
Cell Design Improvements for DCA, Gassing, HRD

How Black Diamond's Cell Designs Have Evolved to Meet Our Needs

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Social Distancing is vital in the ongoing battle against Covid-19, but I simply can't handle:



- The length/state of my hair.
- The absence of sports from TV.
- My inability to go to the Pub.
- My dog now being bored with walks.
- None of the above
- All of the above



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Scope

- At Black Diamond Structures, our primary expertise is Materials Science but our customer and product development needs have required us to expand our capabilities into high-throughput 2 V cell testing
- To accomplish this, we have watched, listened, and learned from industry leaders at these events, and others
 - Special thanks to:
 - Drs Raiford and Monahov (CBI) for their *Best Cell Practices Manual* and extensive personal conversation
 - Drs Hübner and Steiner (MOLL Batterien) for sharing details of their cell design and logic to the field
- Here, we detail key modifications that we found necessary during the development of a reliable test vehicle
 - Focus is on cell design modifications, not active material

Many thanks to BDS' 2 V Lab Team, without whom this presentation could not be possible:

Rhet DeGuzman, Keith Campa, Michael Kurvach, Justin McPherson, Carlos Ramirez

Cell v0.0 – Humble Beginnings...

- As a trained biochemist, I had very different conceptions of what a “cell” should look like than most of this audience!
- **v0.0 Details**
 - Hardware: Industrially-produced PAM plates paired with in-house pasted NS40 NAM grid, 3D-printed polystyrene case (open top)
 - Paste Mixing: 1 L Eirich mixer, 1 kg PbO scale, 4.2 ± 0.1 g/mL density
 - Formation: 1N/1P, 1.05 spgr, crocodile clip connections
 - Testing: 1N/2P, 1.285 spgr, crocodile clip connections, parafilm cover
- **Problems**
 - Massive irreproducibility
 - Lifespan of hours/days due to poor connections
 - Water loss and shorting highly prevalent
 - Leaky cases (both directions)
 - Inability to use data even as triage tool
 - EN DCA, HRD, lifecycle comically out of reach



I have also faced the following problems with my own cell designs:

- 1st | Massive irreproducibility
- 2nd | Lifespan of days, not weeks
- 3rd | Leaking, or high water loss
- 4th | Basic build issues, ex. shorting
- 5th | Weak plate/lug connections



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General Material and Processes Adjustments

- **Material**

- Original paste recipe updated for more global automotive alignment
- Density spec tightened to ± 0.05 (4.25 g/mL)
- Stringent raw material quality control added
- Switched to automotive grade litharge

- **Process**

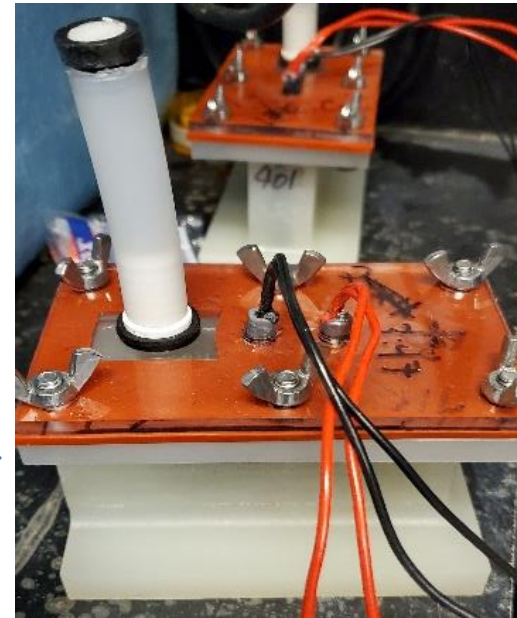
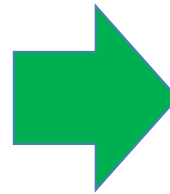
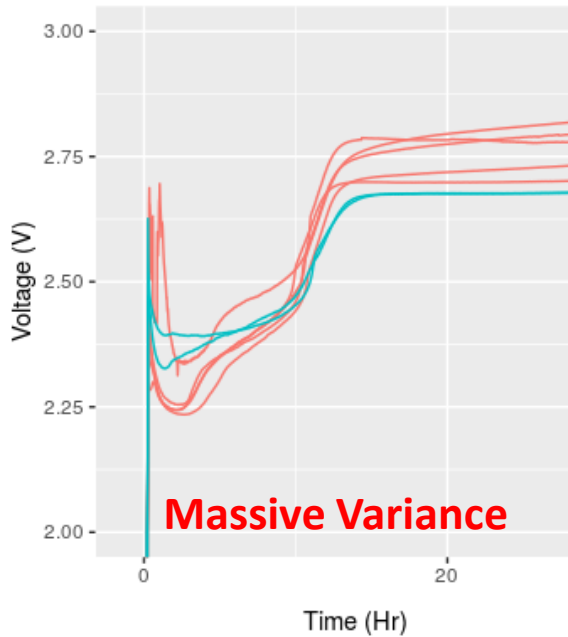
- EL-1 Eirich mixer discarded in favor of double-planetary CMC Milling unit with more real-world blade system
- Curing ovens and protocols updated to deliver post-drying [Pb] <5%
 - Still an issue due to volume in curing oven
- Pasting process conducted with plastering tools or spatulas instead of fingers
- Downscaled to motorcycle plates from automotive plates for speed, efficiency
- Single operator used for each task (mixing, pasting, assembly)

- **If you are having trouble with reproducibility, my advice: ASK EVERYONE!!!**

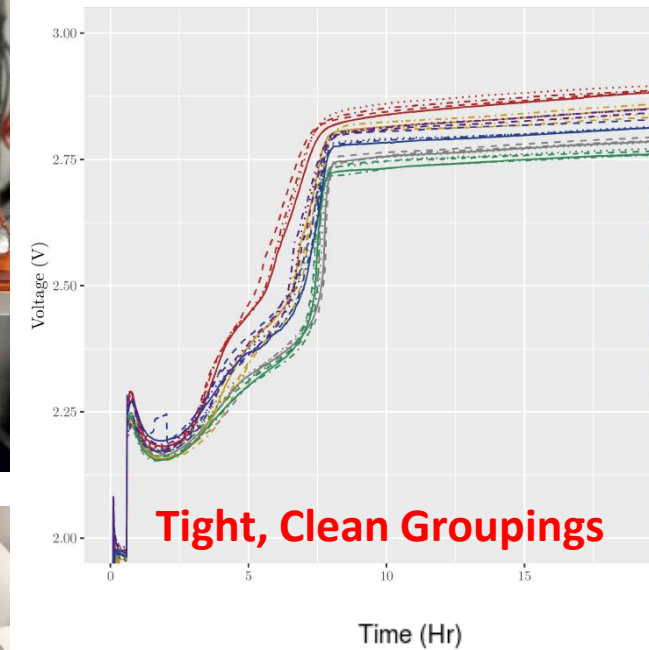
Evolution of Our Test Cell: v0.0 vs. v5.0

- Ground up redesign of cells with tools and processes in place to lower variance/irreproducibility at every step

v.0.0



v.5.0



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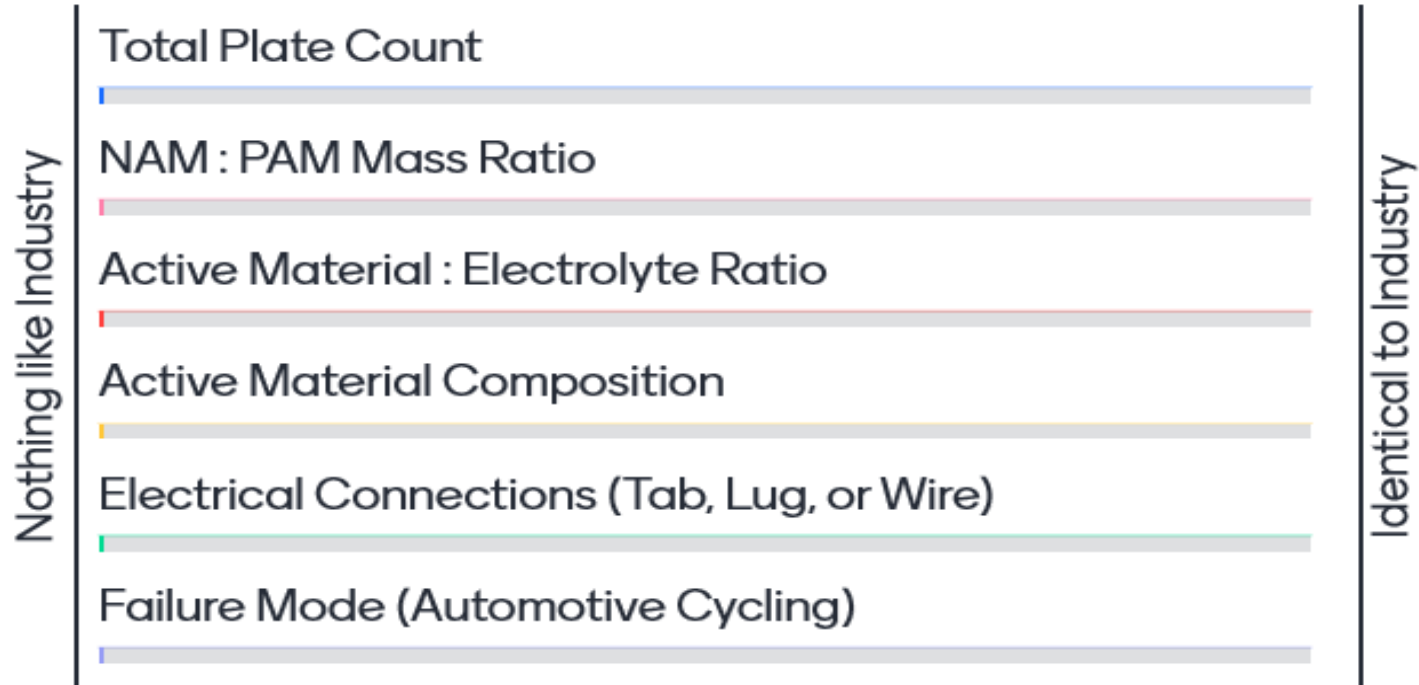
Cell v5.0 – Where We Are Today...

- **Guiding Principle: Shrink a commercial battery, don't build a test cell**
 - PAM:NAM = 1.1: 1.0
 - AM:Electrolyte = ~13 mL/Ah of 1.285 spgr
 - Theoretical/Textbook = 8.6-9.8 mL/Ah
 - Commercial EFB Example = 9.0-10.0 mL/Ah
 - Research Facilities = 15-20 mL/Ah, 10-13 mL/Ah (often constrained by low capacities/plate count, which inflates practical acid volumes)
 - Post-Formation PbO_2 content > 80%
- **v5.0 Details**
 - Hardware: Industrially-produced PAM plates paired with in-house pasted 7Ah NAM grid, custom polypropylene casing
 - Paste Mixing: CMC Milling mixer, 1.25 kg PbO scale, 4.25 ± 0.05 g/mL density
 - Formation: 2N/2P, 1.150 spgr, built-in connections, air-tight casing w/ Luer-lock “snorkel”
 - Testing: 2N/2P, 1.285 spgr, build-in connections, air-tight casing w/ Luer-lock “snorkel”
- **Problems**
 - PAM durability and plate bowing
 - Speed of construction and reclamation is slow
 - Unsure how high-temperature testing will perform (currently inprocess)

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Rate how closely your design matches industry in terms of:



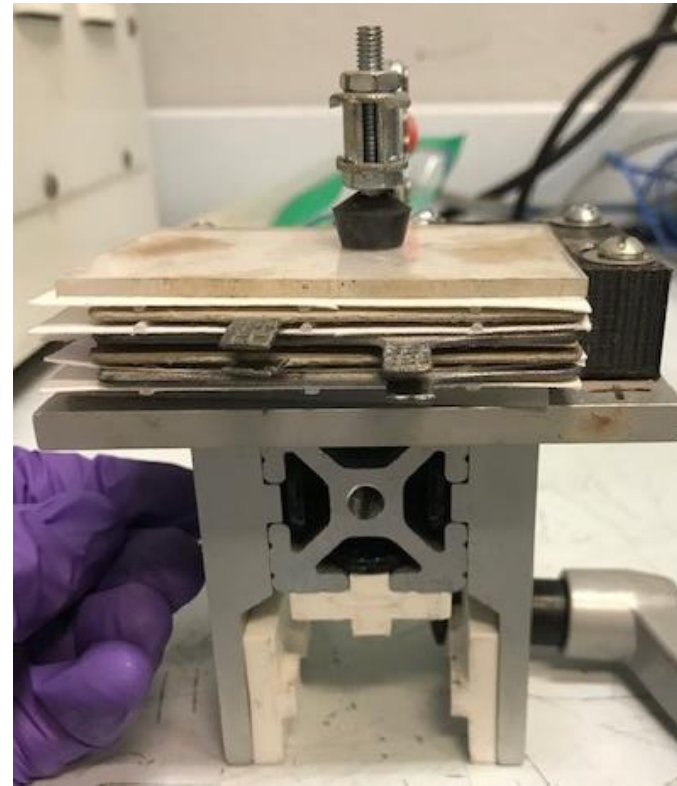
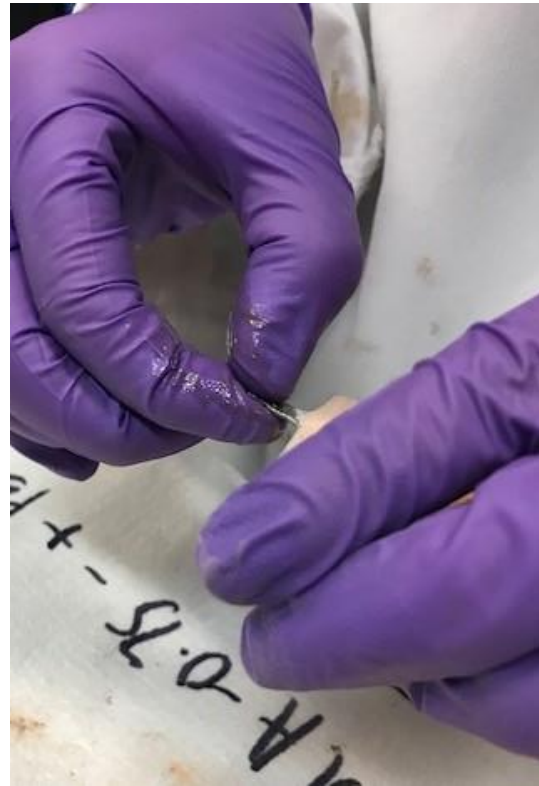
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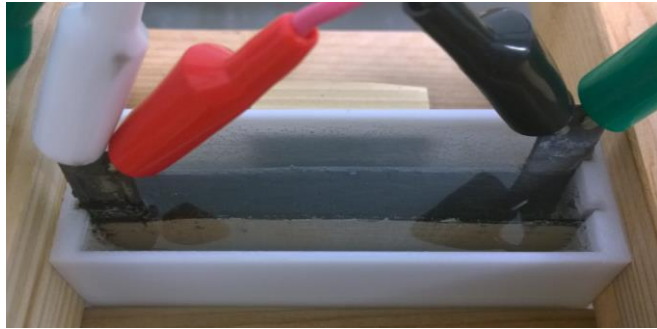
Building: Plate Stack Setup

- Tabs are crimped to increase surface area and rosin is applied to improve upcoming tab/plate weld
- To ensure complete alignment between plates, we built an Assembly Apparatus to locks components in place

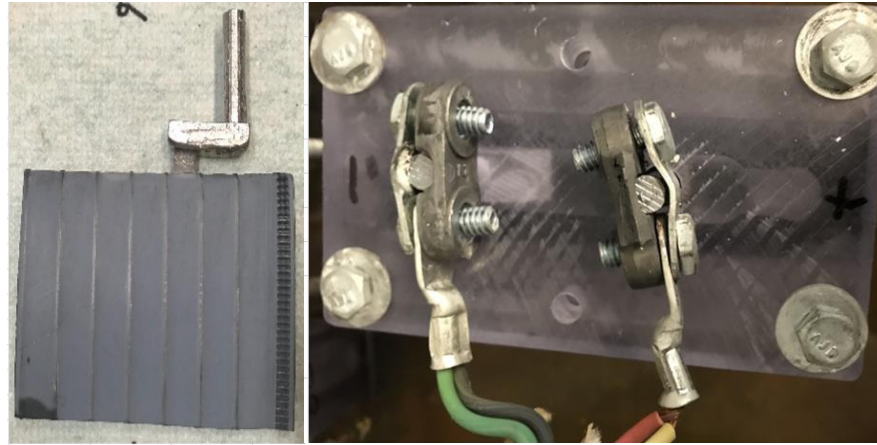


Building: Connections

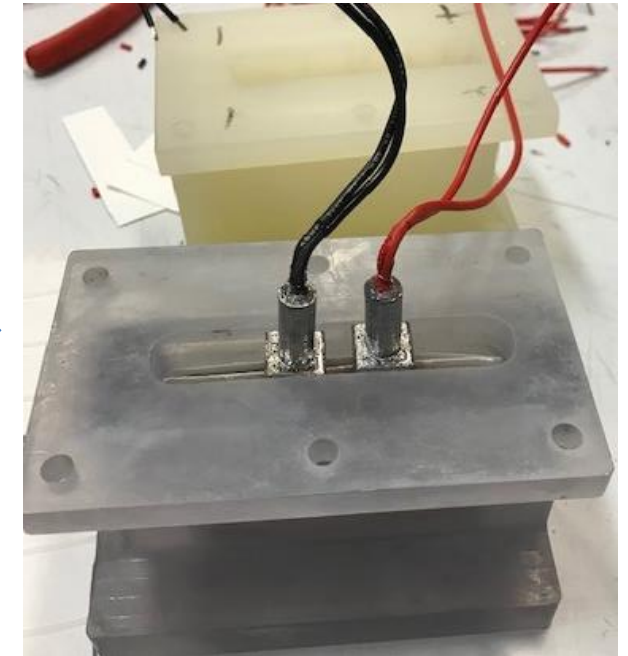
- No single improvement did more for our reproducibility than improving our connections to the testing rig
- Connections must be taken seriously as seriously on the cell level as they are on the battery level!



v.0.0
Crocodile Clips



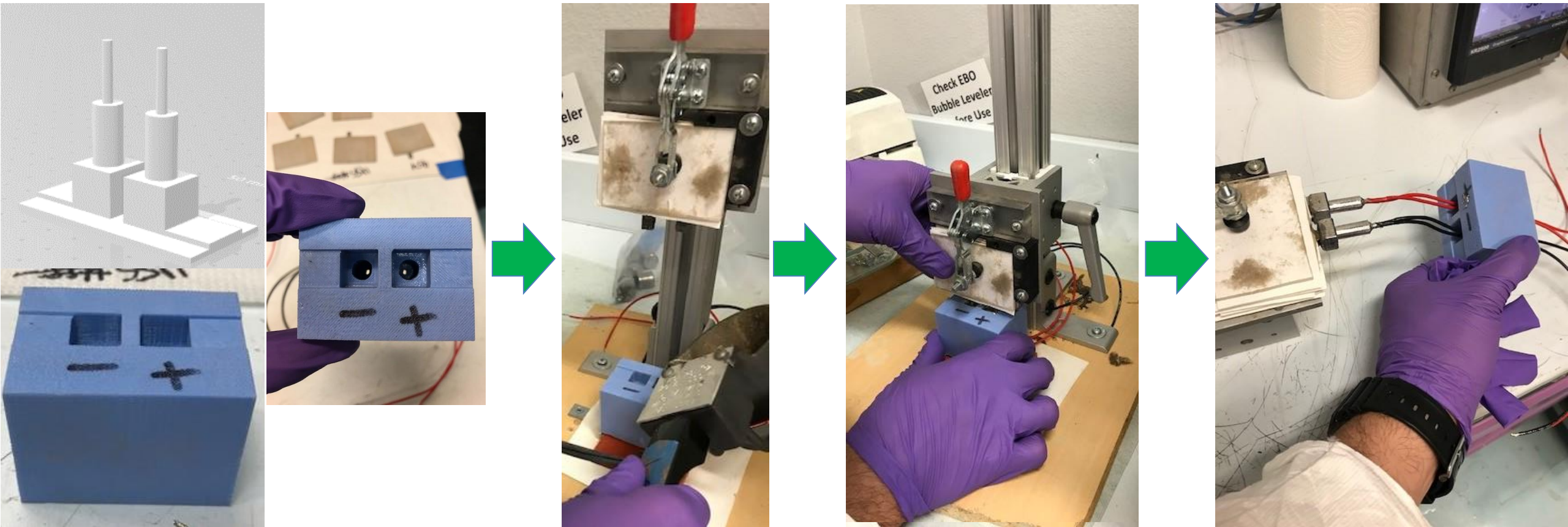
v.3.0
Cast Tabs, Marine Terminals



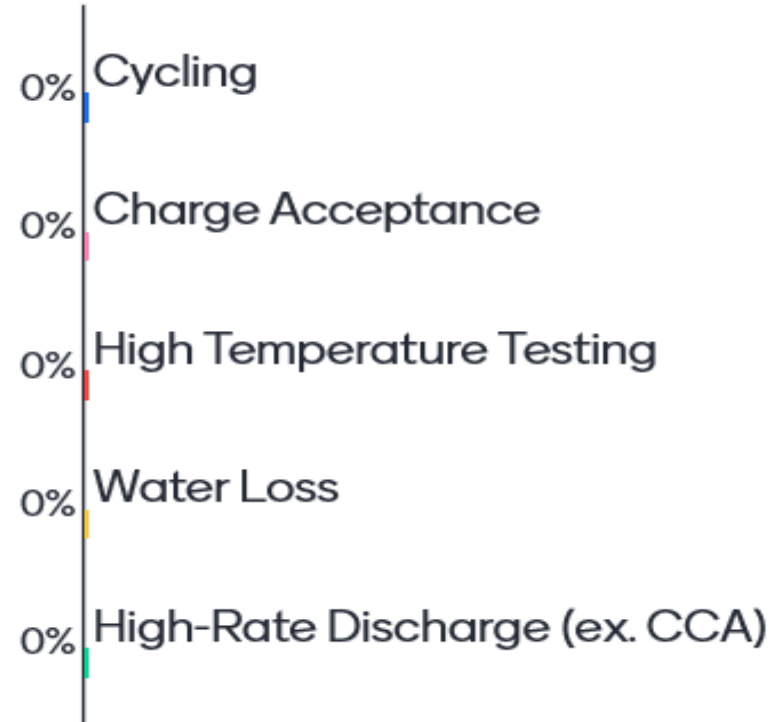
v.5.0
Cast-in-Place Connections

Building: Connections

- Custom 3D-printed negative mold used to create cast tab which includes two splayed wires in each tab
- Assembly Apparatus is attached to Drop Platform so all tabs are optimally positioned every time

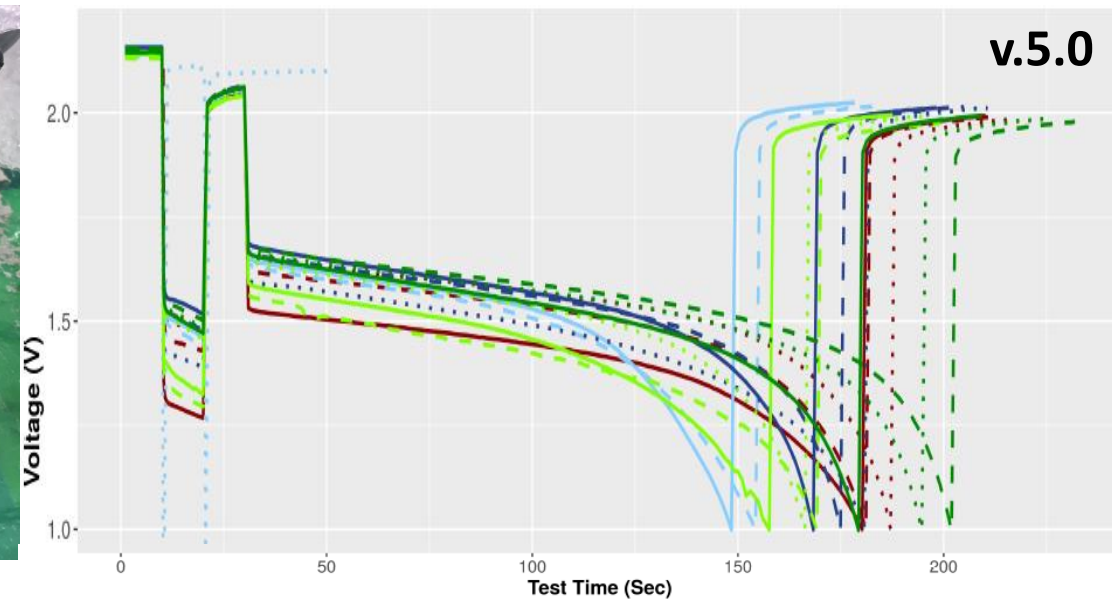
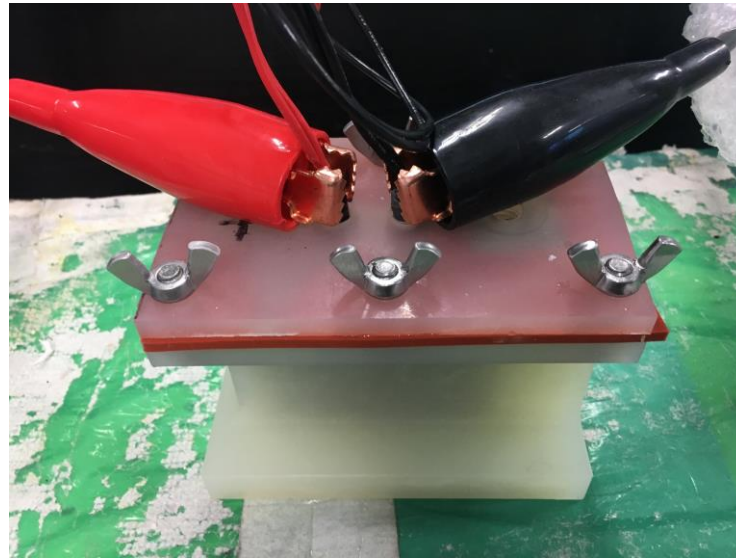
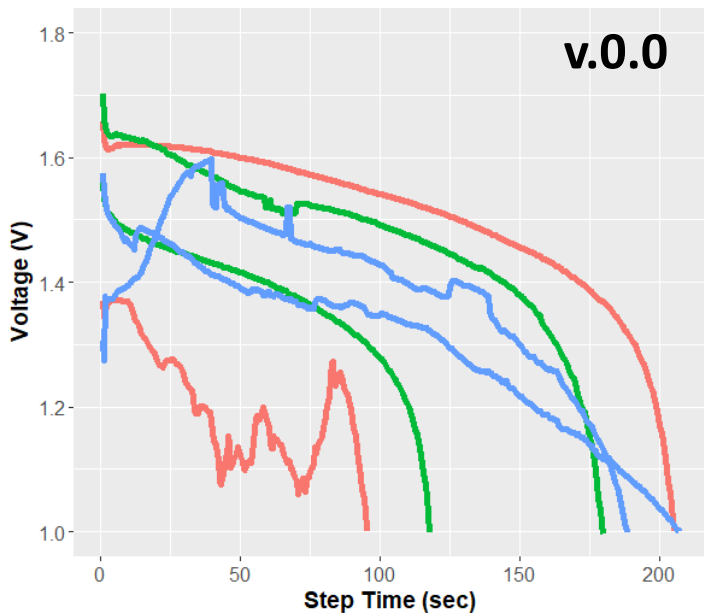


I have problems (i.e. Lab does not match Field) with the following protocols with my cells:



Testing: High Rate Discharge/CCA

- Prior to our cast-in tab solution, HRD/CCA was a cell-destructing process with very high variability!
 - Matched colors are within a group – no conclusions possible
- Cell design v5.0 allows for firm connection to Bitrode circuits and much more reproducible data
- Global CCA ratings for EFB are 7-9X the C_{20} , we chose 8x
- Cells stand up well to -18 °C temp



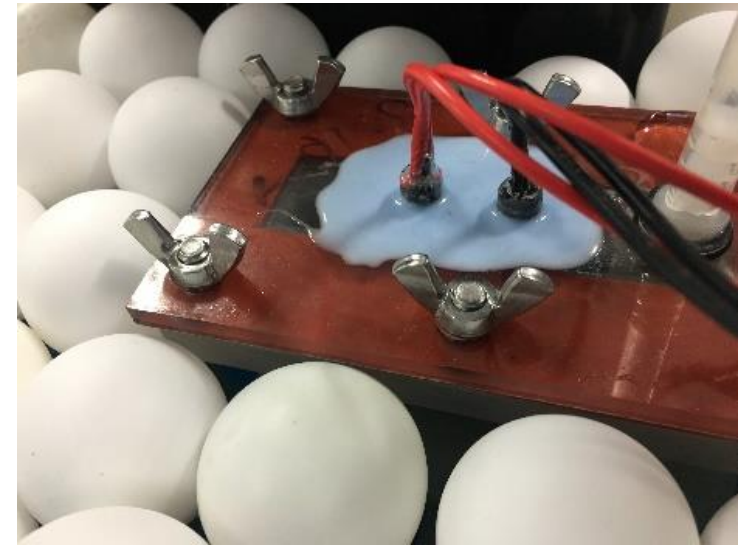
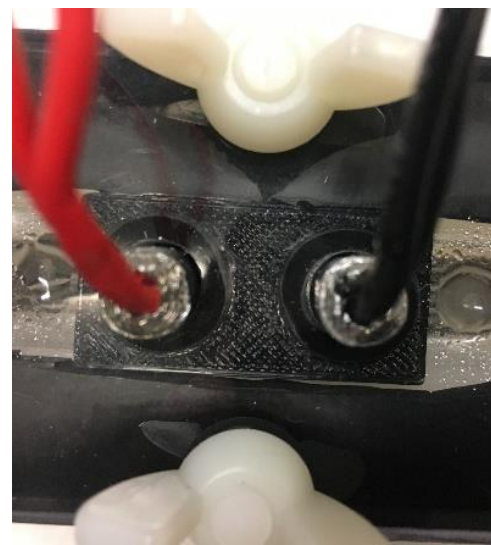
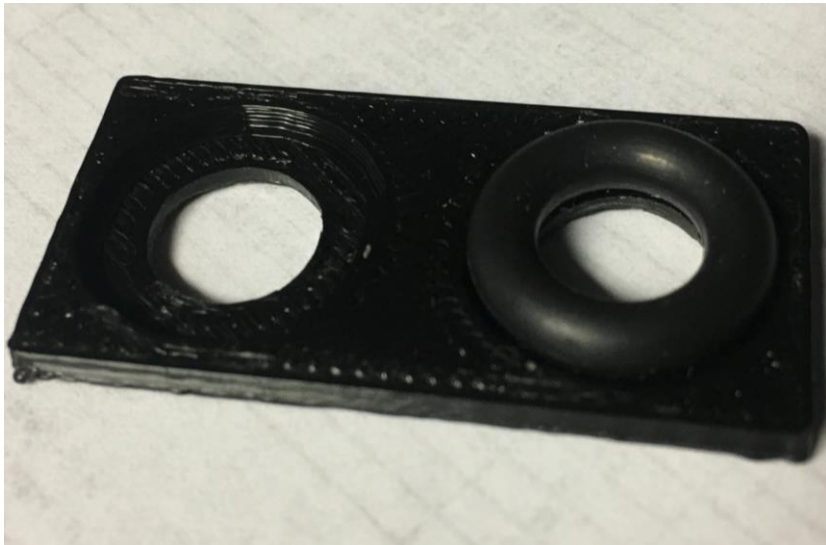
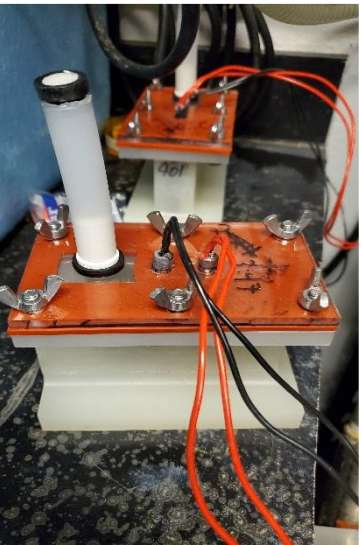
Protocol (Left): SAE/JIS-type DCH
Protocol (Right): EN/IEC-type DCH 40A for 10s, rest 10s, DCH 24A until 1V

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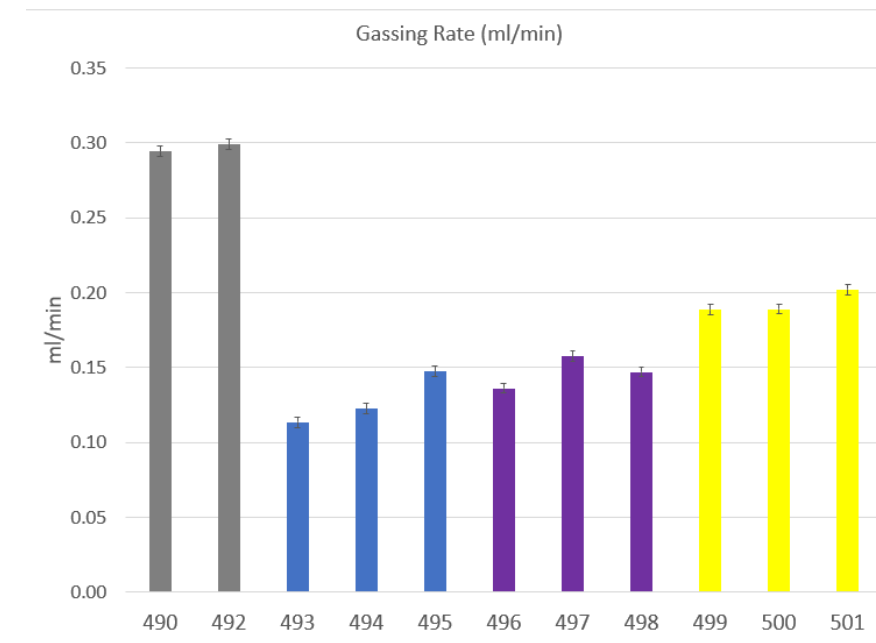
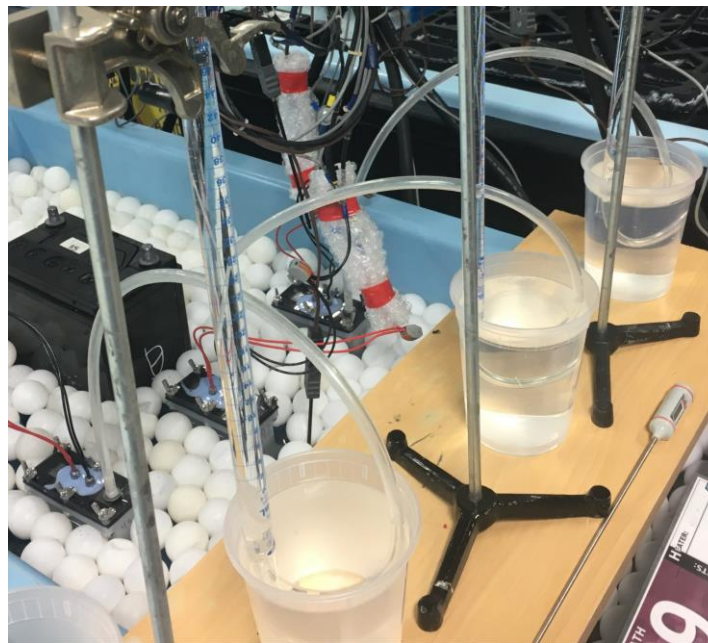
Building: Gas-Tight Seals

- Challenged ourselves to permit gas loss only through 1 orifice: the Luer-lock snorkel attachment
- There are only three holes in the assembled case: snorkel, + terminal, - terminal
 - +/- terminal are fitted with a snugly fitting rubber gasket which sits in a 3D printed seat above the reservoir
- We add a layer of silicone resin around the terminals to remove any chance of longer-term leaking



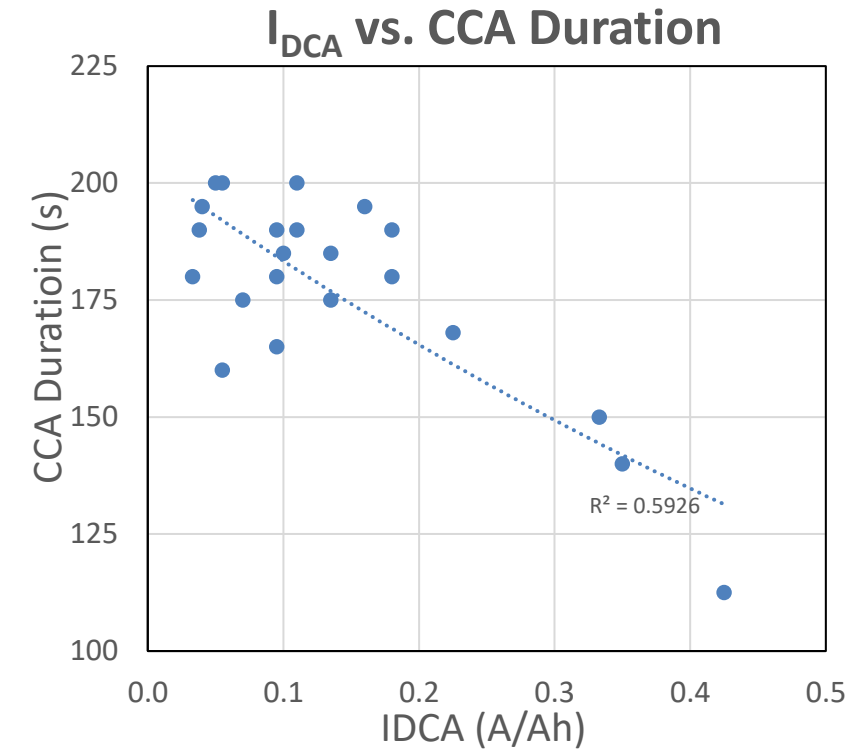
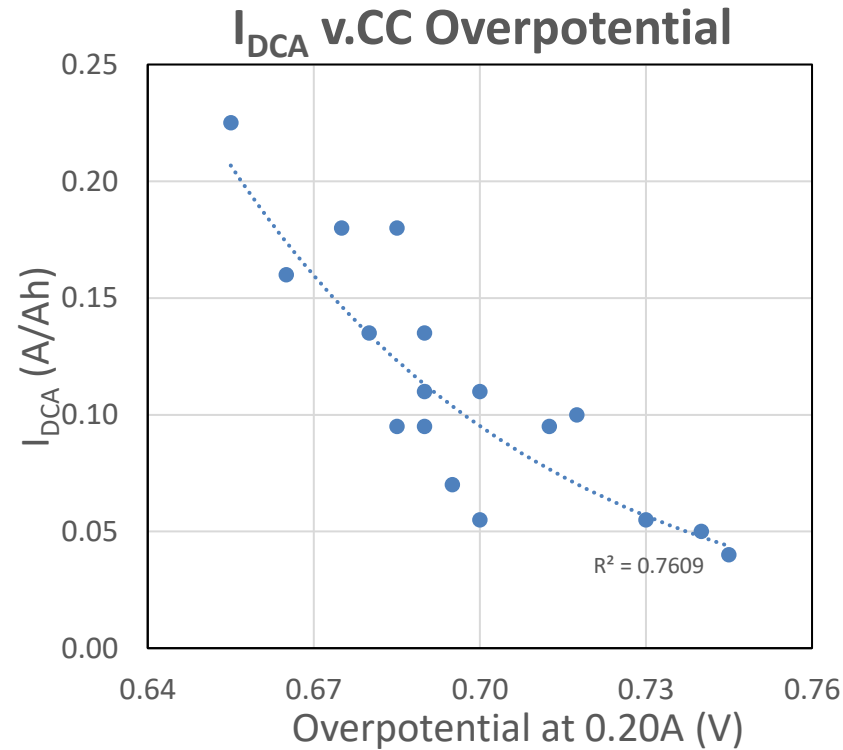
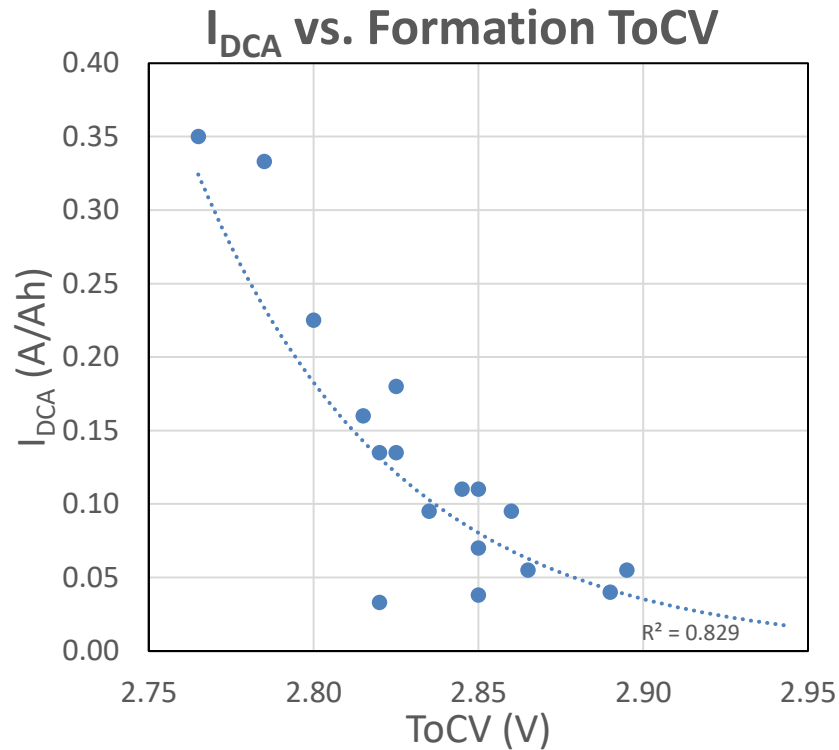
Testing: Gassing Tests

- Combination of rubber gasket, rubber O-rings, O-ring seat, and silicone finishing step allow cell to hold 1PSI
 - Adheres to SAE gassing characteristic specifications
- Test is run at 51.7 °C, test vehicle stands up well to the temperature
- Care taken during build process results in cells with excellent repeatability (low error bars, similar groupings)



Notable Correlations??

- BDS has tested >500 cells since v5.0 was locked in
- Some (perhaps) surprising correlations are arising between various performance metrics
 - Each data point is the average of 3 test cells



Data Taken from 1 Step of a CC Tafel Plot

Conclusions

- **Largest determinants of data quality and scalability in our experience**
 - Tight reproducibility in all aspects of build
 - Rock-solid connections
 - Material recipe, processes, and quality control that matches industry
- **Advice**
 - **Stand on the Shoulders of Giants:** the industry is packed with incredible knowledge and helpful people; use them!!
 - **Take No Short Cuts:** you will learn more by slowly and methodically addressing your needs
 - **Ask Advice from People Outside your Project:** materials scientists, lithium scientists, battery engineers, biochemists(!)
 - **Keep an Eye Open for Novelty:** just because the technology is mature does NOT mean your observations are unoriginal!

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Ask me anything



No questions from the audience!

Incoming questions will show up here so that you can answer them one by one.



 to mark as answered,  to see more questions



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