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JOINT CENTER FOR ENERGY STORAGE RESEARCH

Systematic Variation of Sulfur Cathode Chemistry and Its Effects on Cell Performance

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U.S. DEPARTMENT OF ENERGY

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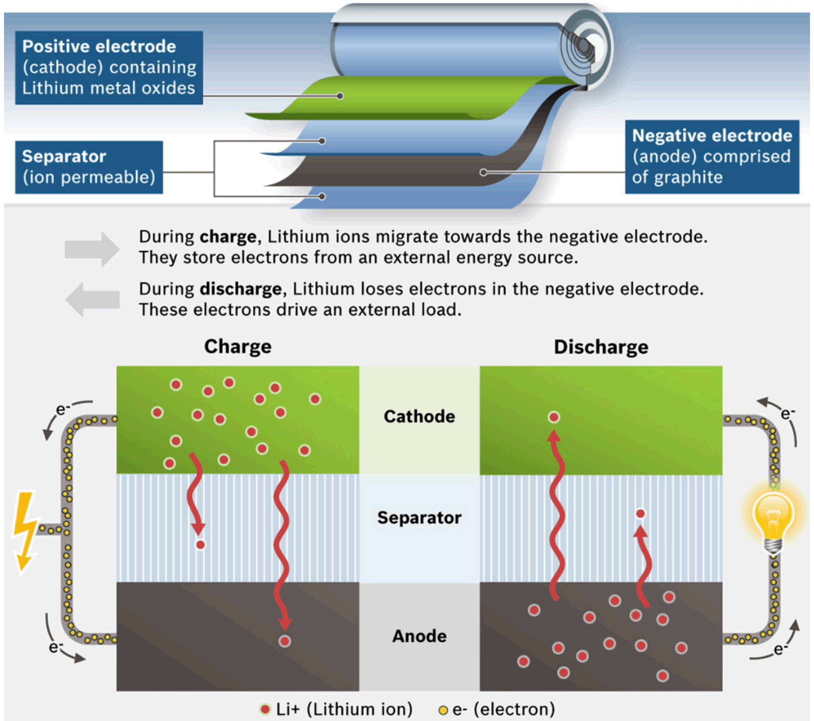
Current State of the Art in Energy Storage The Lithium Ion Battery



One of the greatest success in electrochemical energy storage

It has been adapted to many different platforms and form factors

As transformative as this technology is it can be argued that it is reaching its theoretical limit

https://boschenergystoragesolutions.com/en/blog/-/blog/4334855/how-a-lithium-ion-battery-works

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http://www.bombayharbor.com/Product/13263/Battery_Ion_Battery_Pack_Lithium_Battery_Lim_Ion.html

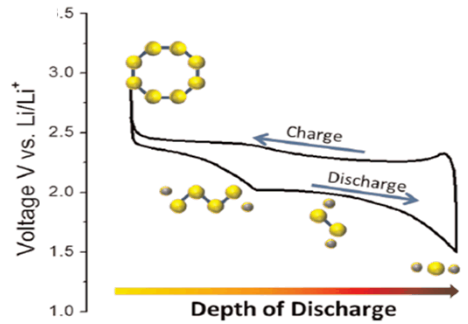
Beyond Lithium Ion: Sulfur Battery

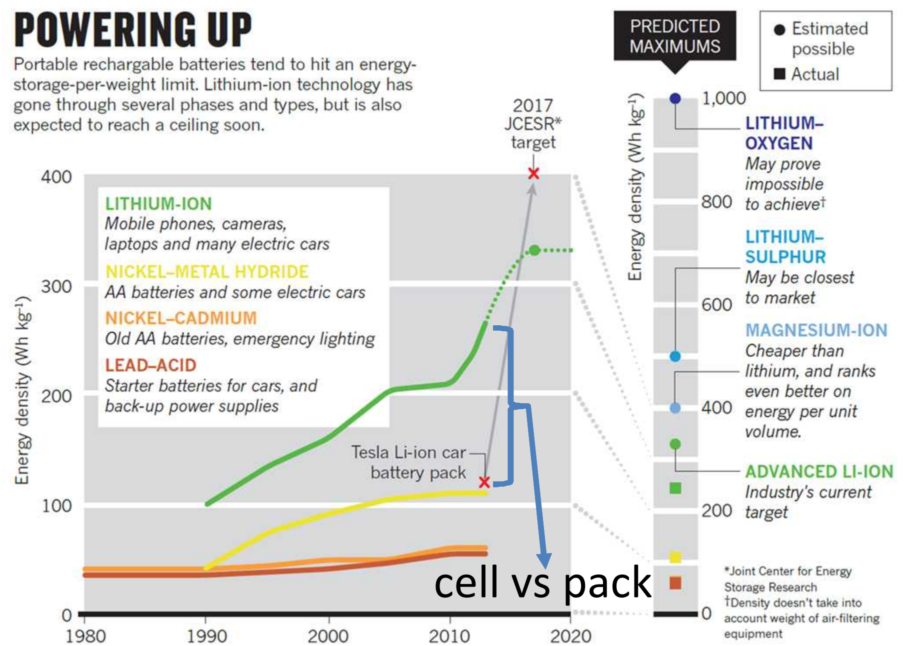
- Lithium sulfur batteries have been extensively studied
- They suffer from two major drawbacks…

  Sulfur is electrically insulating

  Sulfur shuttle mechanism

- Much of the work done in this field is done to mitigate these problems…

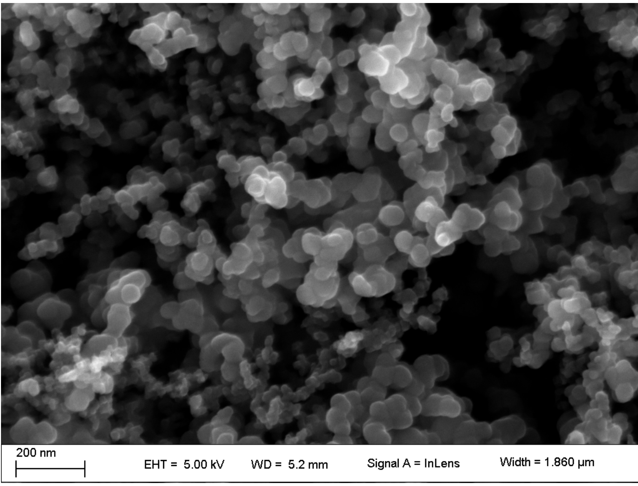




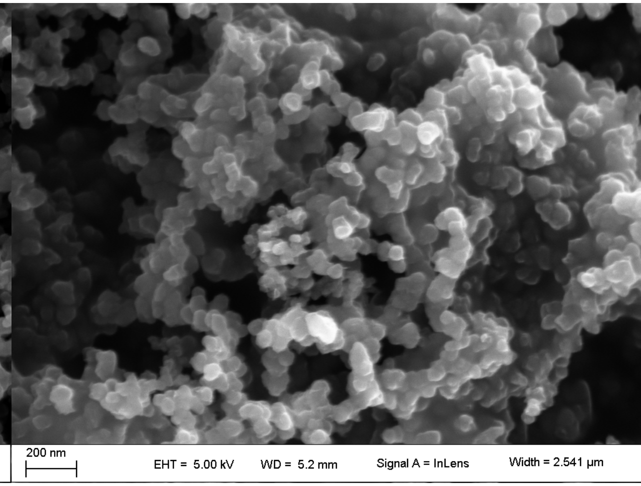
Van Noorden, R. (2014). "A BETTER BATTERY." Nature 507(7490): 26-28.

Evers, S.; Nazar, L. F., New Approaches for High Energy Density Lithium-Sulfur Battery Cathodes. Accounts Chem. Res. 2013, 46 (5), 1135-1143.

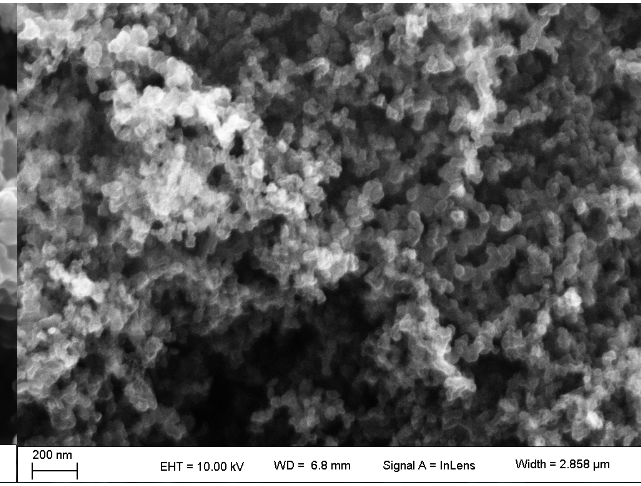
How Do we make the Best Sulfur Cathode? What Are the Tools?



Super P 62 m^2/g



Denka 68 m^2/g



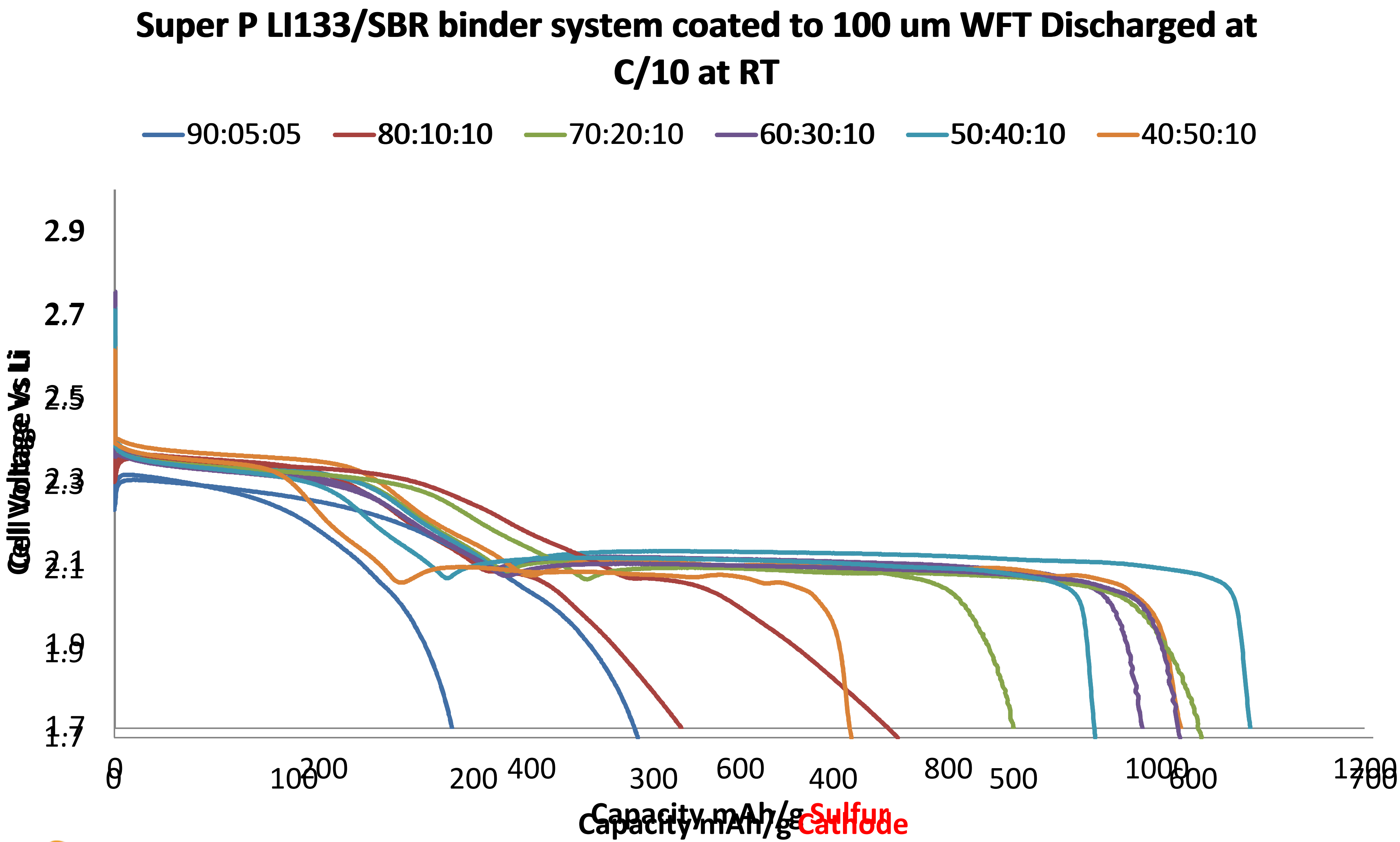
Ketjenblack EC600J 1270m^2/g

Test Matrix			
% active	Carbon	Binder System	Loading/WFT
90	Super P	LI133/SBR	15 mil(380µm)
80	Denka	PVDF	8 mil (200µm)
70	Ketjenblack EC600J		4 mil (100µm)
60			
50			
40			

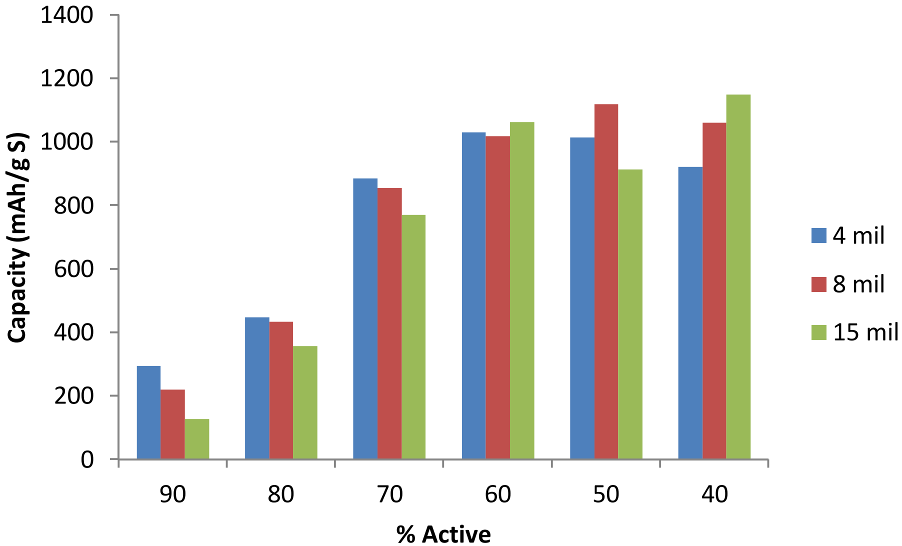
Experimental Details

- Cells utilized a Li metal anode 50um laminated onto 10um copper
- 2X Celgard 3501 separator
- Electrolyte
  - 1:1 v:v 1-3 dioxolane:dimethoxyethane
  - 1M LiTFSi 0.25M $LiNO_3$
- Cycling done at 0.1C at RT
- All cells built in a dry room

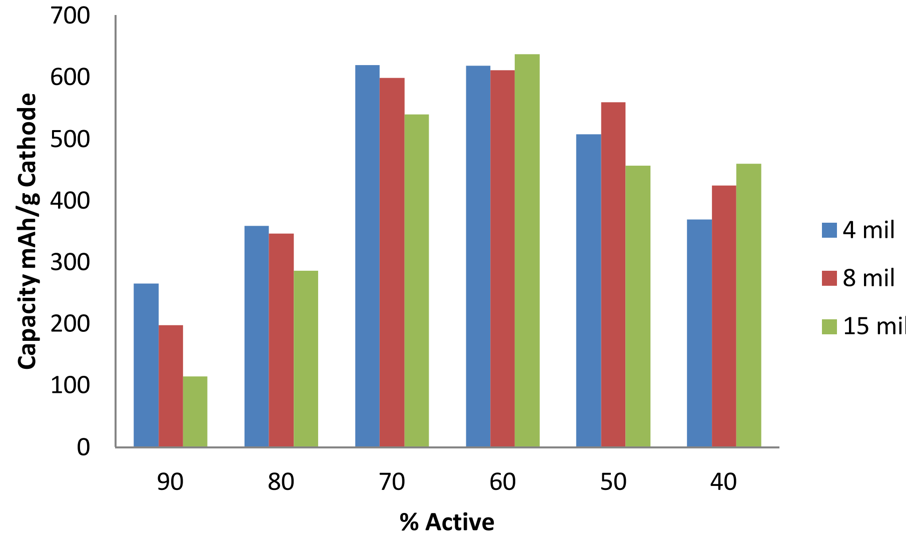
LiS The Promise….
The Reality….



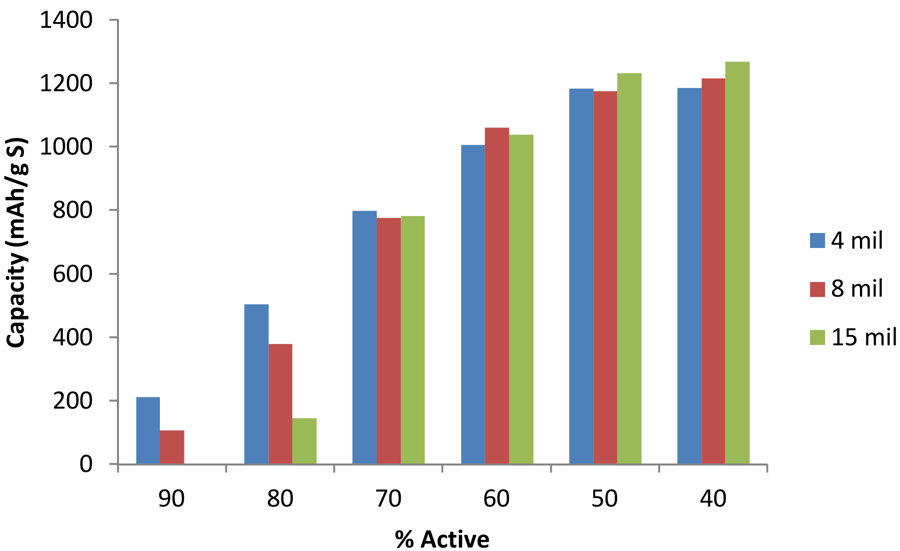
First Discharge Capacity, RT, Super P, LI133/SBR 0.1C RT



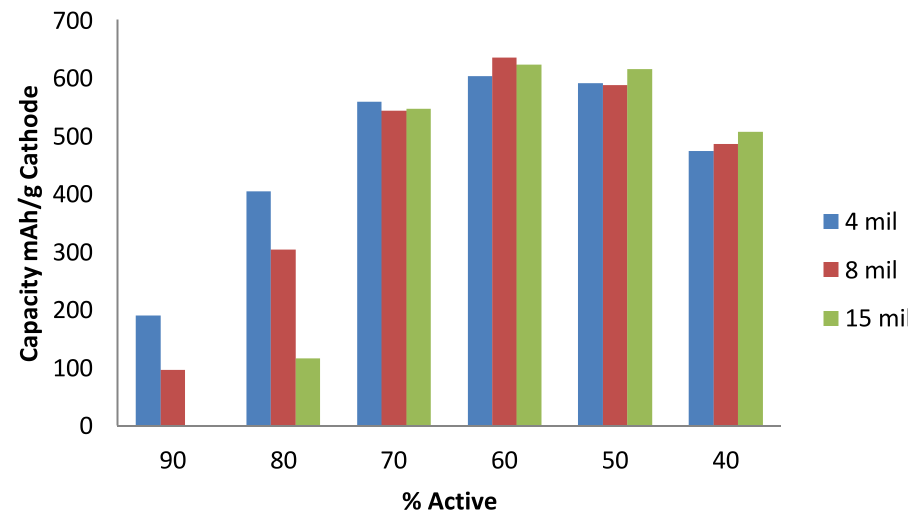
First Discharge Capacity RT, Super P, LI133/SBR 0.1C RT

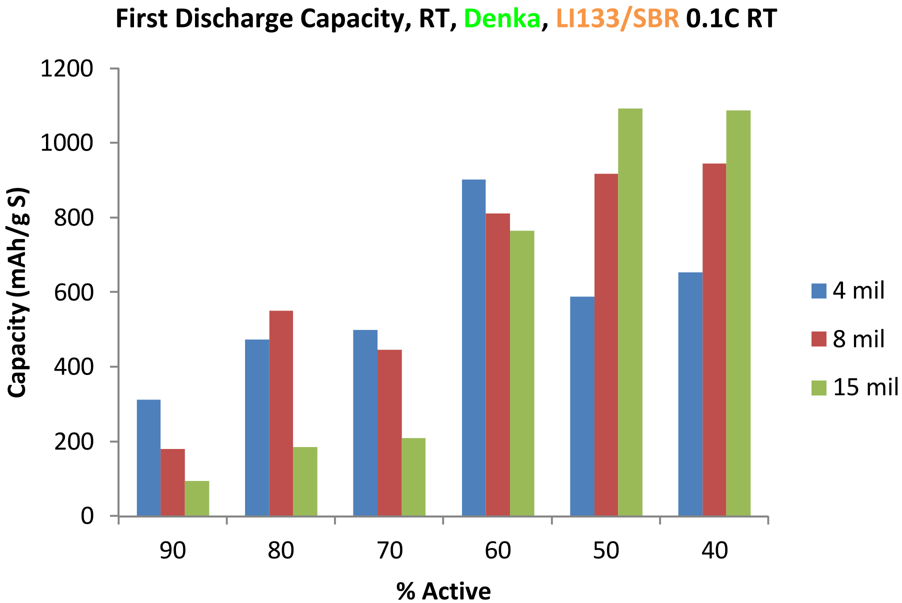


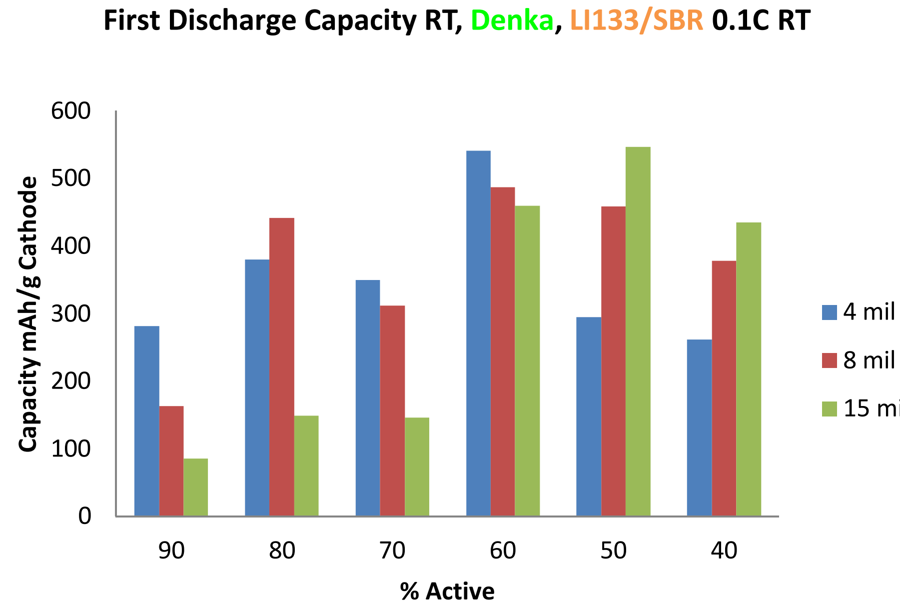
First Discharge Capacity, RT, Super P, PVDF 0.1C RT

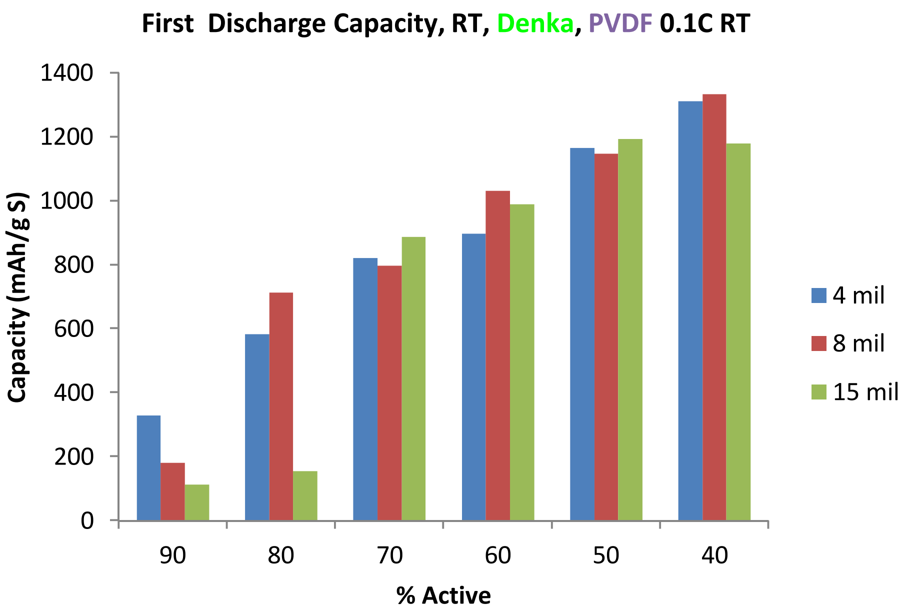


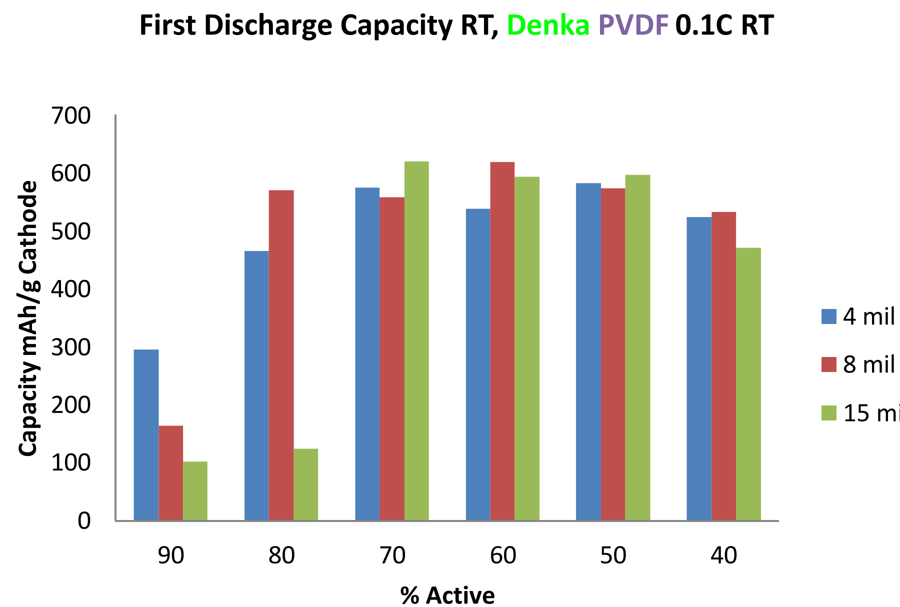
First Discharge Capacity RT, Super P, PVDF 0.1C RT

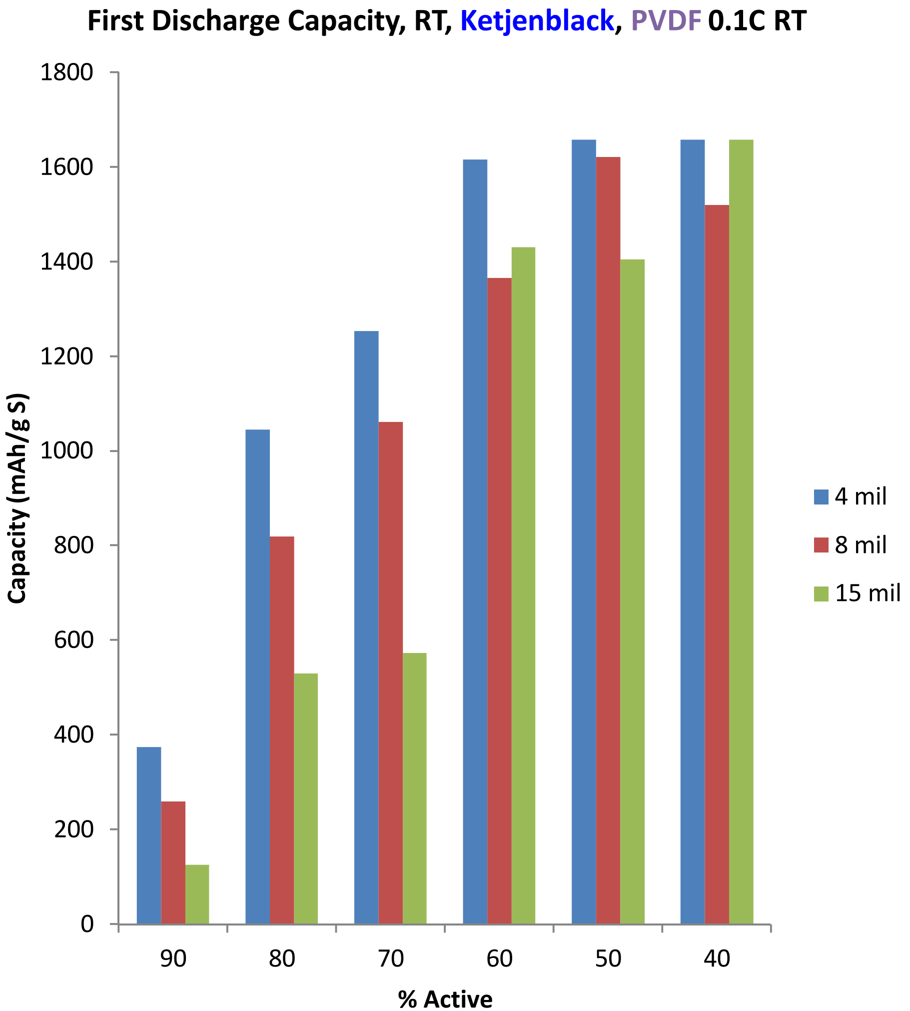


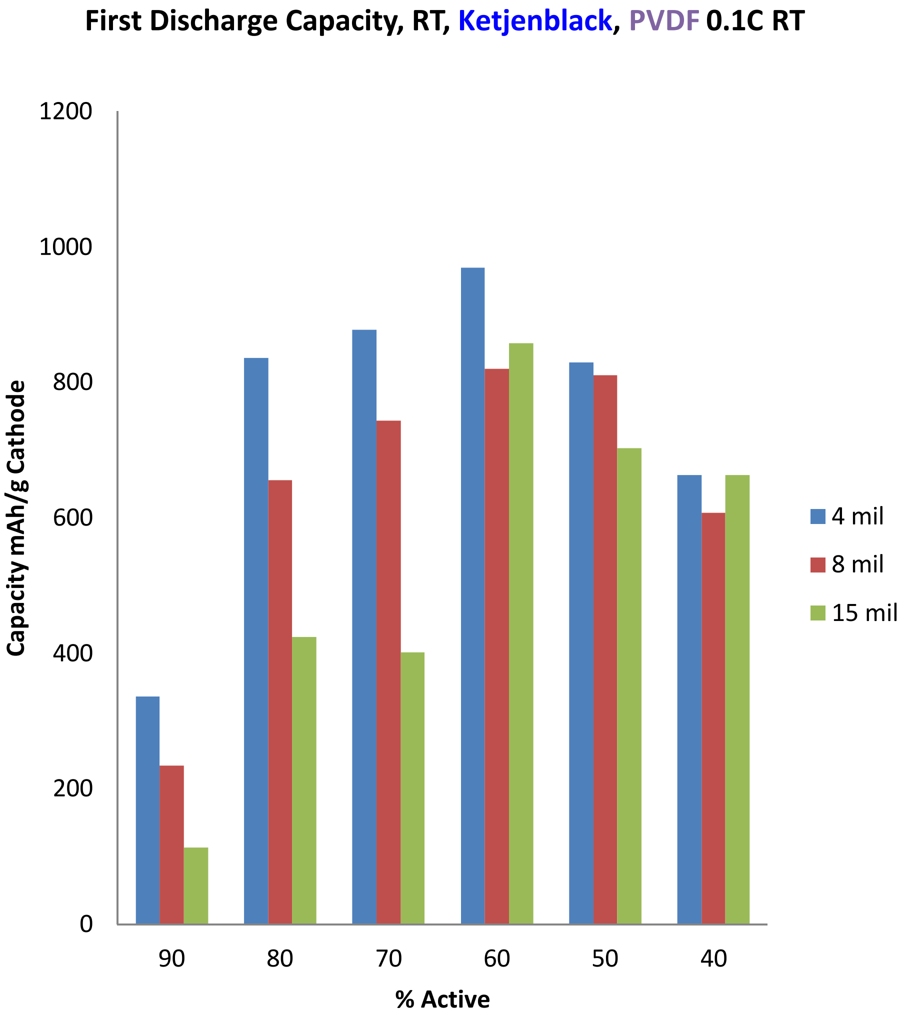

First Discharge Capacity, RT, Denka, LI133/SBR 0.1C RT
Capacity (mAh/g S)
1200
1000
800
600
400
200
0
90
80
70
60
50
40
% Active
4 mil
8 mil
15 mil


First Discharge Capacity RT, Denka, LI133/SBR 0.1C RT
Capacity mAh/g Cathode
600
500
400
300
200
100
0
90
80
70
60
50
40
% Active
4 mil
8 mil
15 mil


First Discharge Capacity, RT, Denka, PVDF 0.1C RT
Capacity (mAh/g S)
1400
1200
1000
800
600
400
200
0
90
80
70
60
50
40
% Active
4 mil
8 mil
15 mil


First Discharge Capacity RT, Denka PVDF 0.1C RT
Capacity mAh/g Cathode
700
600
500
400
300
200
100
0
90
80
70
60
50
40
% Active
4 mil
8 mil
15 mil

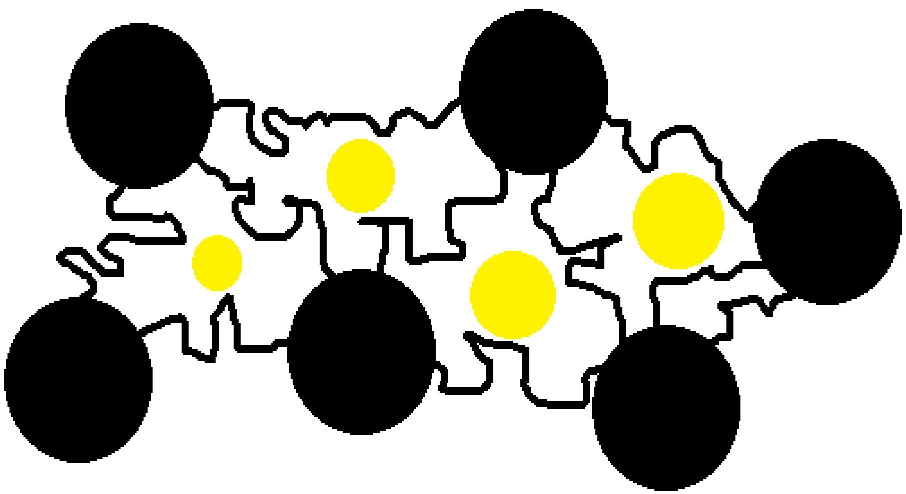


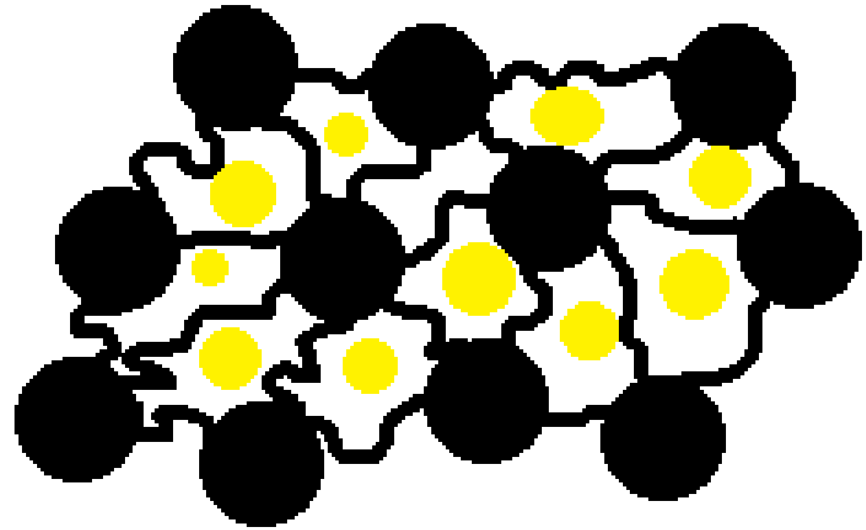


Ketjenblack and the aqueous based binder system were not compatible.

By utilizing a high surface area conducting phase and PVDF a 5x increase in capacity over Li ion is achievable

What are the Properties of the Cathode that Make the Performance Better?





Super P 62 m^2/g Denka 68 m^2/g Ketjenblack EC600J 1270m^2/g

- More than just surface area
- Capillary Condensation Mechanism

Kelvin Equation $$r = -\frac{\gamma V}{RT \ln(P/P^o)}$$

r = Pore Radius

γ = Surface Tension

V = Molar Volume of the Liquid

R = Gas Constant

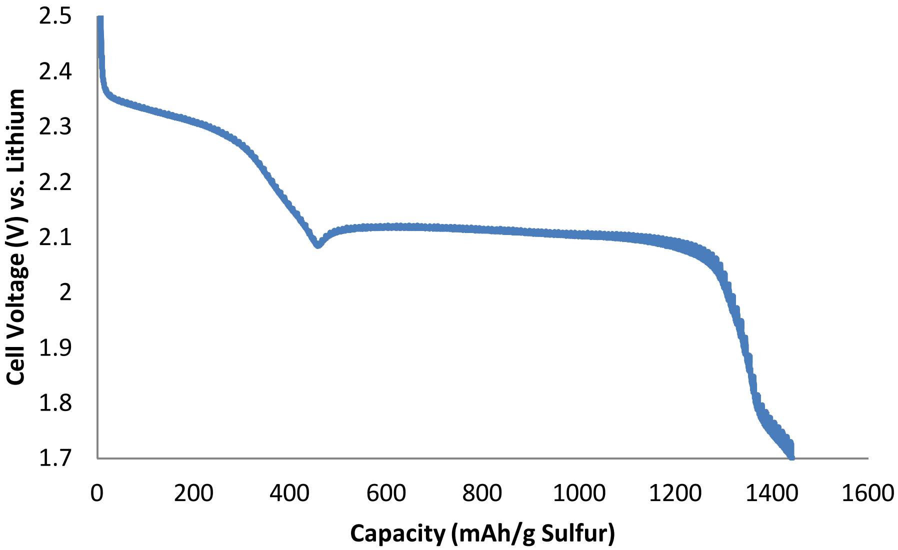
P^o = Normal Vapor Pressure of the liquid

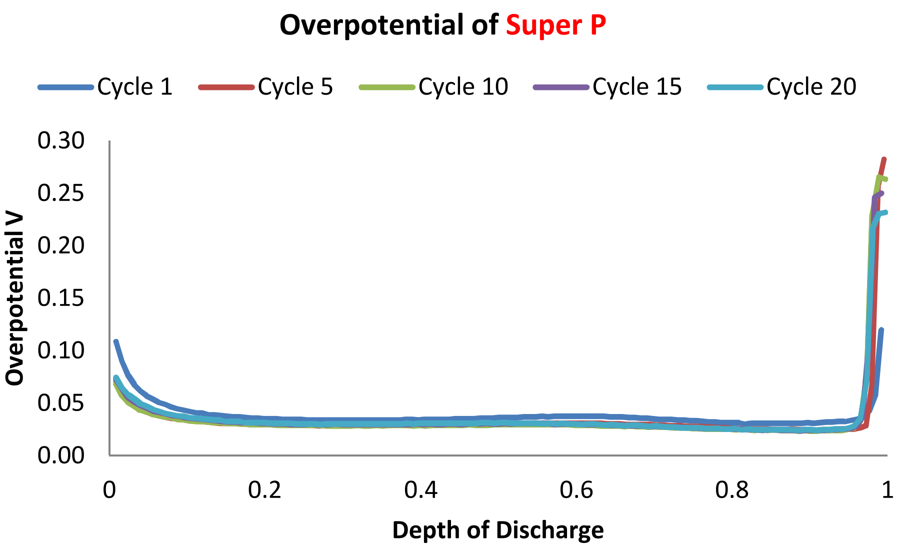
P = Observed Pressure of Vapor

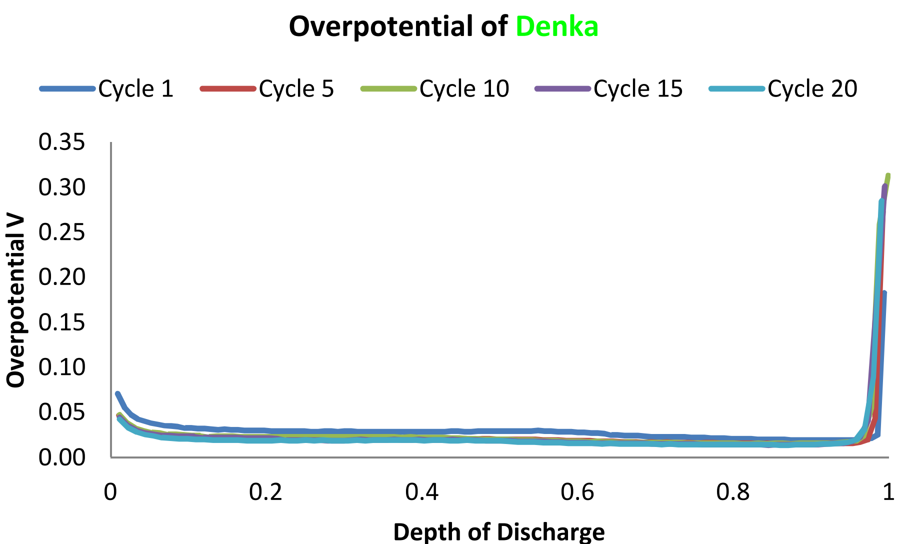
The preparation conditions are expected to increase the total surface area of the porous matrix

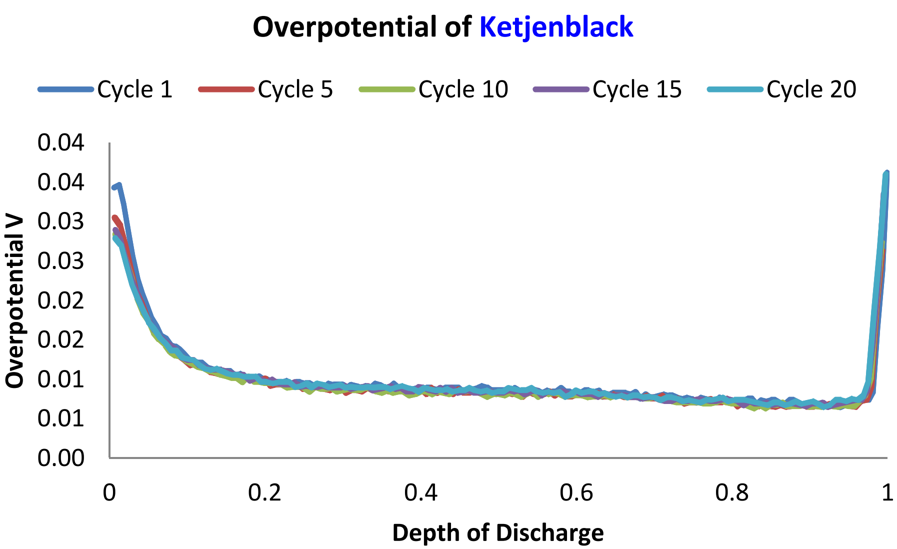
JCESR

How Conducting is the Carbon?

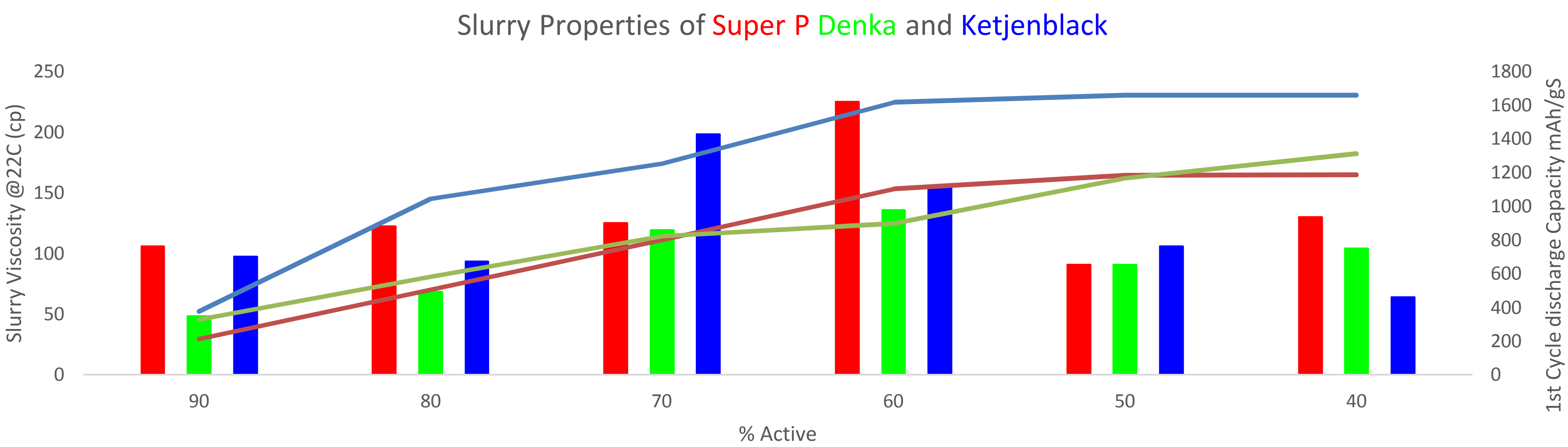


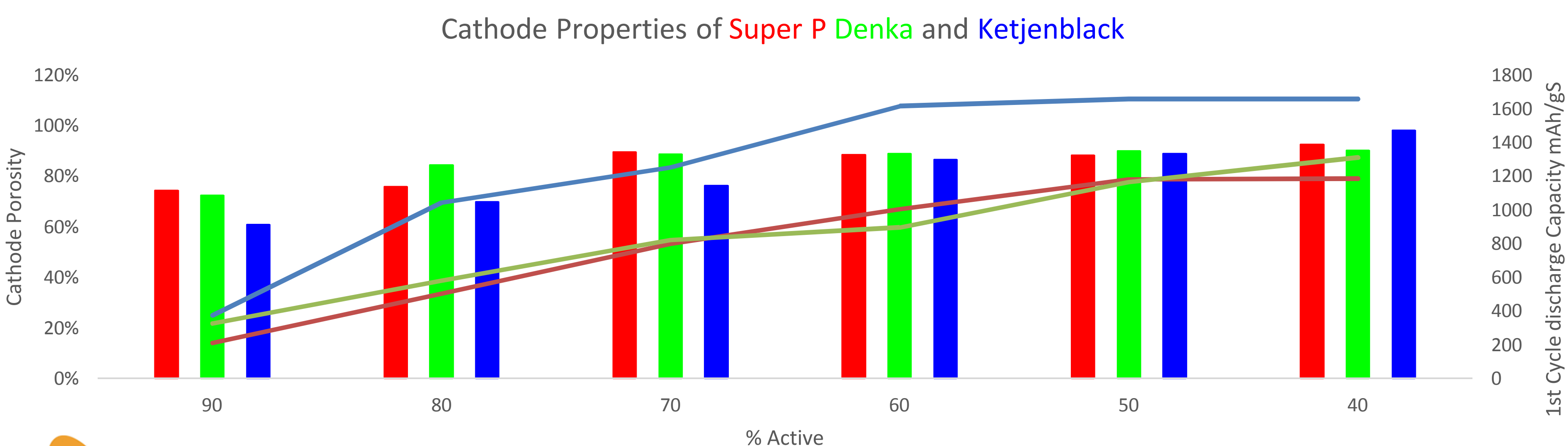




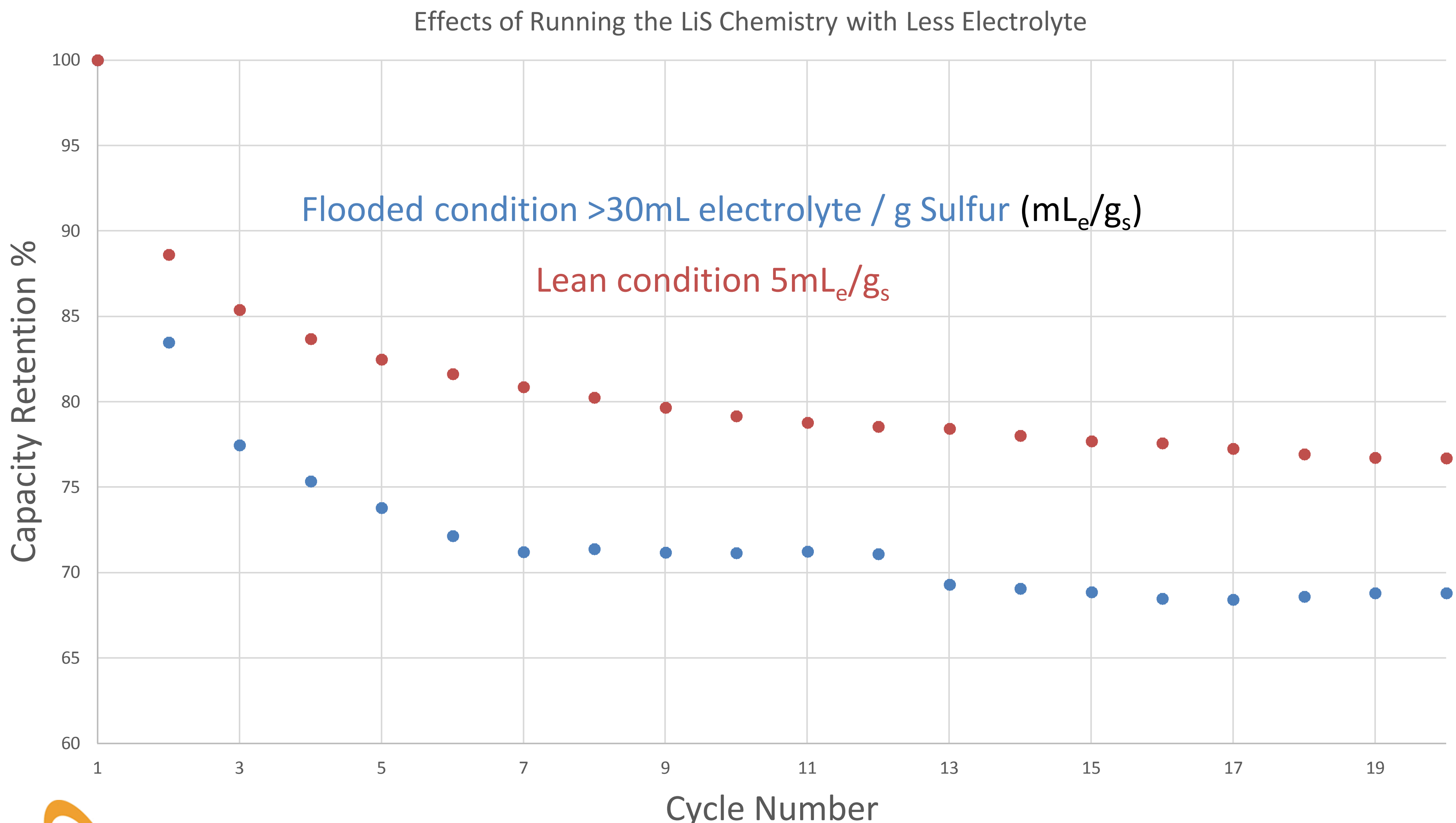


Cathode Preparation and its Effects on cell Performance

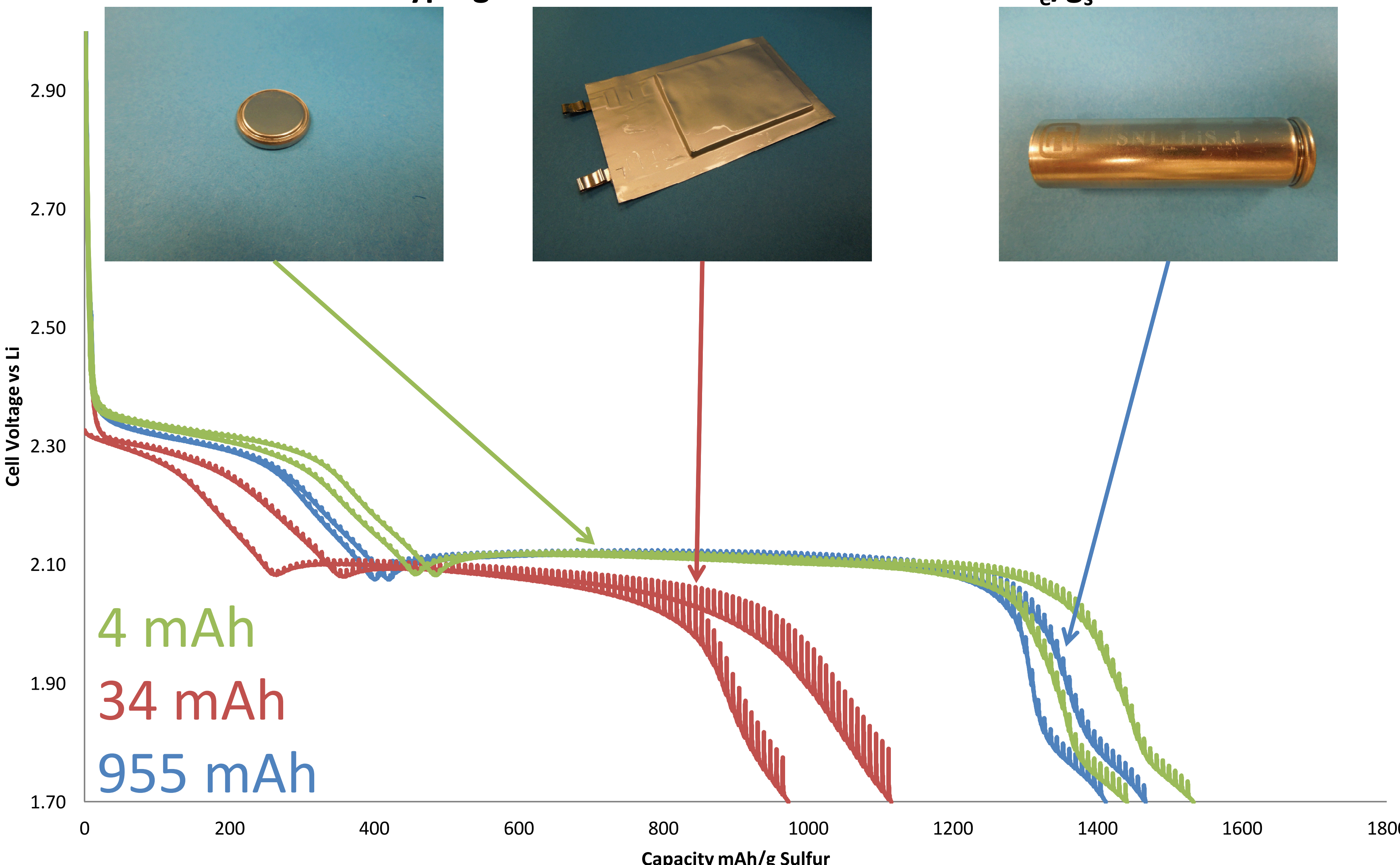




Going Lean a Potential way to Suppress Polysulfide Shuttle?



Prototyping of LiS at Various Levels 0.1C RT 5 mL_e/g_s



Future Directions and Impact

- Increasing the surface area of the conducting phase increased the performance of the cathode
  - If BP2000 is used can we push the limits further?
- The optimal cathode can be fabricated by preparing a KB carbon + PVDF binder in a 60:30:10 ratio slurry viscosity and cathode porosity seem to have minimal effect
- The first ever LiS 18650 prototype

Key Take-Away

- By utilizing the basic building blocks of cathode chemistry a 5x fold increase in capacity is obtainable

Acknowledgements

The Team…

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Chelsea Snyder
Jon Coleman

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