New Applications of MOLECULAR REBAR®

Auxiliary Power for eVehicles, Advanced Automotive, and Deep Cycle/Forklift

Paul Everill, PhD
Chief Technology Officer

BLACK DIAMOND STRUCTURES™

MOLECULAR REBAR® Technology Global Adoption

- **BDS works with >180 battery manufacturers, each at various stages of development and/or commercial sales**
  - Completed >200 commercial scale production trials (>450 1,000kg batches) since 2016
  - Providing in-depth technical support and product integration services
  - Commercial adoption in various countries around the world
- **OEM acceptance of MOLECULAR REBAR®-containing batteries in Automotive, Power Sports, and Deep Cycle**
  - Molecular Rebar is proven to help battery manufacturers meet new OEM requirements
- **Adoption of MOLECULAR REBAR® is extremely cost effective, adding less than 1-3% to the total battery cost**
  - Our products are optimized to deliver required performance at extremely low loading levels (<0.1% wrt PbO)
  - BDS raw material costs have dropped dramatically with commoditization of CNTs in other markets, this is passed along
- **Cost is offset by reduced warranty returns, higher warranties/premium products, direct cost reductions**
  - Enhanced performance provides flexibility in both approach to design and product positioning in the market
  - Molecular Rebar often allows manufacturers to remove active material while improving performance
  - Energy costs can be reduced by using Molecular Rebar to reduce the time and/or energy input of formation

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Innovation Across the Energy Storage Landscape

Lead-Acid Batteries

- Charge Acceptance >25%
- Cycle Life >25-300%
- Enables Partial State of Charge Operation
- Improved Thermal Operations Range

Energy Dense Lithium Anodes

- Higher Energy Density >20-45%
- Longer Cycle Life >20-100%
- Increased Electrode Strength >30-100%

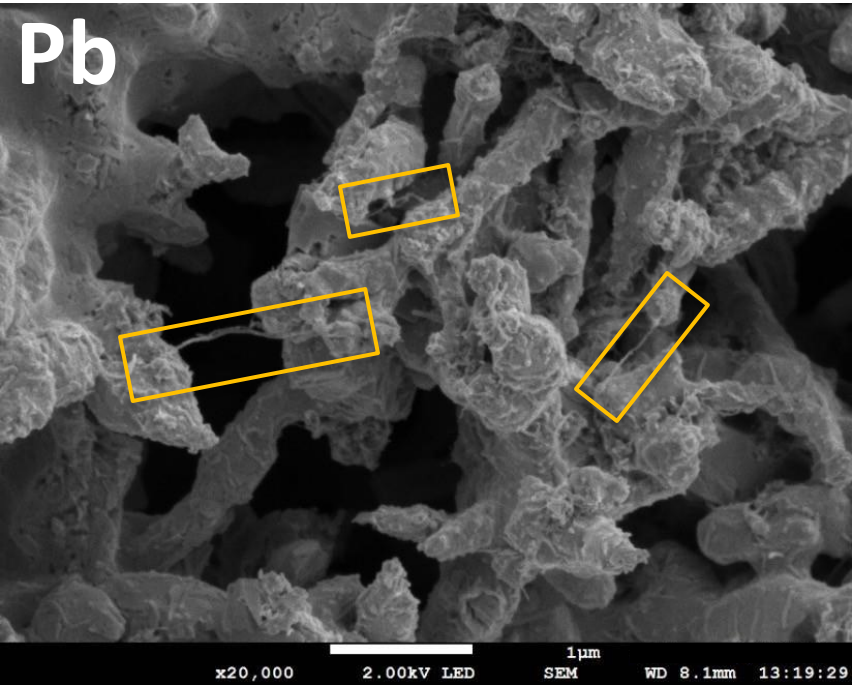
NMC/LFP Lithium Cathodes

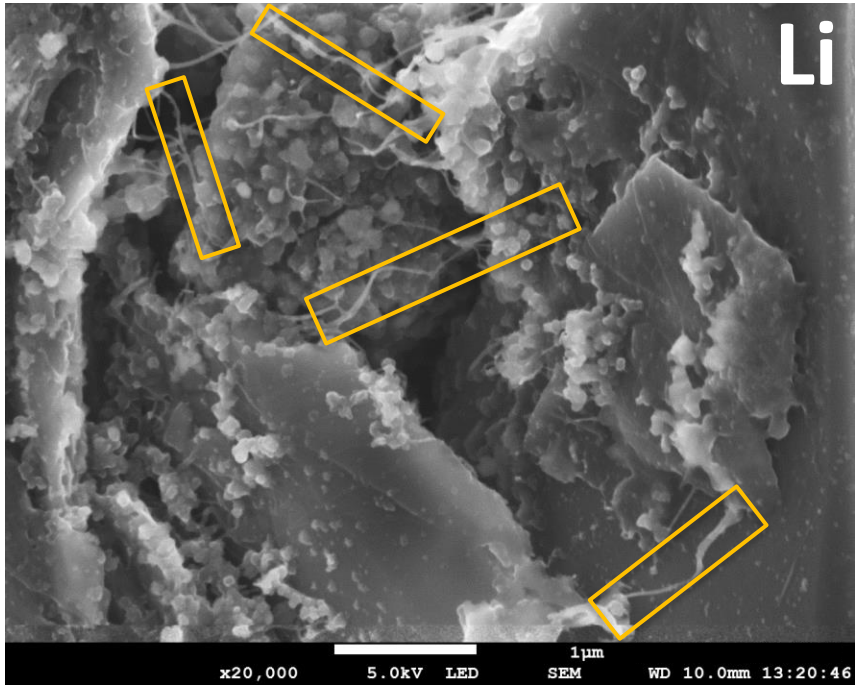
- >15 min Fast Charging Enablement (4C Rate)
- Enhanced High-Power Discharge Capability
- >5-10% Longer Cycle Life

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

MOLECULAR REBAR®: Battery Technology

- **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™

MOLECULAR REBAR® Products for:

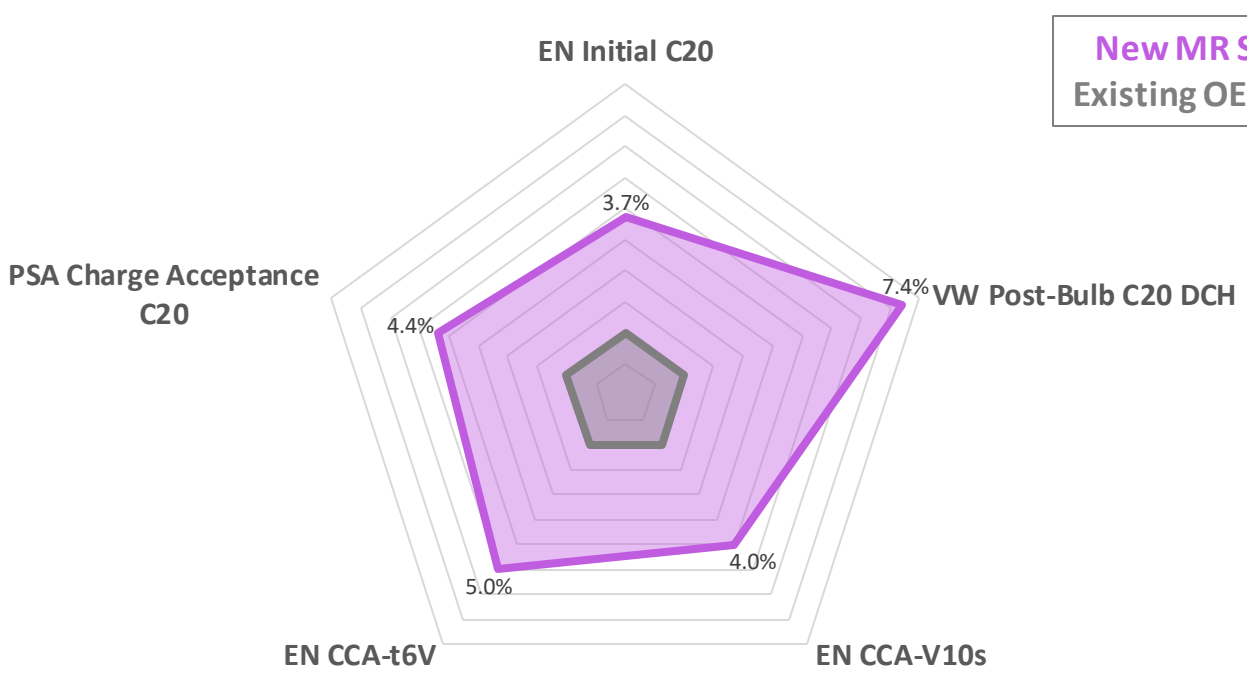
E-VEHICLES AUXILIARY BATTERIES

BLACK DIAMOND STRUCTURES™

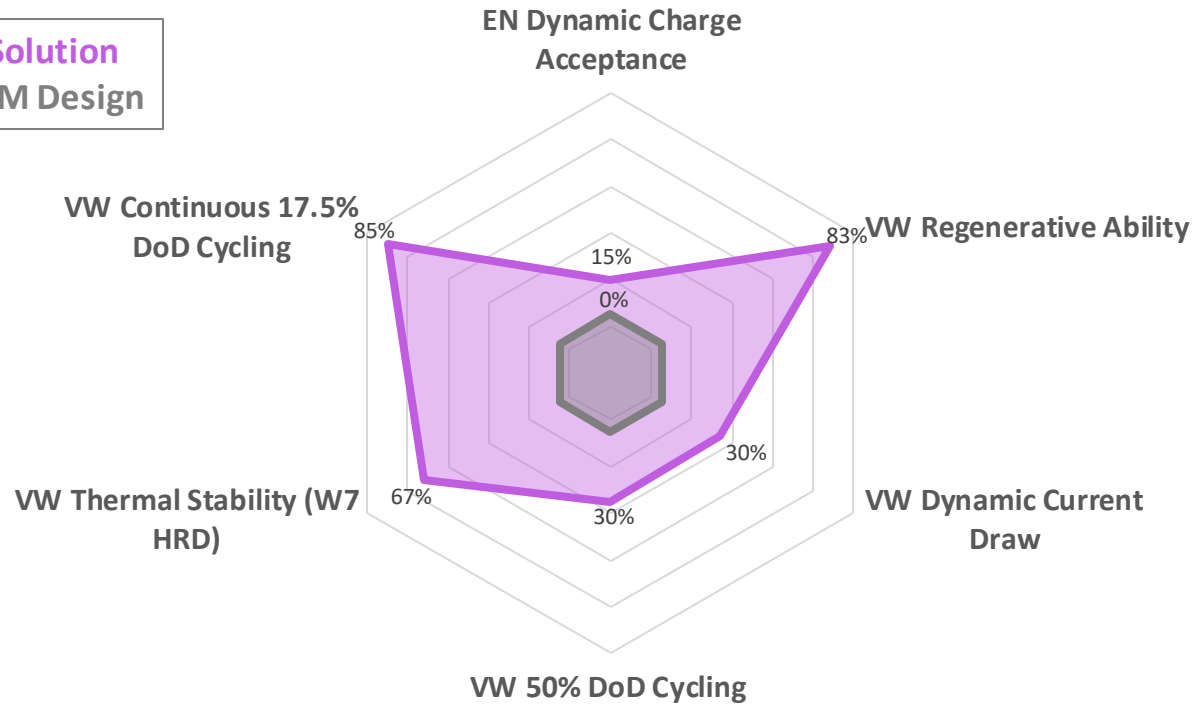
Our New Solution Provides Broad Benefits to AUX

- **Our New Solution consists of MOLECULAR REBAR® and a jointly development Addenda expander package**
  - Validated in an OEM-approved, European-built L1 design (49 Ah, 540 A) sold for start/stop and AUX applications

Initial Characterization Improvements



Charge Acceptance + Life Improvements

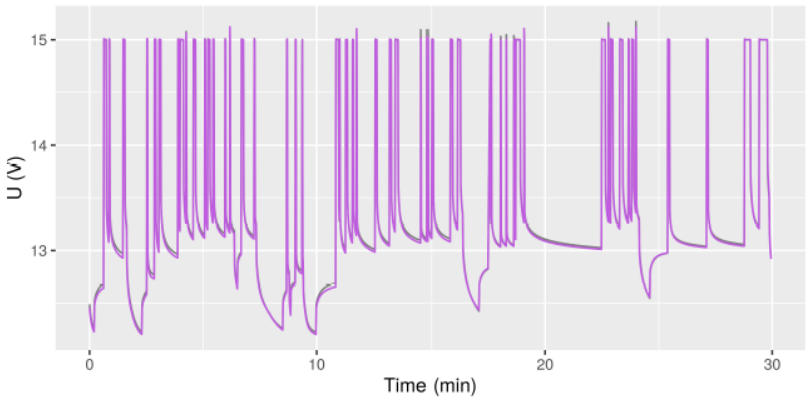


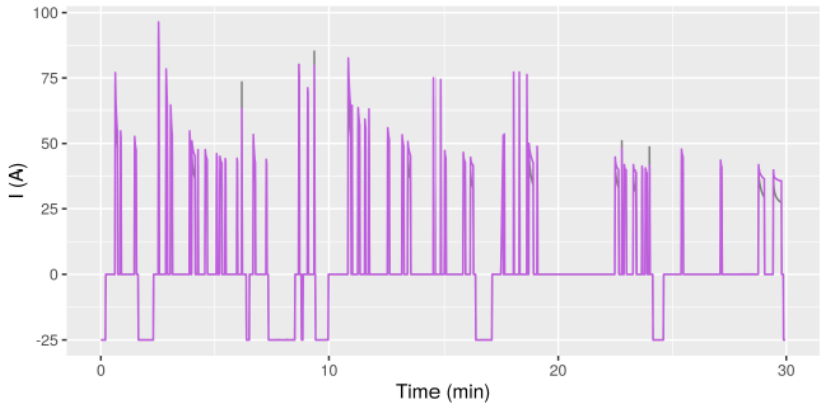
BLACK DIAMOND STRUCTURES™

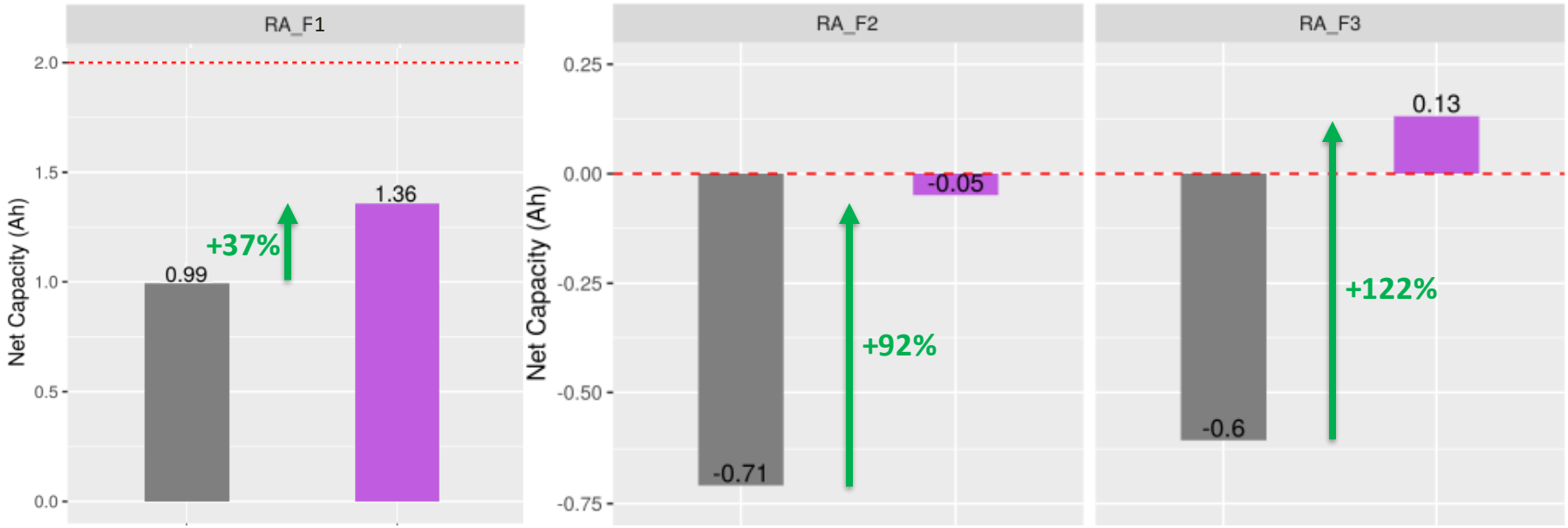
Improved VW Regenerative Ability with MR

- 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







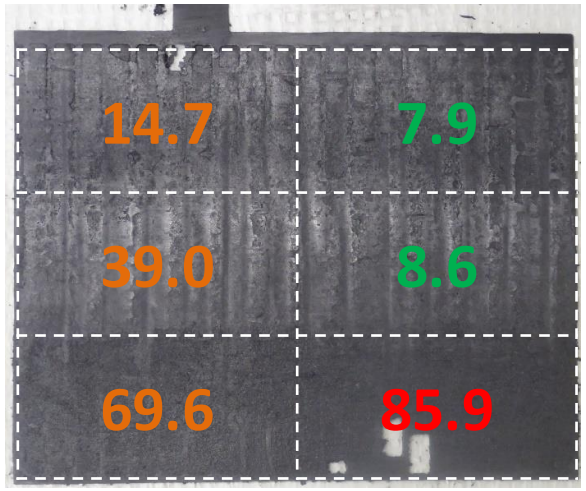
BLACK DIAMOND STRUCTURES™

VW 17.5% Failure Mode Mitigated by New 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

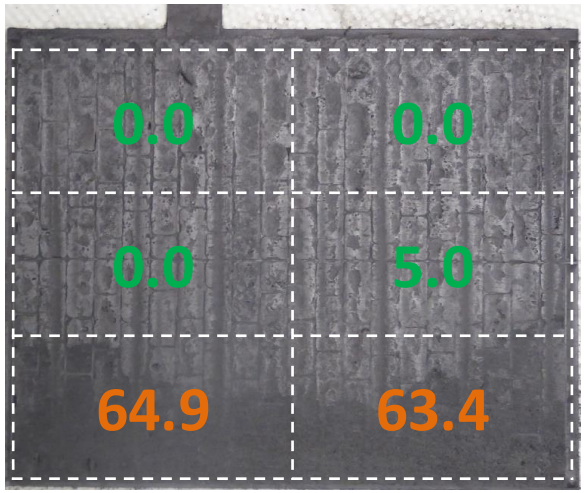
Existing OEM Design

Average $PbSO_4$ = 37.7%; Total Cycles = 390



New Solution

Average $PbSO_4$ = 22.2%; Total Cycles = 726

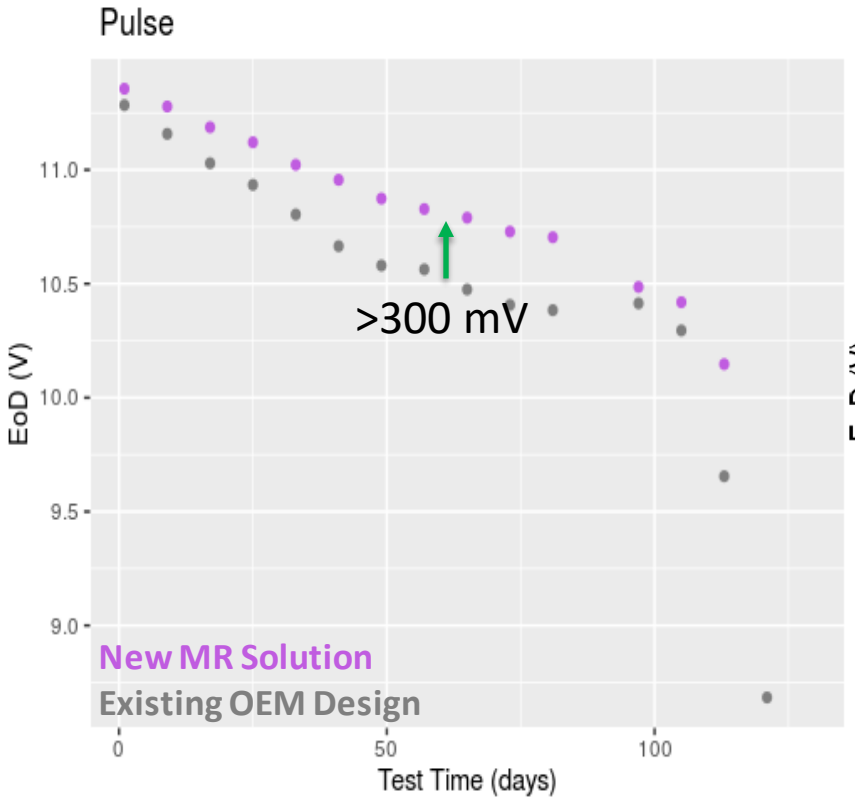


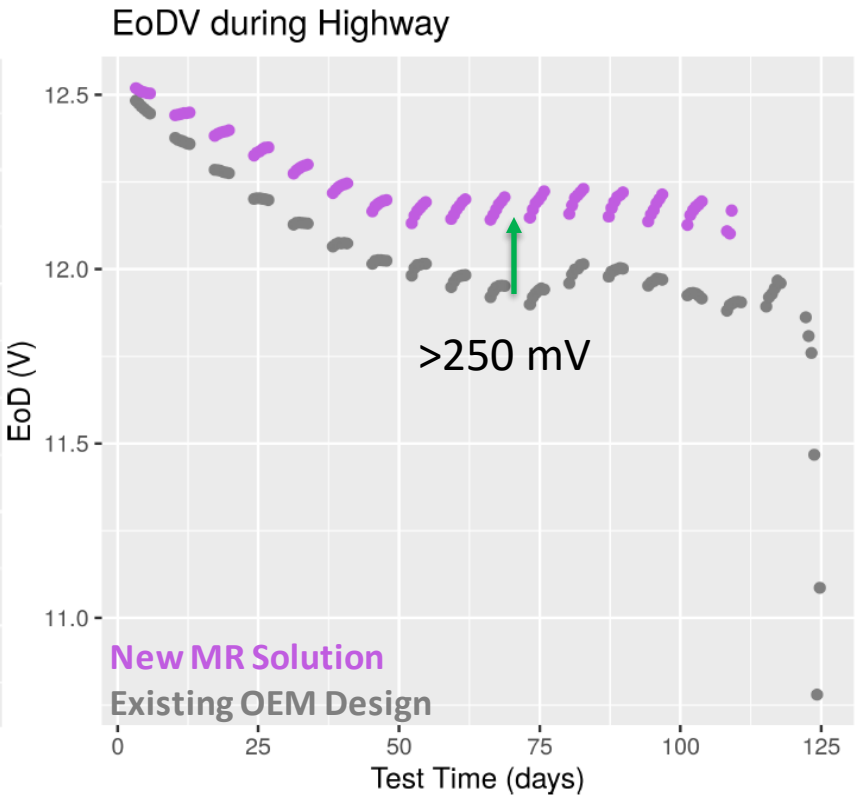
Numbers indicate $PbSO_4$ Composition by XRD

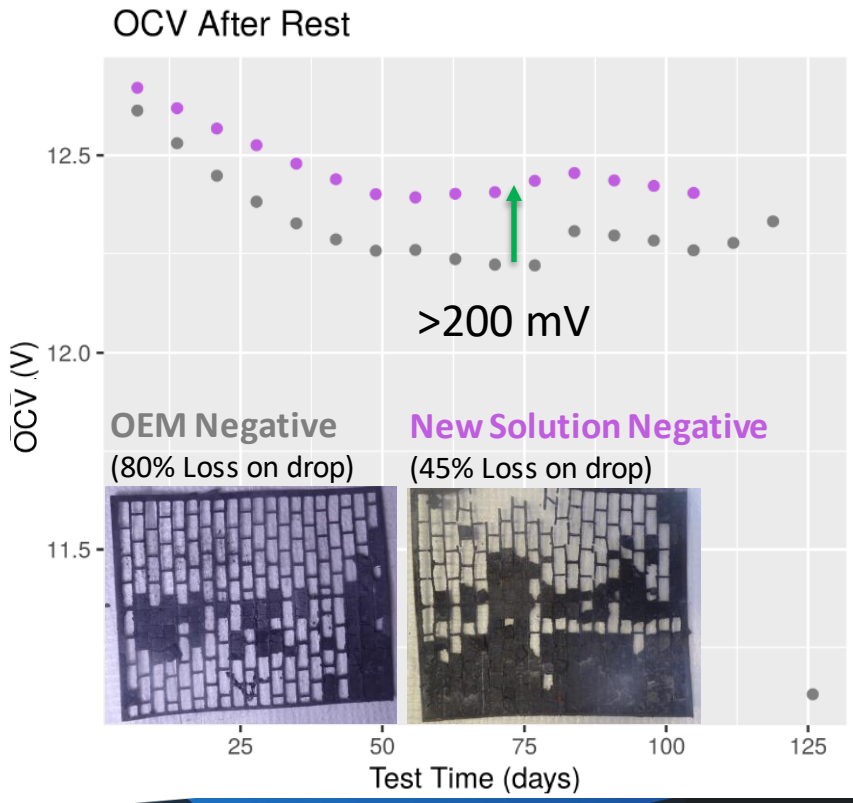
BLACK DIAMOND STRUCTURES™

Improved Health During nKLT/HTE Testing w/MR

- **Although nKLT lifetime was similar, New Solution State of Health (SoH) metrics were consistently superior**
  - Higher voltages seen during pulse, cycling, and rest over the entire test suggest longer in-field start/stop function
  - **New Solution** delayed Negative plate shrinkage- and adhesion-based failures as seen after drop test (bottom right)
  - **New Solution** and **OEM-approved Control** reach 16±1 weeks in High Temperature Endurance / nKLT Testing ("H4 level")







BLACK DIAMOND STRUCTURES™

MOLECULAR REBAR® Products for:

ADVANCED AUTOMOTIVE BATTERIES

BLACK DIAMOND STRUCTURES™

Our Proven Approach

Black Diamond Structures Does Not Prescribe to a One-Size-Fits-All Mentality

- **Our adoption process delivers a highly tailored solution:**

1. **Evaluate your needs and the target battery's current design, performance, and challenges**
   - Desired performance targets
   - Degree of "overbuild" which may be eliminated
   - Current expander/additive package and its limitations

2. **Recommend a MOLECULAR REBAR®-based product and loading**
   - Derived from our >100y of global lead-acid battery experience
   - Tried and tested with >180 manufacturer engagements

3. **Work to ensure optimal incorporation of MOLECULAR REBAR® into your paste**
   - Your geographically-assigned Application Development Engineer will support this entire process

4. **Monitor your electrical validation via data analysis and reporting, or support your evaluation with our Bitrode circuits**

Ex: Willard Batteries Achieves Market-Leading DCA

AUTOX / Willard Batteries THE POWER OF TECHNOLOGY

1. Evaluation of Needs

- AutoX / Willard Batteries (S. Africa) sought improved DCA with no CCA / H_2O loss detriment in an L3 EFB+C

2. Product Recommendation

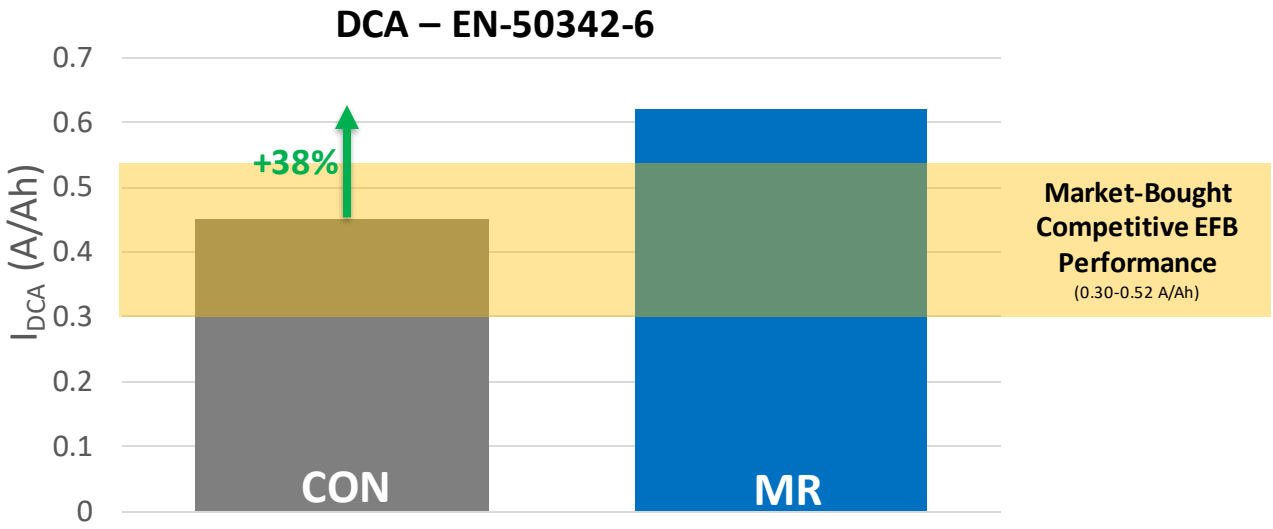
- After thorough analysis, we believed the NAM could be rebalanced with 60% less carbon and a customized loading of MOLECULAR REBAR® (Pb1210N)

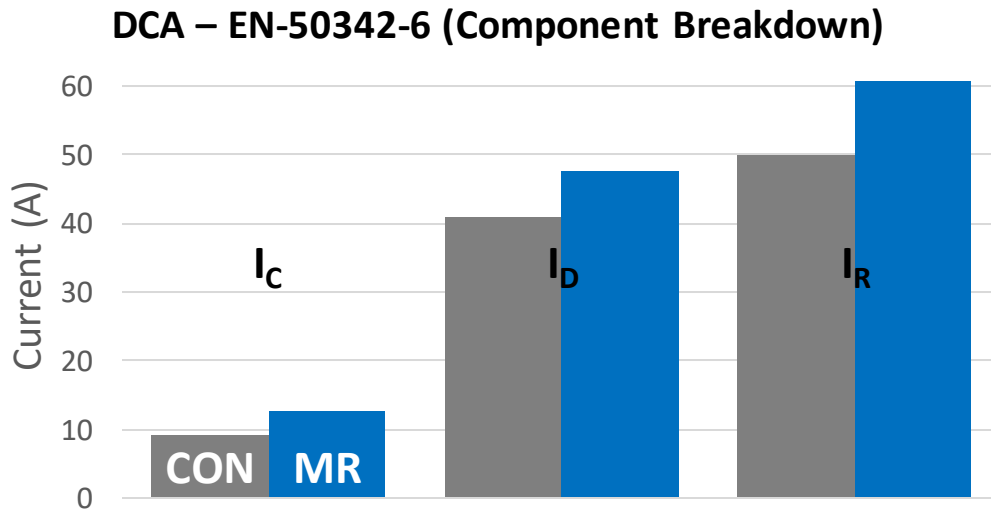
3. Implementation

- Our Sr. Application Engineer worked with the AutoX / Willard team to ensure optimal integration of product

4. Performance Analysis

- 38% improvement in Dynamic Charge Acceptance
- Unbiased 3rd party lab results from L3 batteries



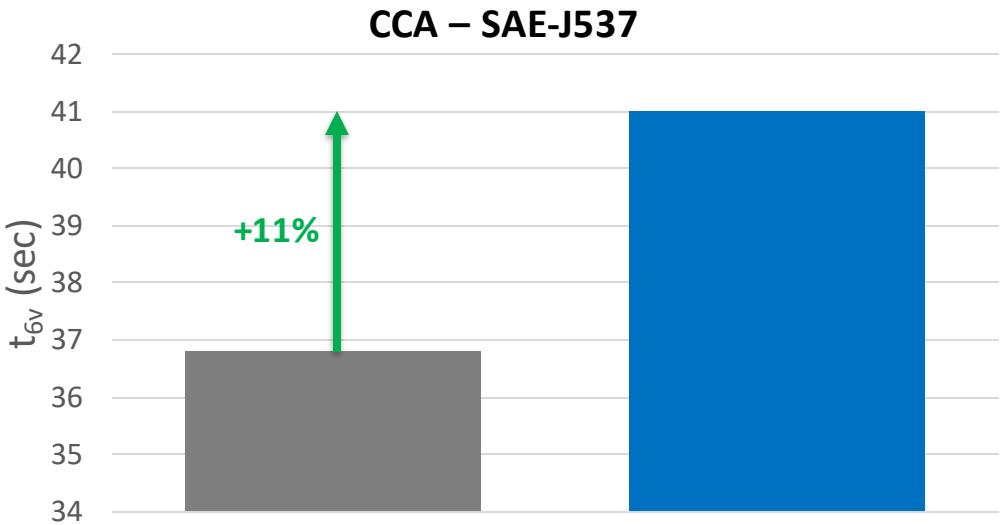


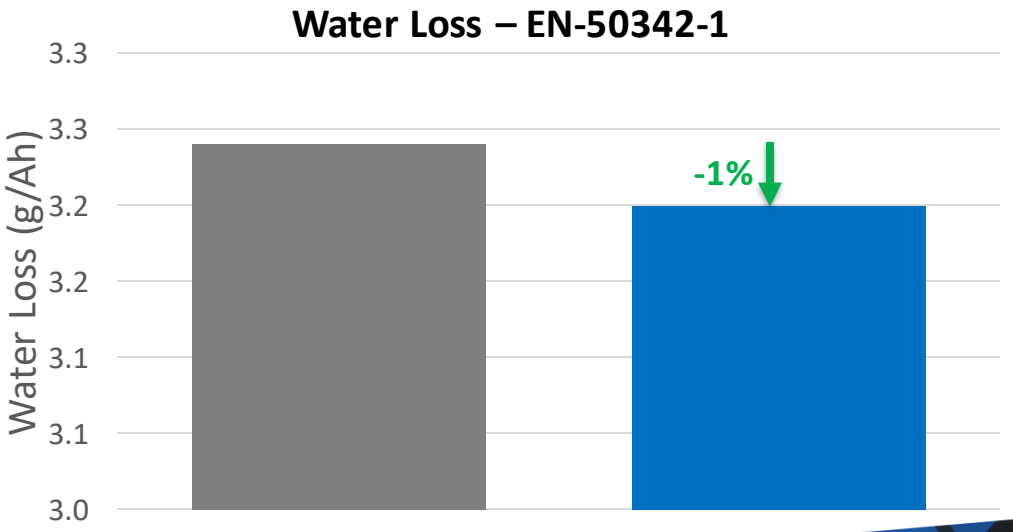
BLACK DIAMOND STRUCTURES™

Ex: Balance Achieved; No CCA / H_2O Loss Detriment

AUTOX / Willard Batteries THE POWER OF TECHNOLOGY

- **Per, Manufacturer's request, our recommendation had no detrimental effect on:**
  - CCA (SAE-J537)
    - 11% increase in t_{6V}
    - Improved power performance (V_{30s})
  - Water Consumption (EN 50342-1)
    - Maintained W3 rating (-1.2% reduction)
- **Results duplicated in additional models, inc. L1**





BLACK DIAMOND STRUCTURES™

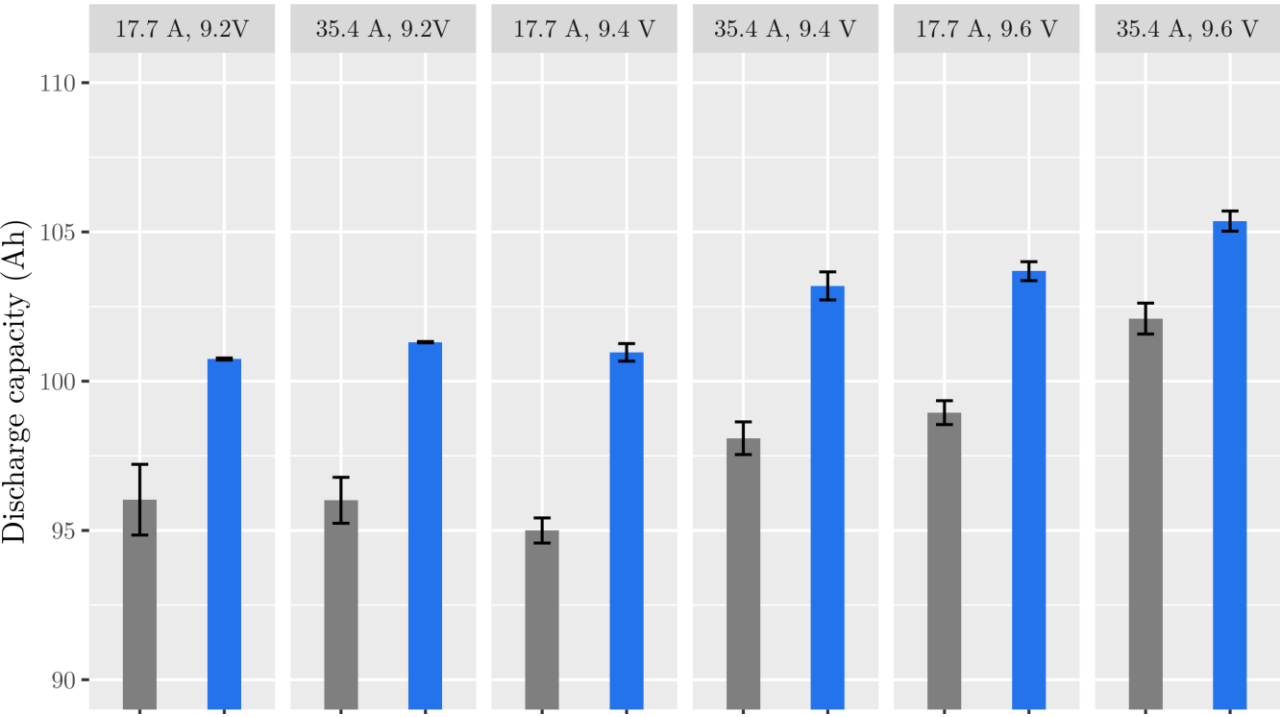
MOLECULAR REBAR® Products for:

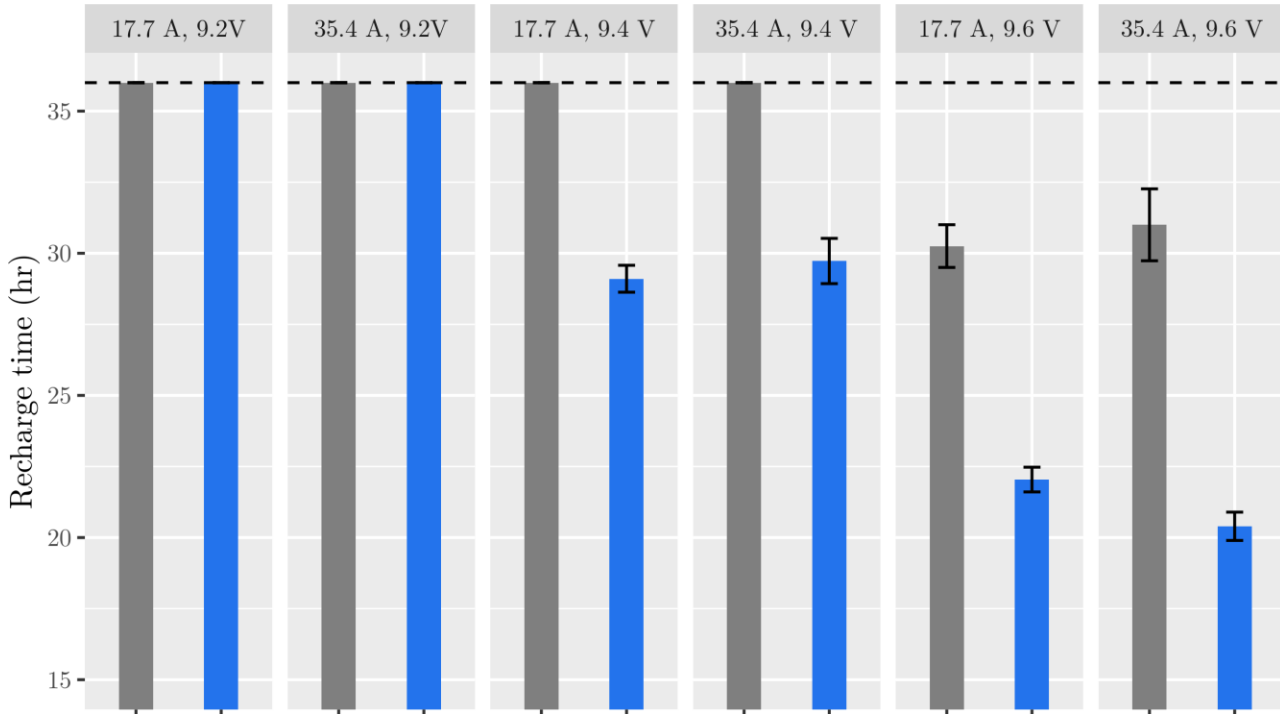
DEEP CYCLE AND TRACTION BATTERIES

BLACK DIAMOND STRUCTURES™

Pb3200N Gives Faster Charge Recovery in 8V GC8

- **~3-4% higher capacity**
  - Initially (i.e., improved formation)
  - Throughout (i.e., consistent performance)
- **Up to 30% reduced charge time to 110% Ah-return**
  - Over application-relevant charging voltages and currents



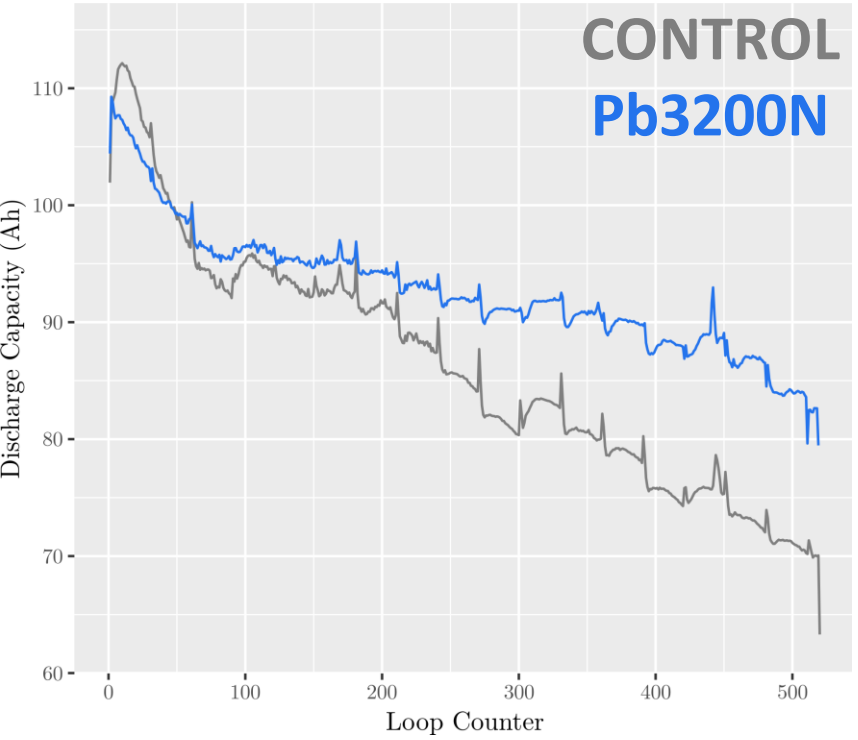


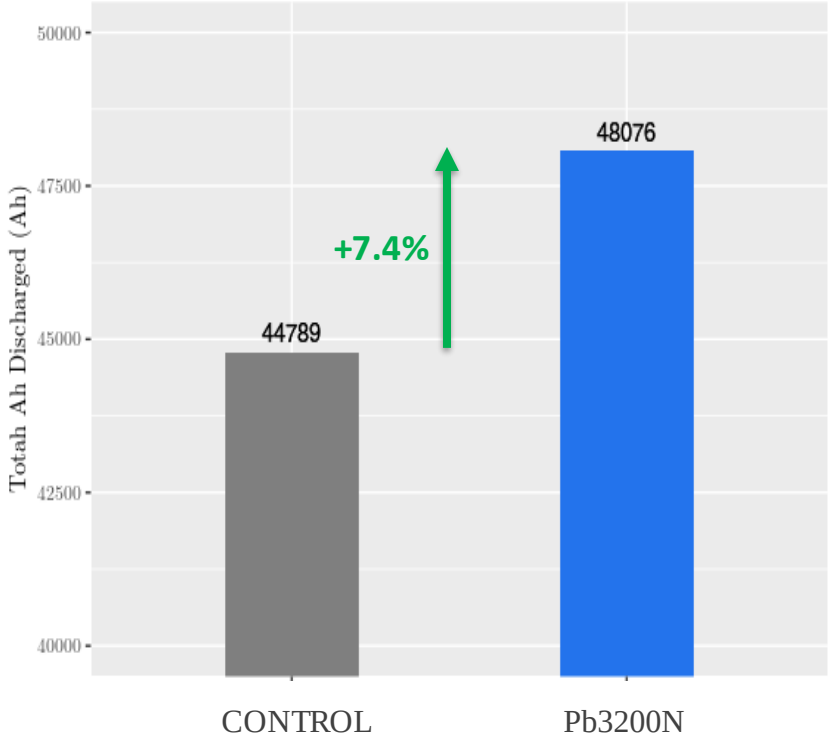
CONTROL **Pb3200N**

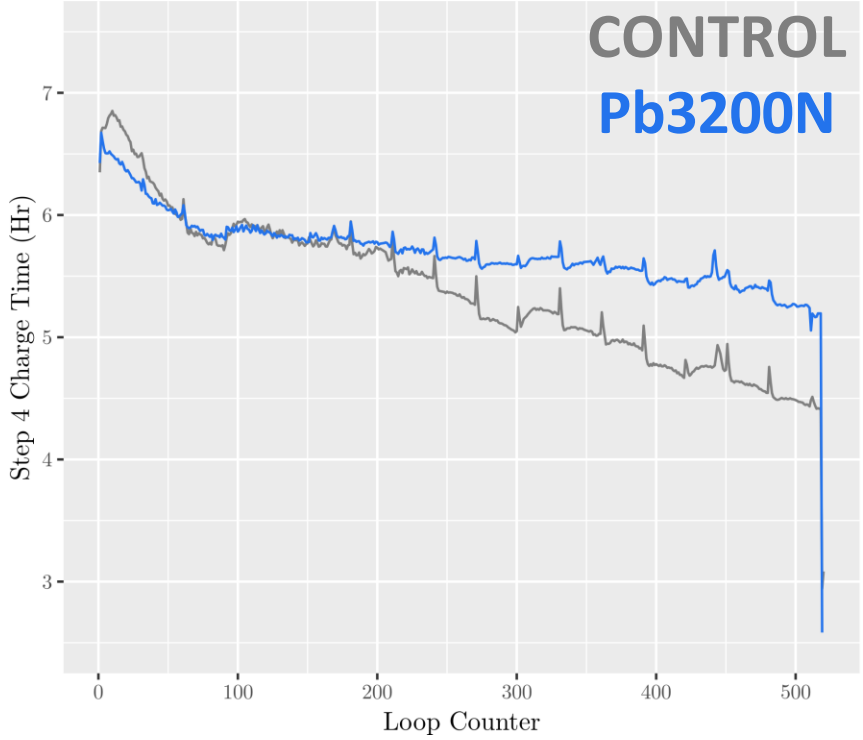
BLACK DIAMOND STRUCTURES™

Pb3200N Improves Performance Consistency

- **~15% higher Capacity for >200 cycles**
  - 5% more Ah-input in <2% longer recharge time
  - 7.4% higher discharge throughput over this period
- **10-20% longer time spent in constant-current charge**
  - Lower resistance, decreased charging voltage
  - Indicates improved health of battery





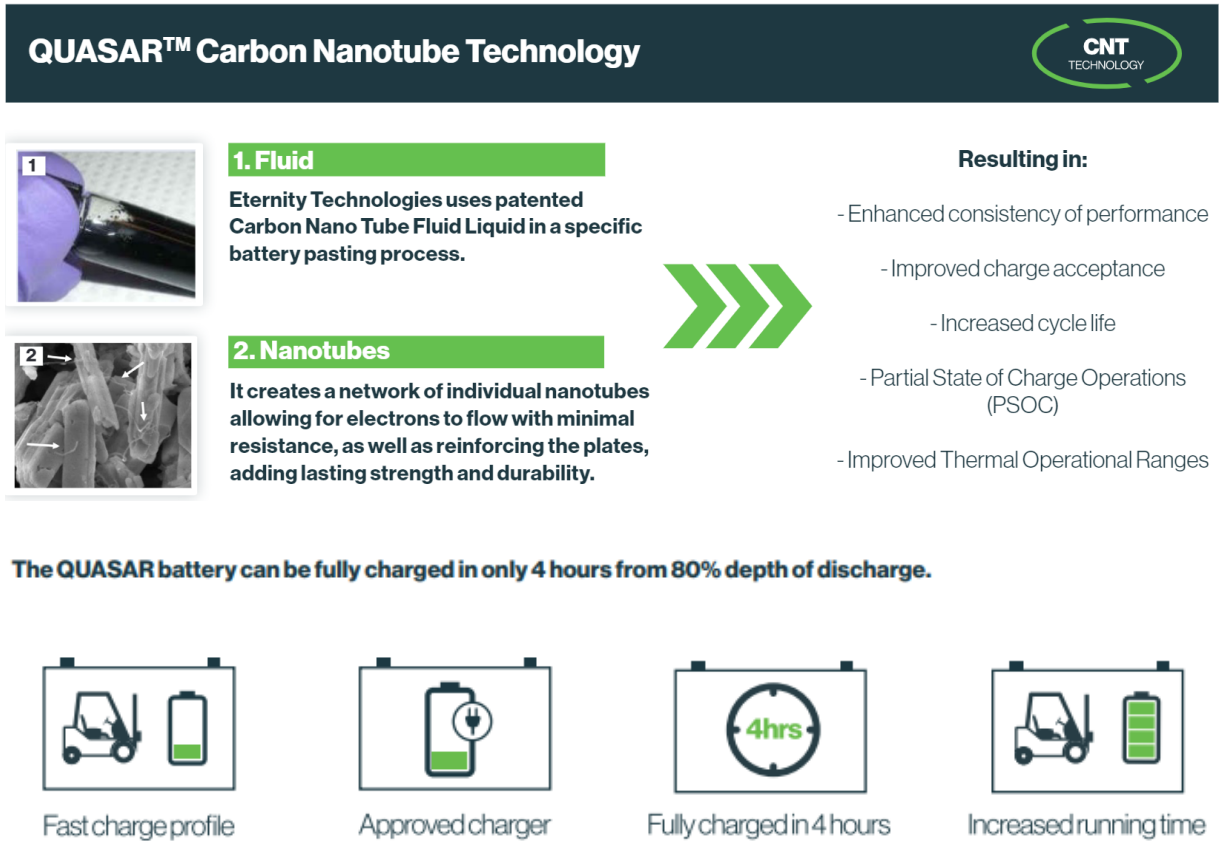


Protocol:
BCI-06 Cycling, modified by customer request to lock Ah-return to 105%, batteries were watered every 30 cycles

BLACK DIAMOND STRUCTURES™

World's Leading Traction Designs Use MR Products

- **In advanced designs, MOLECULAR REBAR®:**
  - Increases the negative plates fast charge capability
  - Reinforces active materials
  - Provides consistent capacity return
- **Black Diamond Structures was pleased to support Eternity technologies with the material they needed to build their next generation traction product**
- **Following our Collaborative Approach, we provided nanomaterial implementation support, materials analysis reports, and electrical testing**



Ref: Quasar Carbon Nano Gel Brochure (29-03-22)

Conclusions

- **MOLECULAR REBAR® will be a fundamental component in Auxiliary Batteries for eVehicle applications**
  - Our products provides excellent performance in EFB / VRLA designs, much of which translates to AUX application needs
  - We are here to help overcome your challenges, as OEM and CENELEC/IEC specifications begin to finalize

- **Our collaborative approach, exemplified by AutoX / Willard, permits our customers to reach their goals fast**
  - Market-leading DCA performance in a South African market study, with no detriment to CCA or H_2O consumption
  - NAM re-optimization with MOLECULAR REBAR® can offset the need for high carbon usage, or eliminate it

- **MOLECULAR REBAR® is found in Eternity Technology's most advanced traction cell designs**
  - Our material provides fast charge and active material durability in some of the world's most advanced batteries
  - Improved charge return in BCIS-06 and extended constant-current charging can be achieved in Golf Cart batteries

THANK YOU FOR YOUR TIME!

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