Carbon-Enhanced VRLA Batteries

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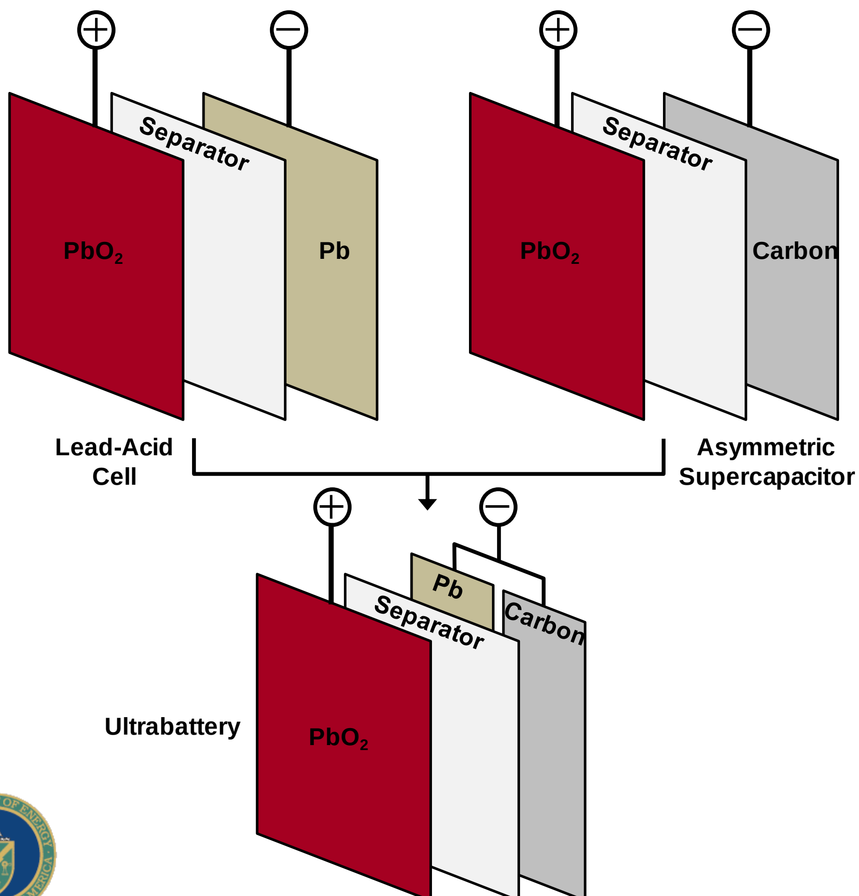
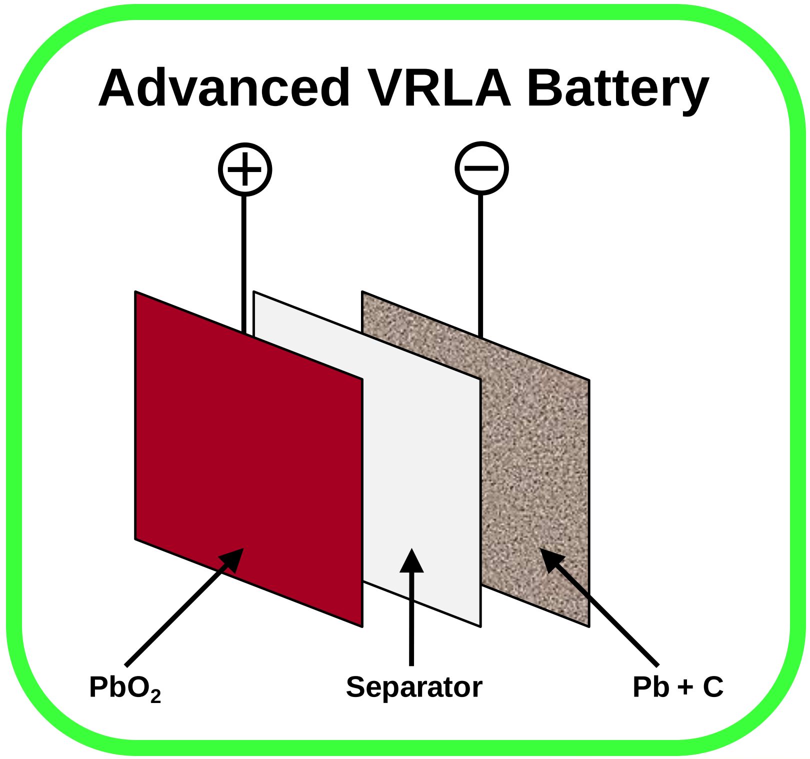
The Advanced VRLA Battery

- Recently, there are several manners in which carbon has been added to a Pb-Acid battery
  - ➢ The work presented here deals with the Advanced Battery, where carbon has been added to the negative active material

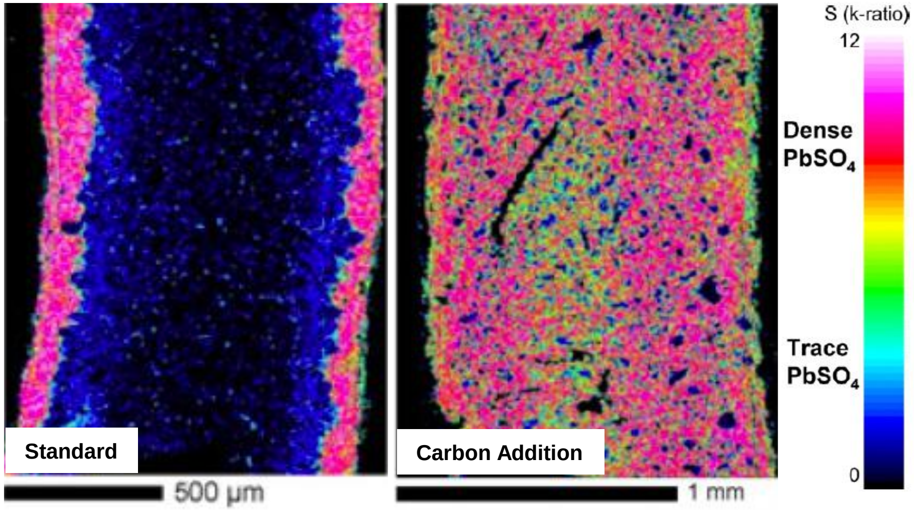




Why add excess carbon to the NAM?

- **Carbon additions to the negative active material (NAM) can substantially reduce hard sulfation**

  - ➢ **Fernandez, 2010***



*M.Fernandez, J.Valenciano, F.Trinidad, N. Munoz, Journal of Power Sources, Vol. 195 (2010), pp. 4458-4469.

Research Goals

- **The overall goal of this work is to quantitatively define the role that carbon plays in the electrochemistry of a VRLA battery.**
  - **What reactions/changes take place on the surface of the carbon particles?**
  - **What processes govern the increase and then eventual decrease in capacity with increasing # of cycles?**
  - **Are the kinetics of the charge/discharge process different when carbon is present vs. when it is not?**
  - **Why are some carbons effective additions while others are not? Are there any distinguishing characteristics of effective additions? Is the effectiveness controlled by aspects of the plate production method? etc.**

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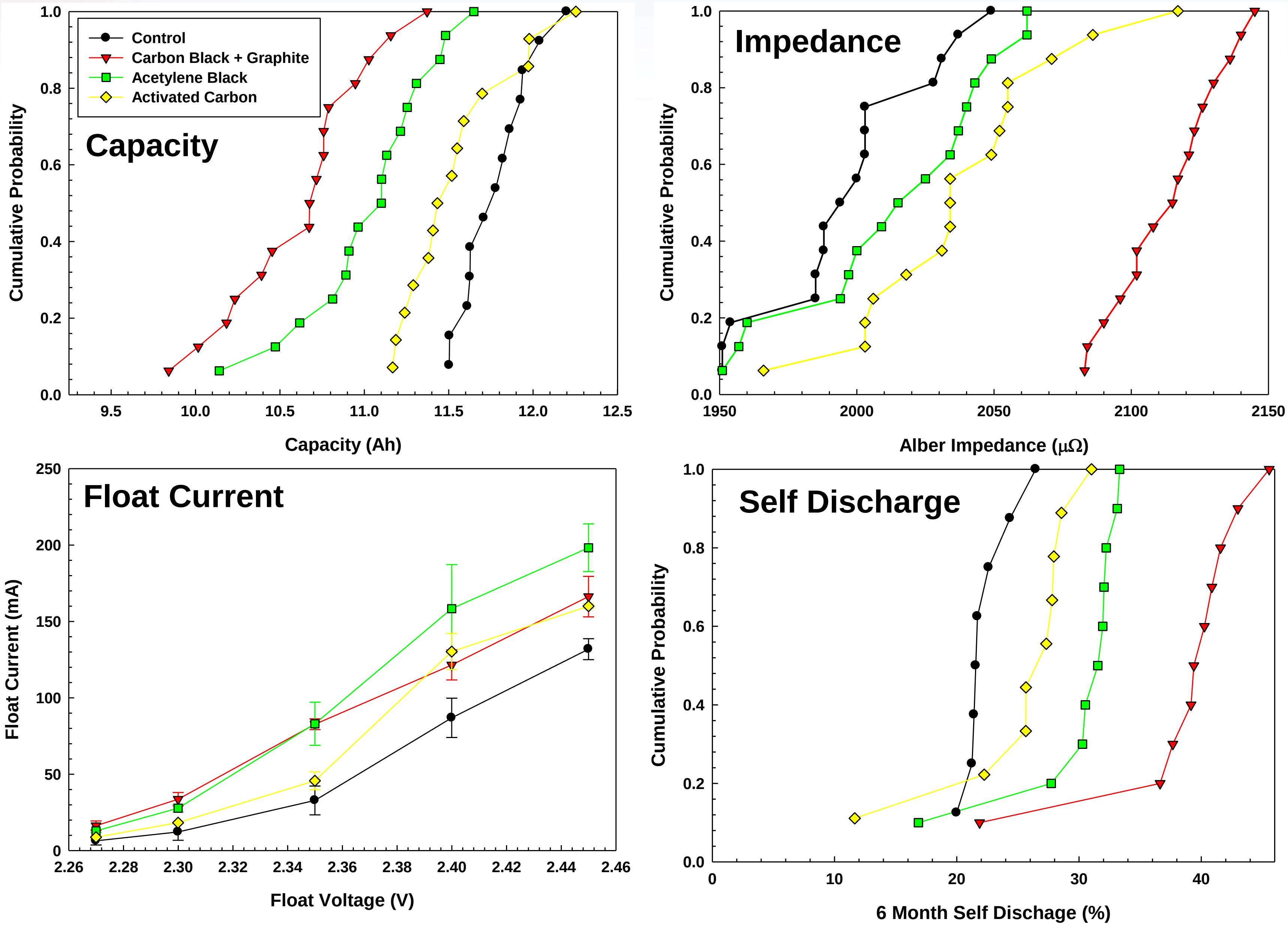
Constituent Material Analysis

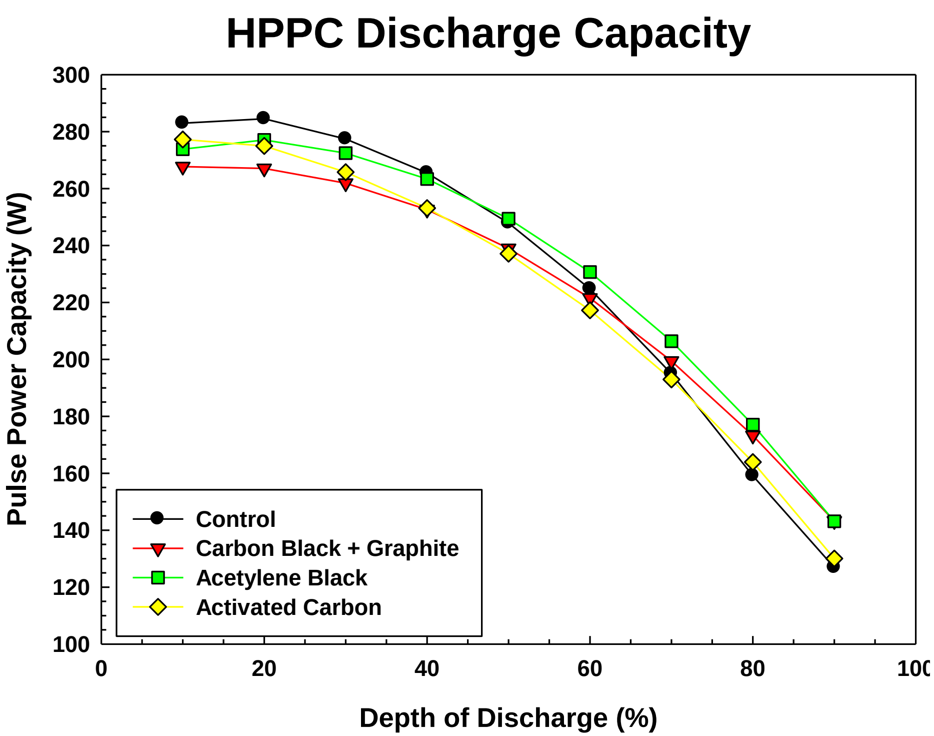
- **Given the limited understanding of what characteristics yield an effective carbon addition, a broad spectrum approach is being taken to quantify the carbon particle properties.**

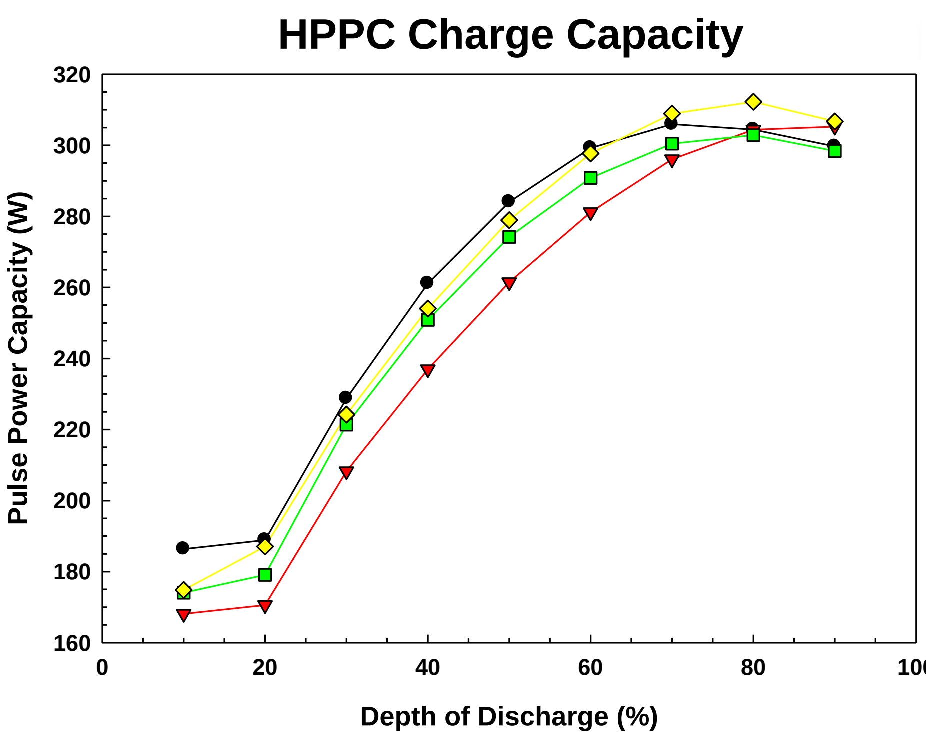
	Carbon Black	Graphite	Actetylene Black	Activated Carbon
Particle size	20 nm	20+ µm	20 nm	100+ µm
Effective surface area (BET)	75 m^2/g	6 m^2/g	75 m^2/g	>2000 m^2/g
Structure (XRD)	Semicrystalline	Crystalline	Semicrystalline	Amorphous
Acid Soluble Contamination	Clean	Clean	Very Clean	Na, PO_4

Performance Testing Shows Some Differentiation between Control and Carbon Modified Batteries



Performance Testing Shows Similarities Between Control and Carbon Modified Batteries





Note: These HPPC data are for new cells

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More Dramatic Differentiation Observed as the Batteries are Cycled

- **Comparable behavior observed for all four battery types at 1k cycles**
- **At 10k cycles, capacity loss was evident in the control, acetylene black, and activated carbon batteries (but not in the carbon black + graphite cell)**
- **Control battery failed at 11,292 cycles**
  - **Failure defined as a capacity loss of greater than 20% after three discharge/charge cycles in an attempt to recover.**

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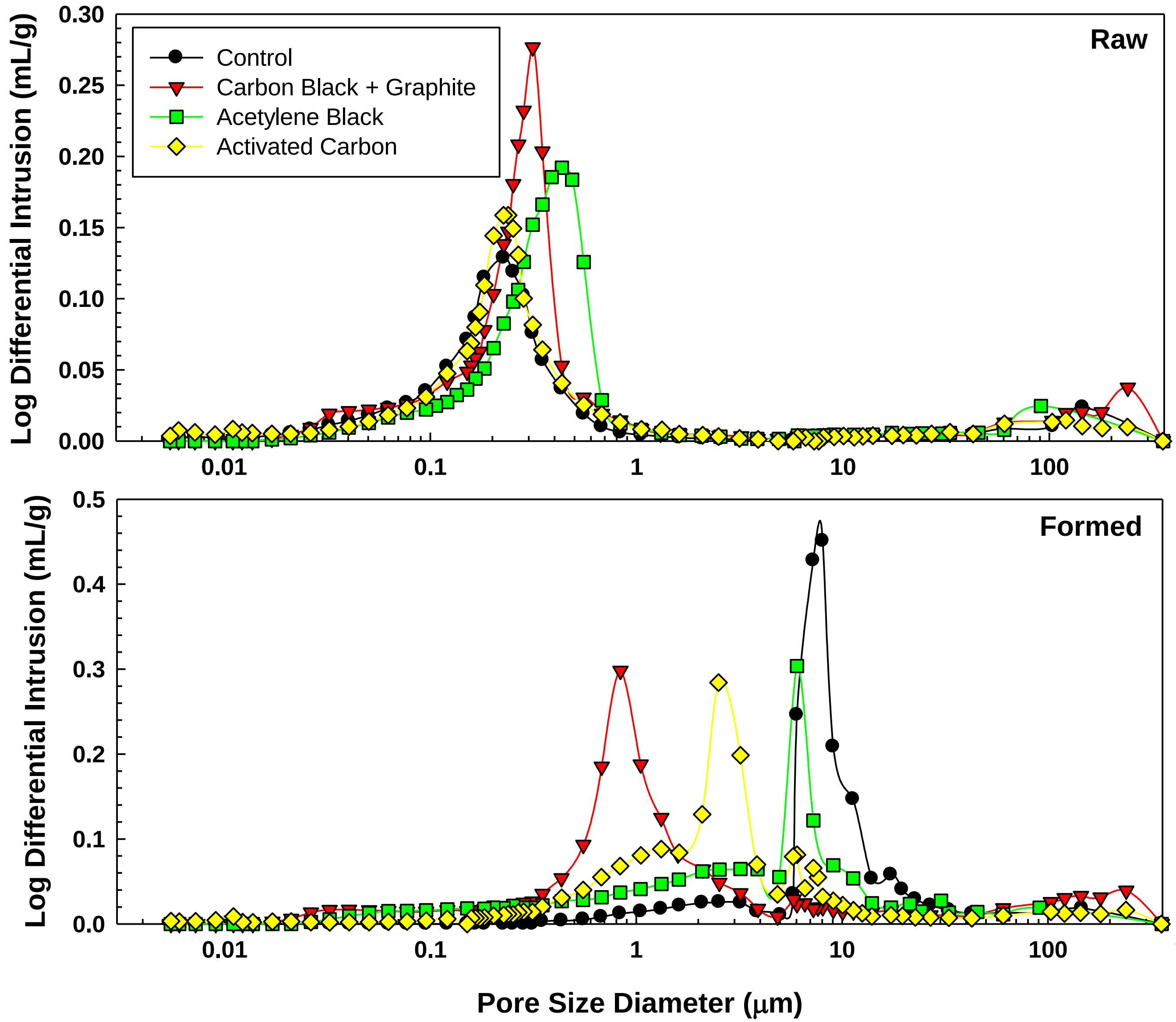
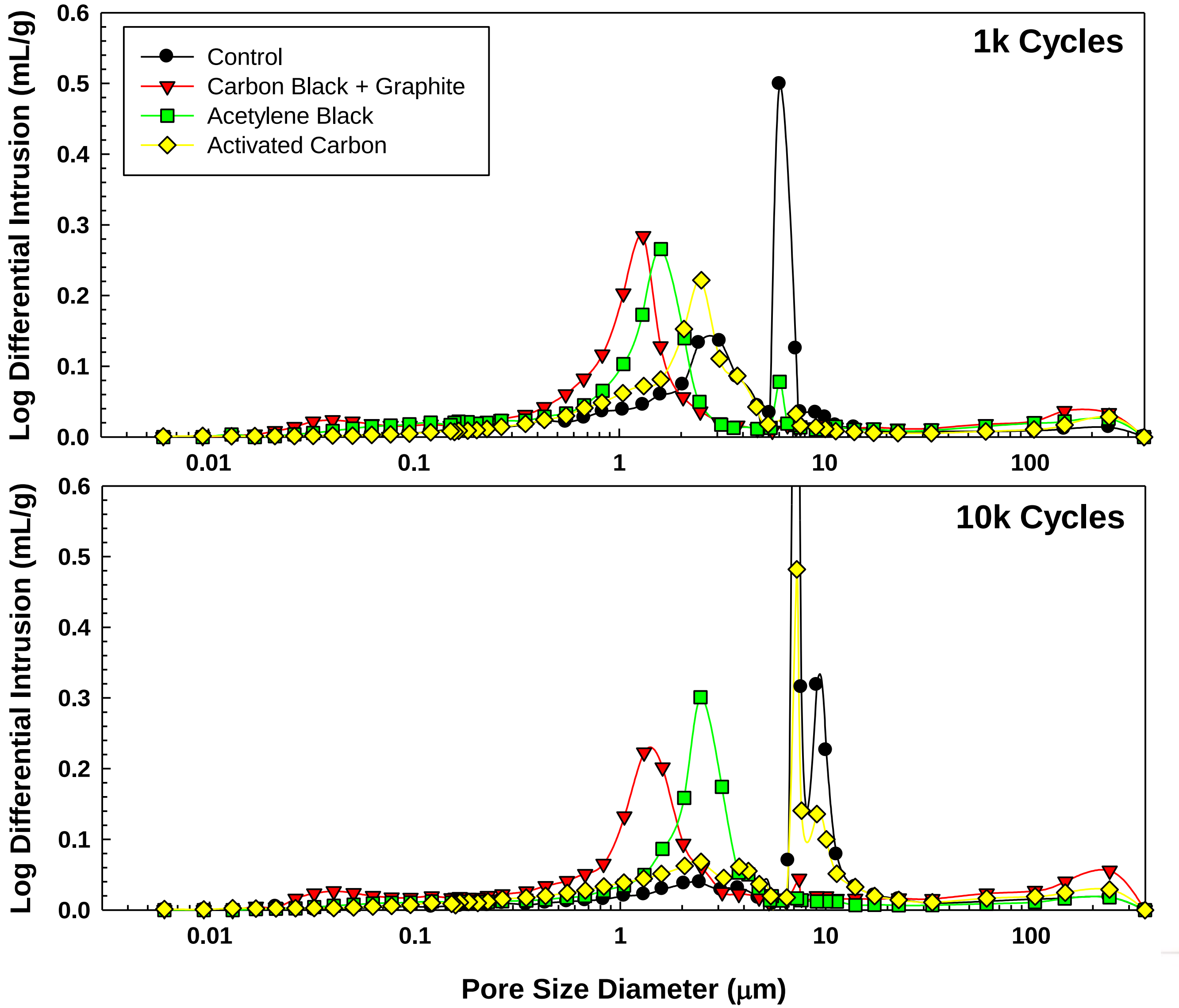
Porosity and Pore Size Distribution

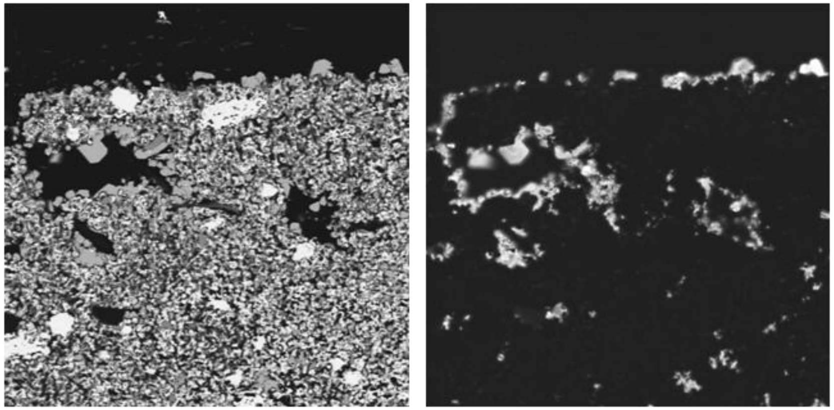


Porosity and Pore Size Distribution

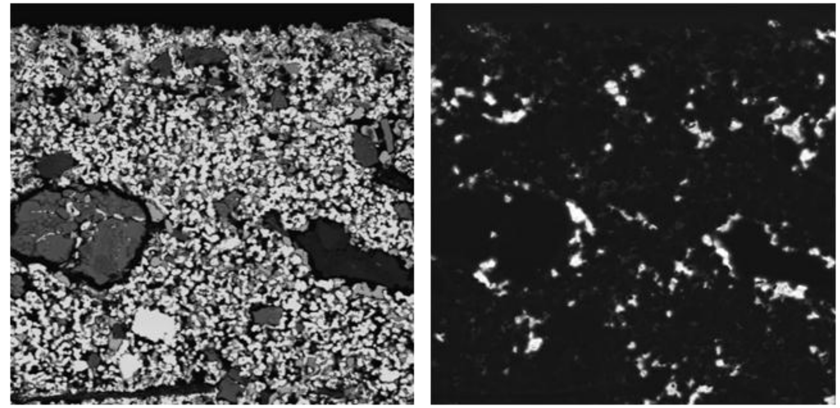


Minimal Sulfation at 1k Cycles

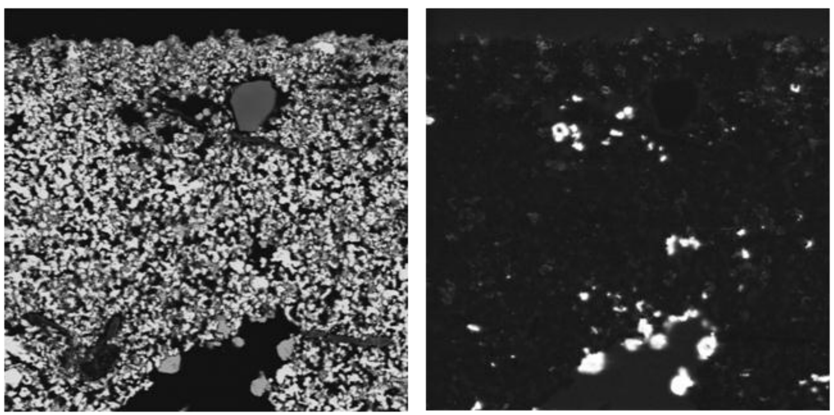
Control



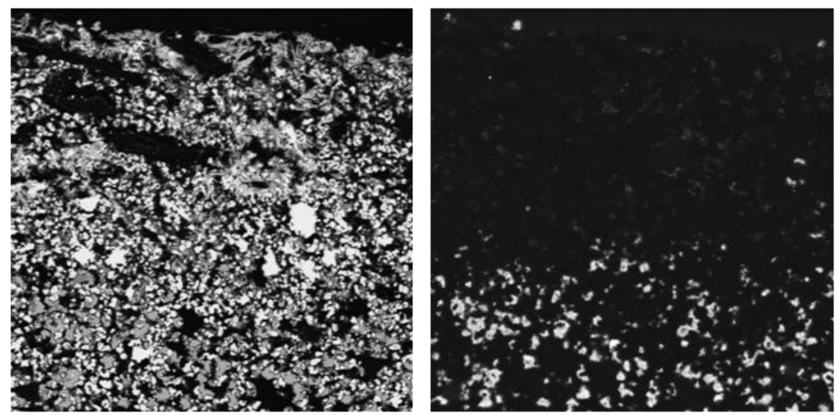
Activated Carbon



Acetylene Black



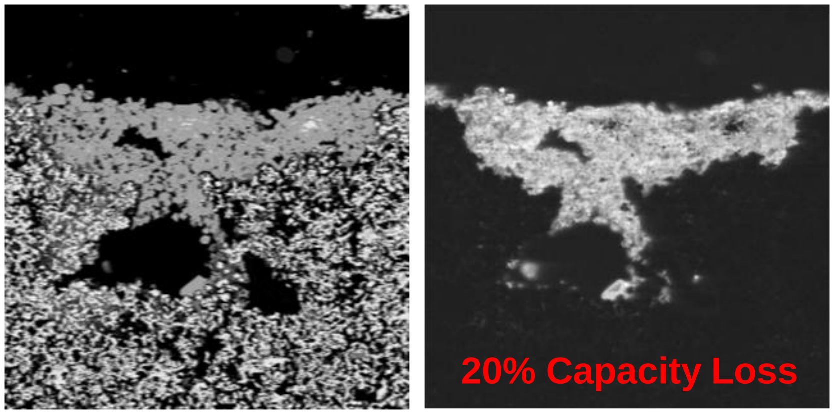
Carbon Black + Graphite



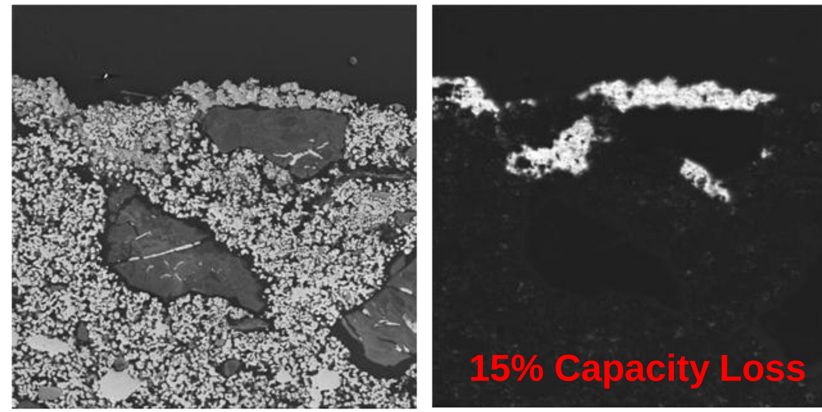
100 microns

Significant Sulfation at 10k Cycles for Two of the Batteries

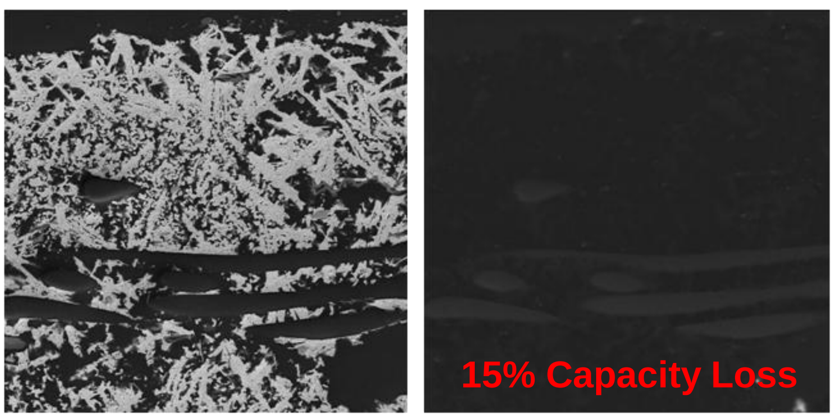
Control



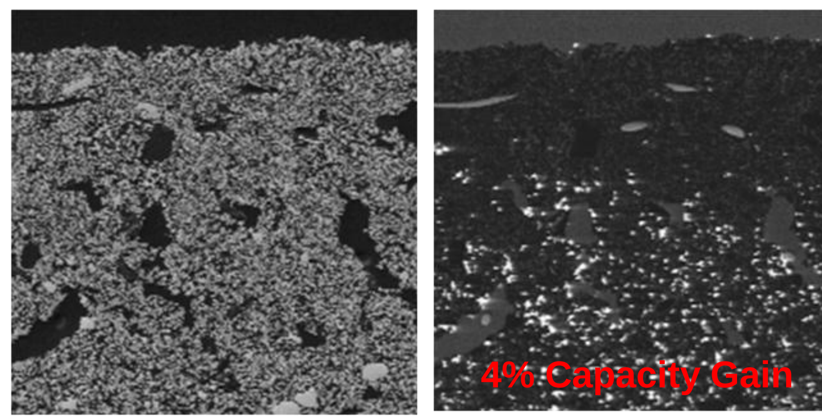
Activated Carbon



Acetylene Black



Carbon Black + Graphite



100 microns

250 microns

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Summary/Conclusions to Date

- Battery performance
  - Pb-C batteries had lower initial capacity, higher initial internal resistance, higher float current, comparable HPPC performance, and superior HRPSoC cycling performance
- Material Characterization
  - Pore structure in Pb-C batteries notably smaller (order of magnitude), but comparable in overall volume
  - Hard sulfation becoming significant after 10k cycles with the control battery and activated carbon battery

Future Tasks

- Cycle testing will continue
  - 50k and 100k cycles
  - Cycle to end of life
  - Analysis of cycled battery materials

- Program will conclude in August 2012