial

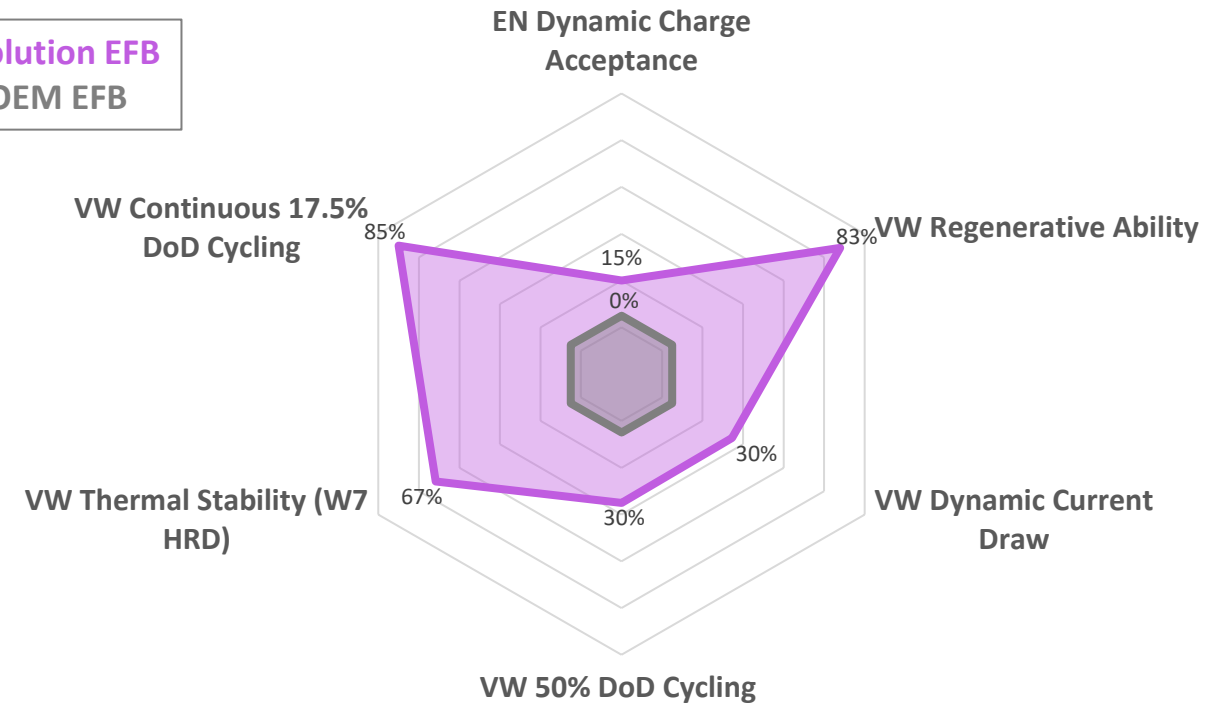
- One of our New Solutions was graduated from our 2V Lab and validated in an EU 12V build of excellent quality:
 - L1, 49 Ah, 540 A, dry battery weights within 1 g of each other

Initial Characterization Improvements

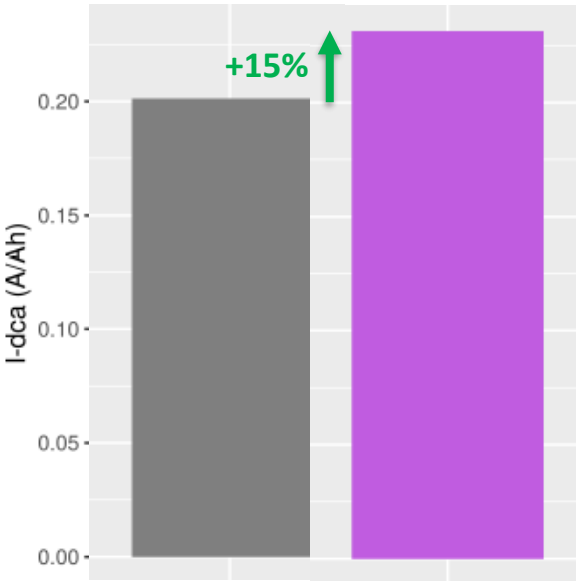


New MR Solution EFB
Existing OEM EFB

Charge Acceptance + Life Improvements



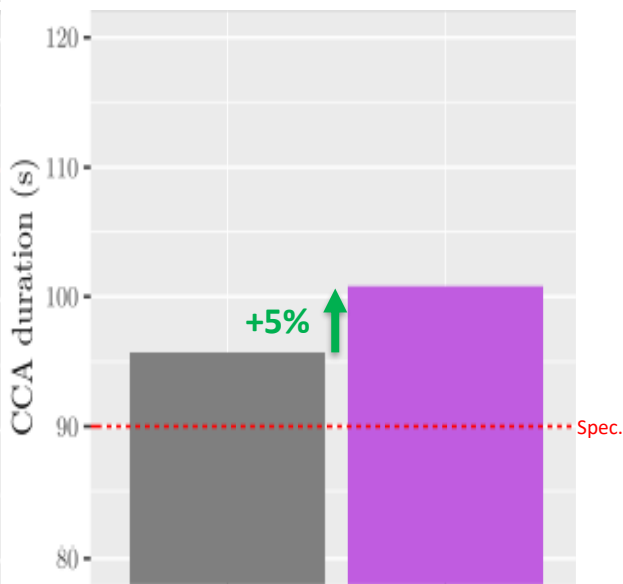
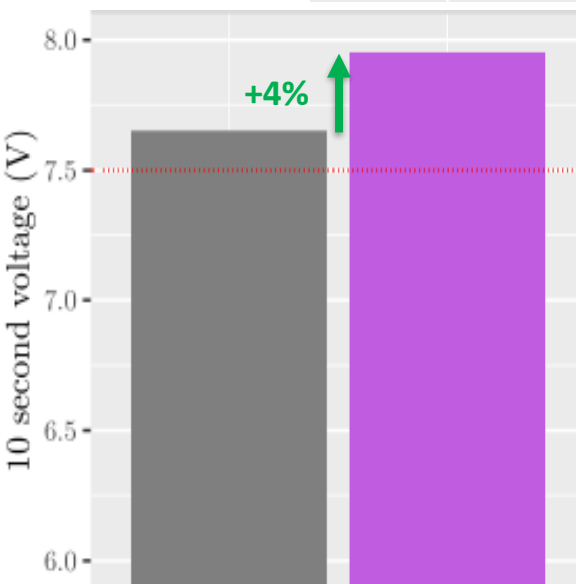
3rd Generation Manufacturer Testimonial



H₂O Consumption Rating:

W4

Components Mixed and Sourced by:

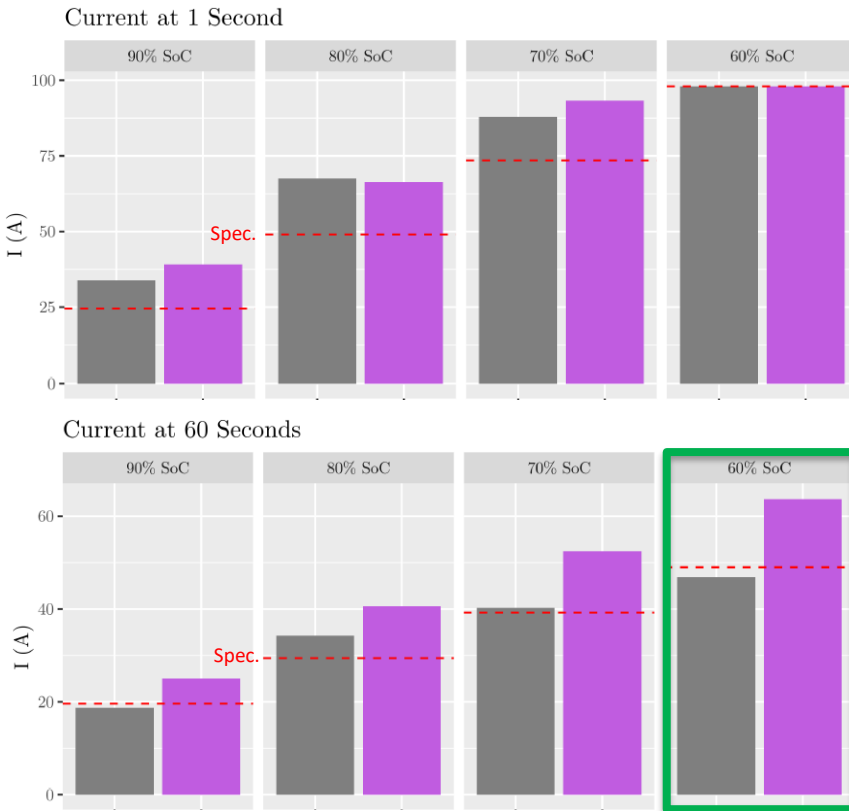


- Vs. the company's highly-optimized, OEM-targeted expander package, **Our New Solution** provides:
 - +15% DCA
 - Acceptable W4 water consumption rating (≤ 4 g/Ah, 42d)
 - ~4% improved V_{10s}
 - ~5% improved t_{6V}

OEM Charge Acceptance Requirements Met

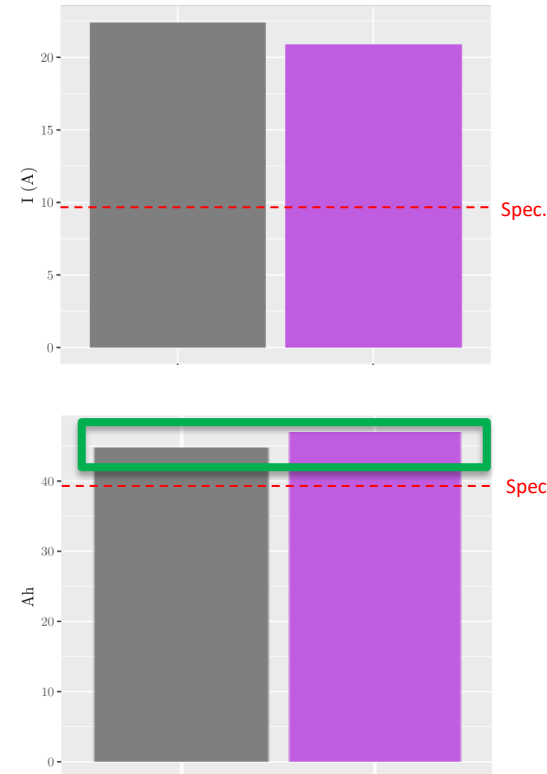
Dynamic Current Draw (26 °C)

(VW 75073:2020-7.8)



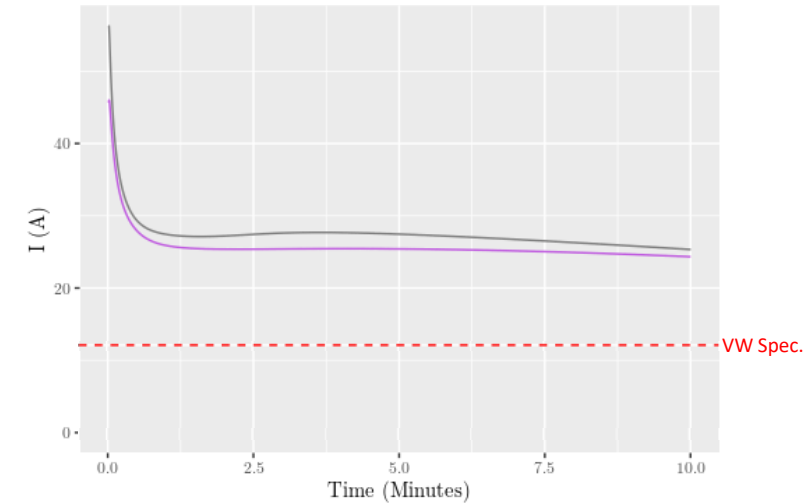
50% SoC Charge Acceptance (0 °C)

(PSA 01553:2016-8.5.1)



Static Current Draw (0 °C)

(VW 75073:2020-7.4 = EN 50342-1:2015-6.4 ≈ GB/T 22473:2008-7.5)



| GB/T Metrics | Est. C_{10} | I_{10mins} | $I_{10mins} / (0.1 * C_{10})$ |
|------------------|---------------|--------------|-------------------------------|
| Standard Battery | 46.7 | 25.3 | 5.42 |
| New Solution | 48.8 | 24.3 | 4.99 |
| Specification | - | - | FLD >3, AGM >2 |

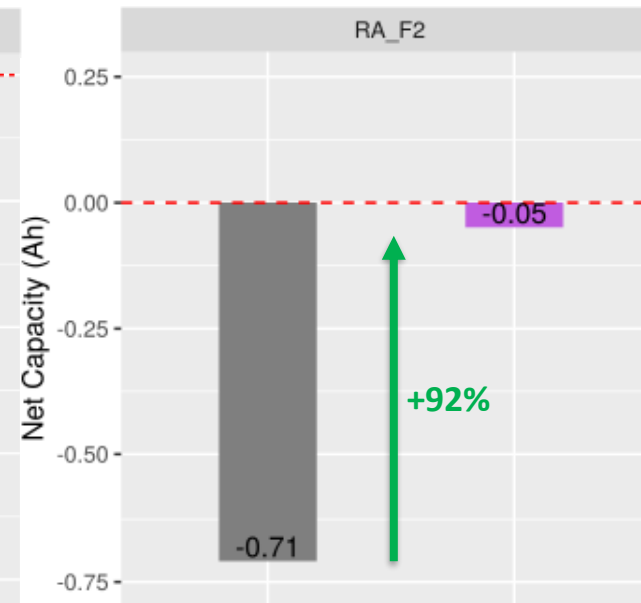
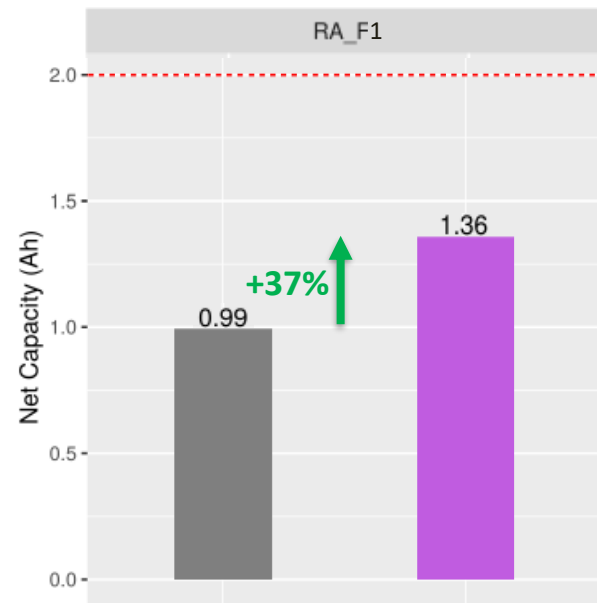
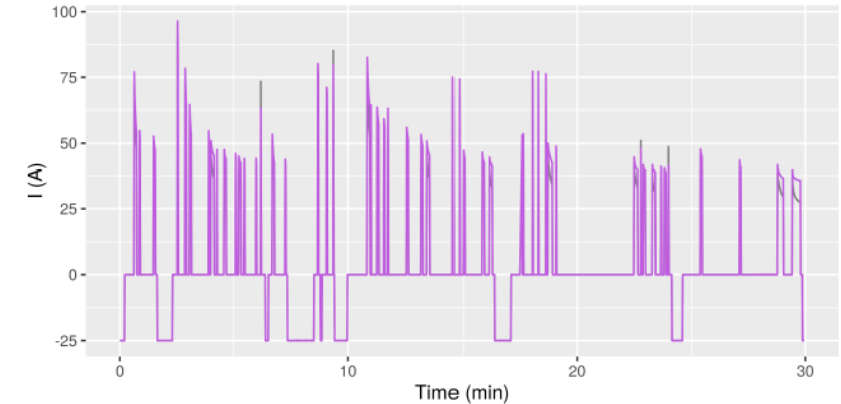
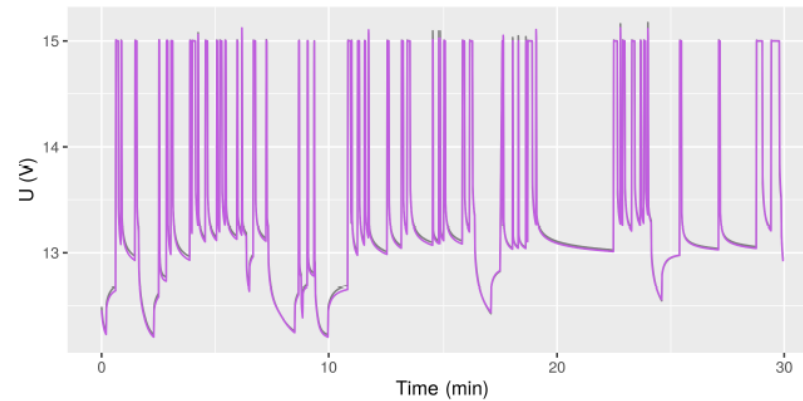
NOTE: C_{10} is estimated from C_{20} . C_{10} not measured.

- Only our New Solution meets Volkswagen's DCD requirement, Standard Build does not
 - Improved current draw at all SoC
- This New Solution meet's PSA requirements and delivers 6% more Ah than CON post-test
 - More efficient charge
- The New Solution exceeds VW/EN/GB-T requirements
 - Ratio influenced by higher C_{10}

Improvements to Volkswagen Regenerative Ability

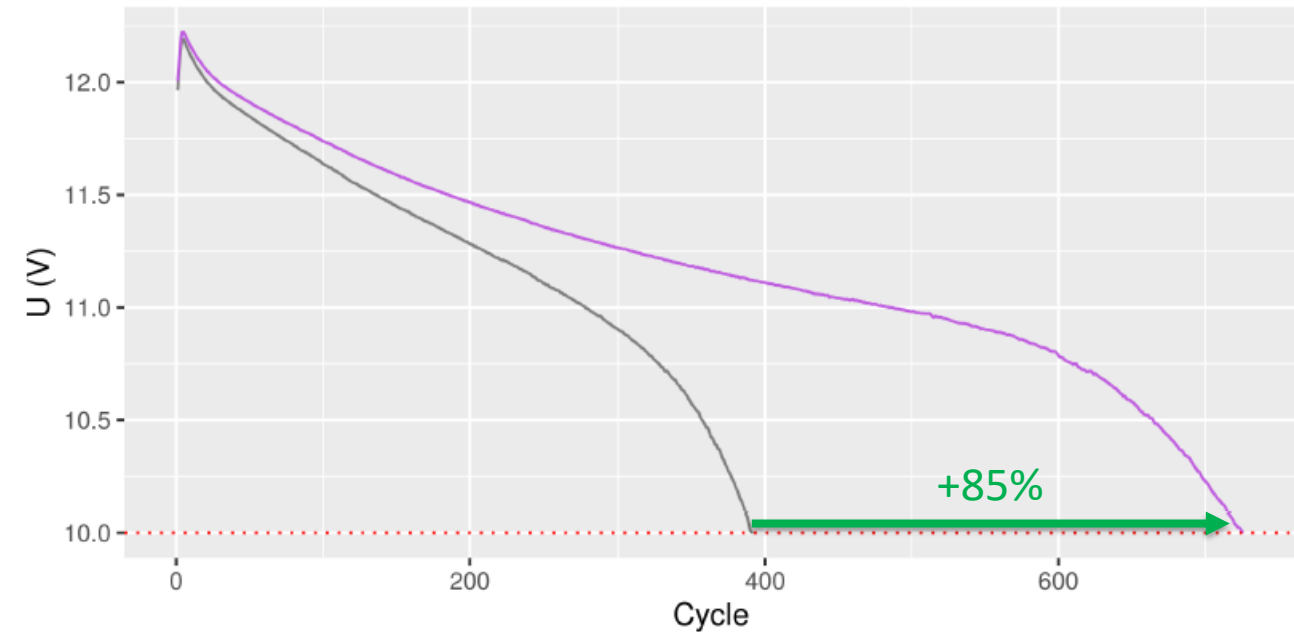
- In drive simulations, this **New Solution** provides performance where few other solutions can
 - VW 75073:2020-7.10
 - Protocol overview (I/V), top
- This **New Solution EFB** offers performance more typically observed in AGM designs
- Benefits seen across F1-F3:
 - F1 = **37%** improvement
 - F2 = **92%** improvement
 - F3 = **122%** improvement

Results were unparalleled in manufacturer's experience



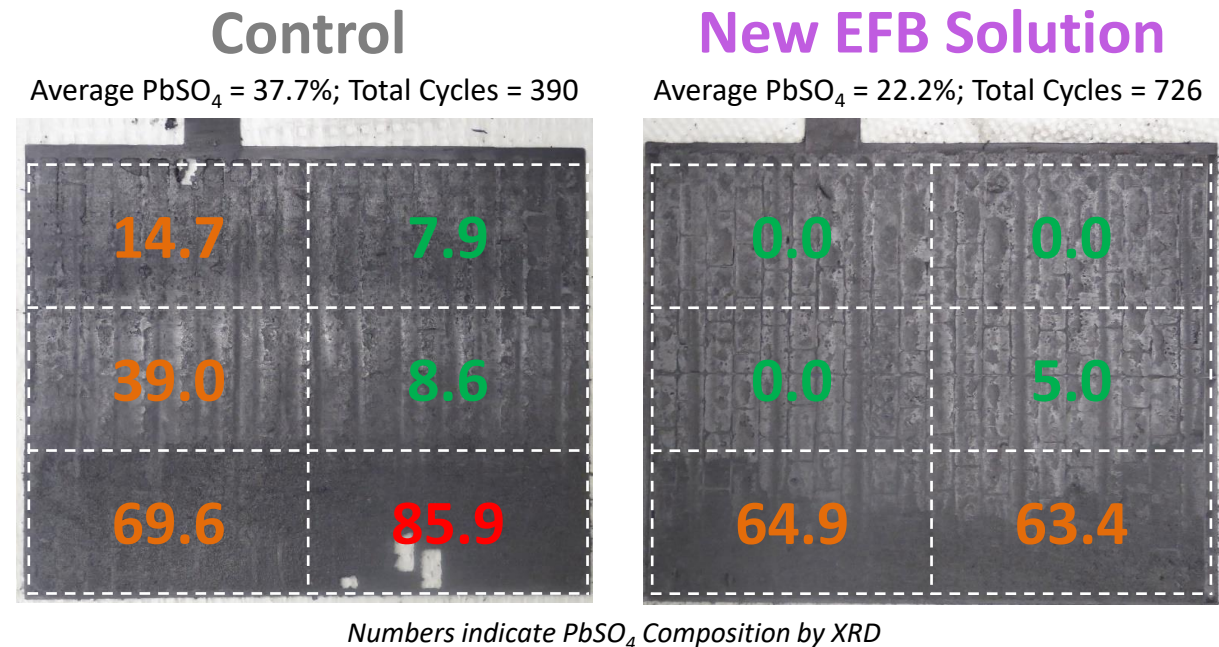
Dramatic Enhancements to 17.5% Micro-cyclability

- 85% improvement in continuous 17.5% Cycling (VW 75073:2020-7.13) with this **New Solution**
 - CON = 392 cycles
 - New EFB Solution = 726 cycles
- 13% less water loss per cycle
 - CON = 0.136 g/cycle
 - New EFB Solution = 0.117 g/cycle



17.5% Failure Modes Mitigated by New EFB Solution

- This **New Solution** reduced sulfation build up by 40%
 - Lower sulfation, despite 85% longer life
 - Upper four plate sections were “like new” (fresh Pb)
- **Improved uniformity of plate utilization**
 - Upper four plate sections show excellent uniformity
 - No left/right non-homogeneity, as with Control
- **Stratification-based failure delayed**
 - 20% reduction in SG differential despite 85% longer life
 - Contributed to keeping the plate healthier, longer
 - May remove the need for passive mixing elements



Pb1200 Series: Summary and Future Directions

- **Our cost-effective New Solutions enable Battery Manufacturers to:**
 - Take dramatic steps towards meeting challenging OEM requirements
 - Replace costly or poorly balanced expander/carbon mixtures
 - Reduce costs by eliminating the need for excessive material or components
- **Exemplar improvements from our EU Manufacturer testimonial:**
 - 15-120% higher charge acceptance, depending on spec
 - 15-85% longer micro-cycling durability, depending on spec
 - 4-5% improved cranking performance
 - Water loss within acceptable limits (W4)
 - No compromise to capacity
- **A commitment to the future**
 - We believe in continuous improvement: new, honed Molecular Rebar + Addenda solutions are under development
 - We are expanding our partnership with Addenda to identify PAM-focused synergies between our technologies

New Solutions Co-Developed with:

