High Energy Rechargeable Li-S Cells for EV Application. Status, Challenges and Solutions

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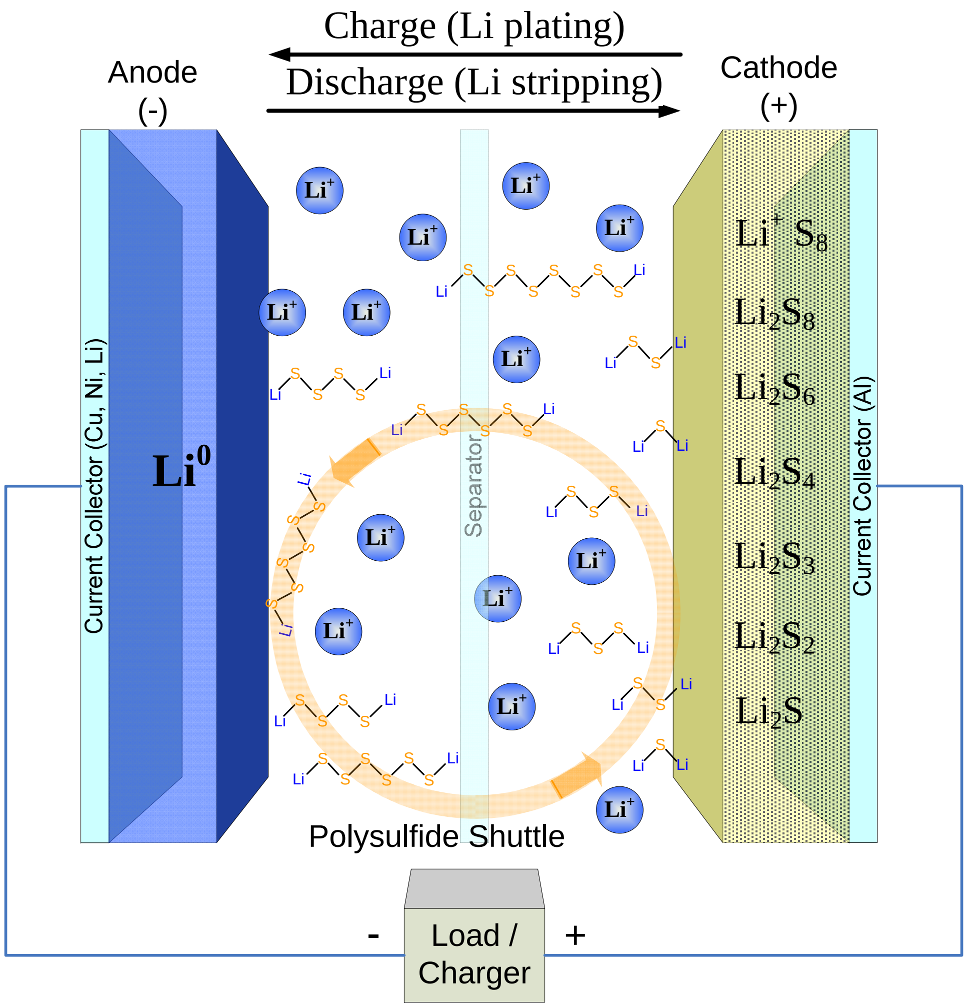
Outline

- Why lithium-sulfur technology?
  - Specific energy.
  - Rate capability.
  - Low temperature performance.
- Status of lithium-sulfur technology.
- Addressing the challenges.
- New approach pursued by Sion in collaboration with BASF for EV applications.
- Conclusions.

Why Lithium Sulfur Technology?

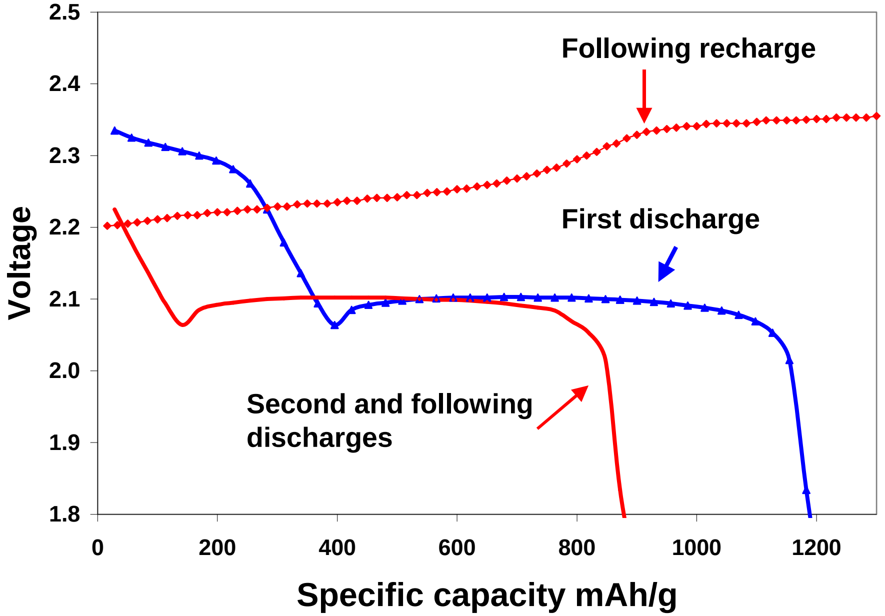


- **Lithium ions are stripped from the anode during discharge and form Li-polysulfides in the cathode.**
  - Li_2S in the cathode is the result of complete discharge.
- **On recharge the lithium ions are plated back onto the anode as the Li_2S_x moves toward S_8**
- **High order Li-polysulfides (Li_2S_3 to Li_2S_8) are soluble in the electrolyte and migrate to the anode scrubbing off any dendrite growth.**

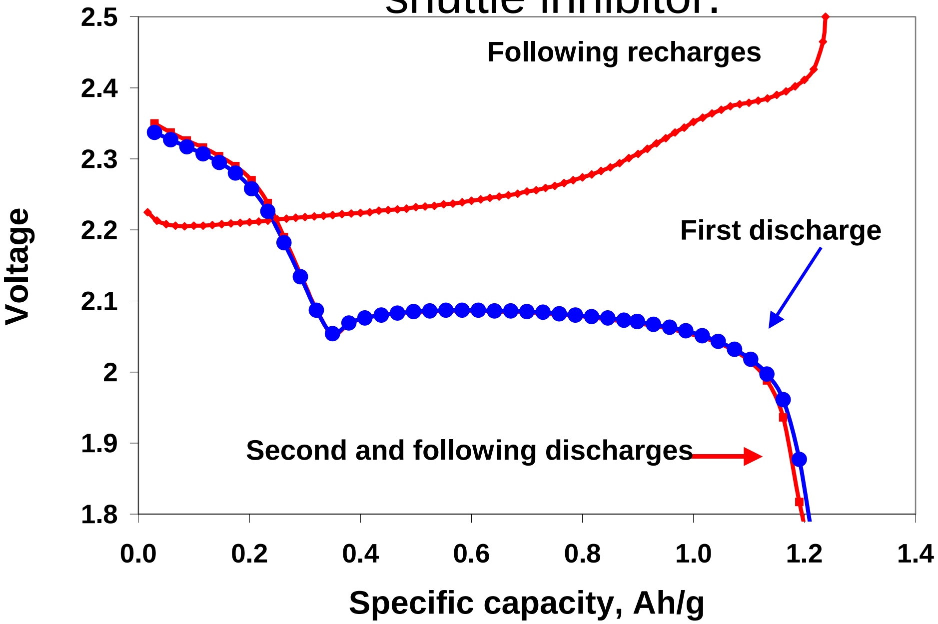
Theoretical Energy: ~2800Wh/l and 2500 Wh/kg

Why Lithium Sulfur Technology?
Specific Energy

Typical experimental discharge and charge profiles with strong shuttle.



Charge and discharge profiles with shuttle inhibitor.



With NO_3^- additives Sion Power controls shuttle and achieves 100% of high plateau sulfur utilization, 99.5% charge efficiency and 350 – 450 Wh/kg

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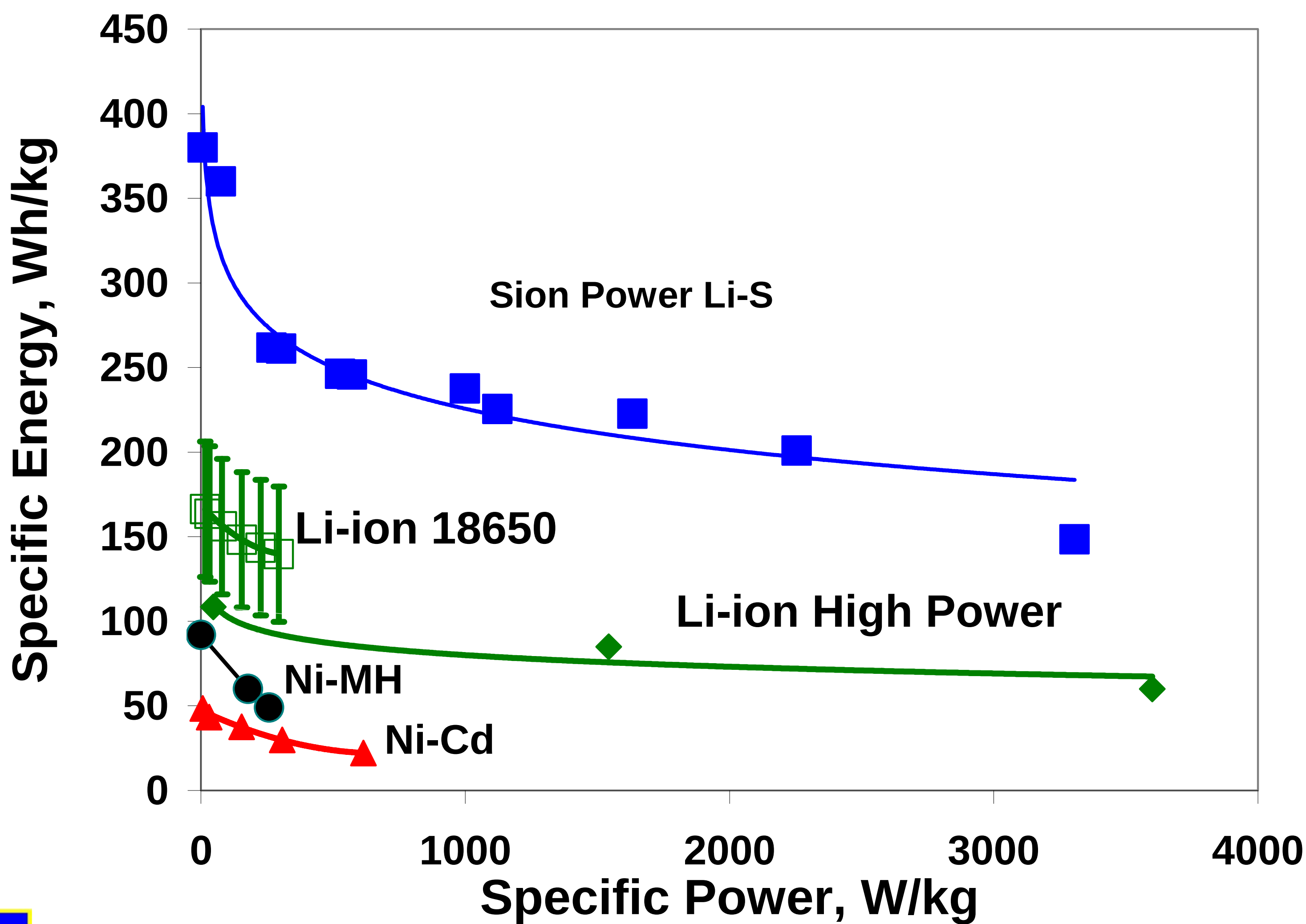
Why Lithium Sulfur Technology?

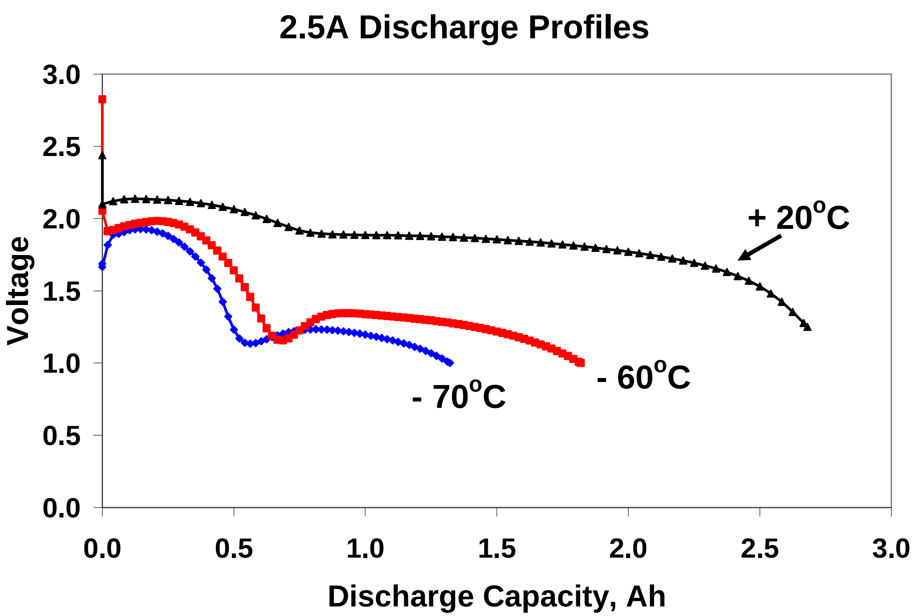
Rate Capability

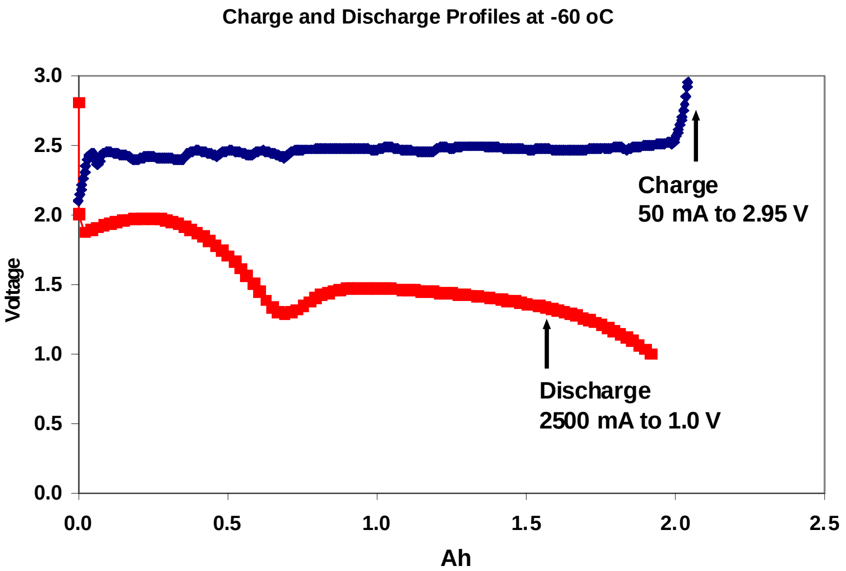


Why Lithium Sulfur Technology?

Low Temperature Performance

Work partially support by NASA Glenn Contract NNC06CA85C





Batteries with optimized solvent and salt concentrations delivered:

1)~160 Wh/kg at -60°C at 1C,

2)~130 Wh/kg at -70°C at 1C,

3) The battery can be recharged at -60°C.

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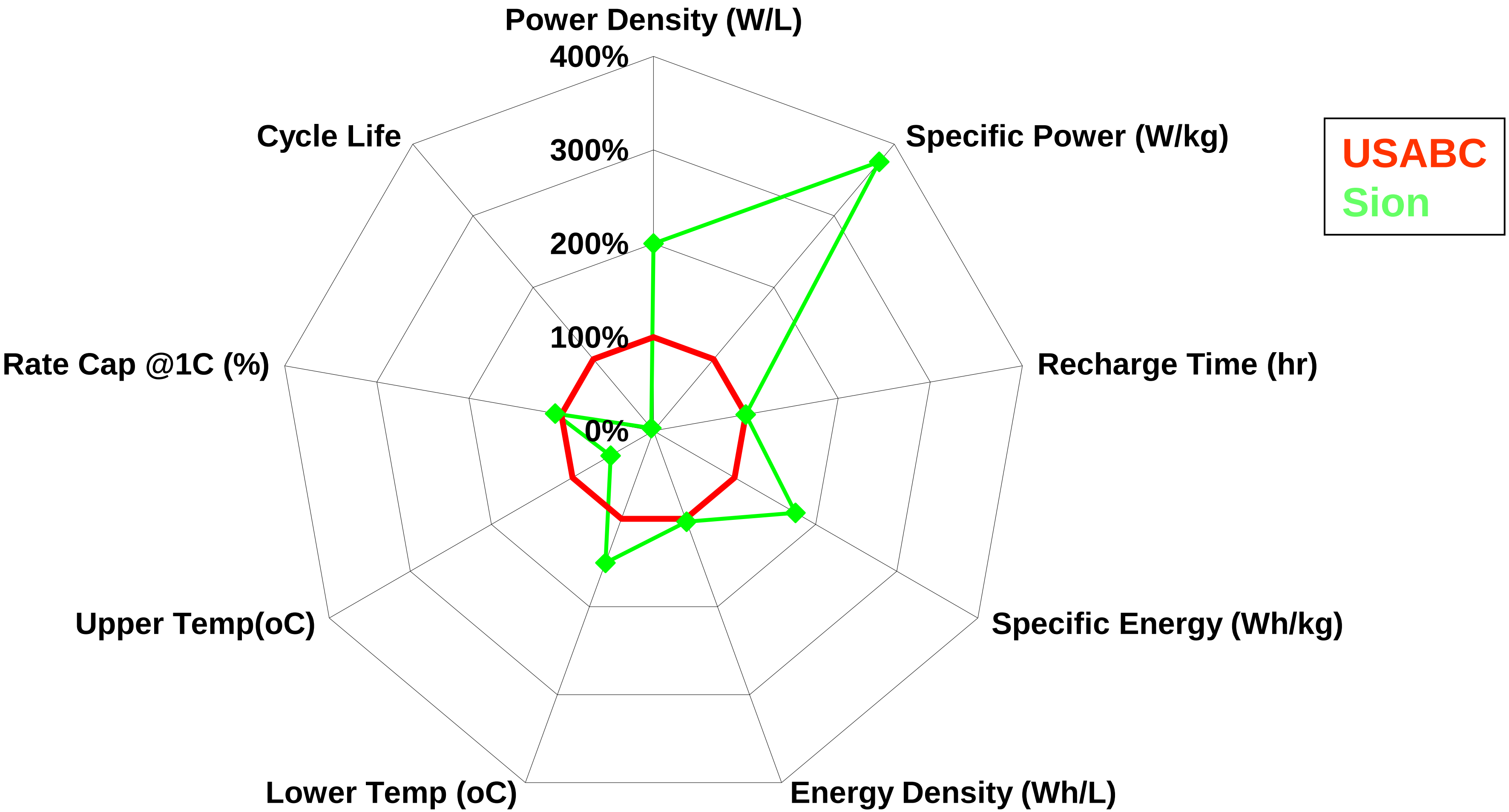
Status of Lithium Sulfur Technology



Limiting Mechanisms: 1) Rough lithium surface during cycling 2) Li/electrolyte depletion.

Addressing the Challenges

Keys to the EV Market for Lithium-Sulfur

- Challenges - cycle life and high temperature stability:
  - Dynamics of lithium surface roughness and cycling.
  - Solvent depletion chemistry.

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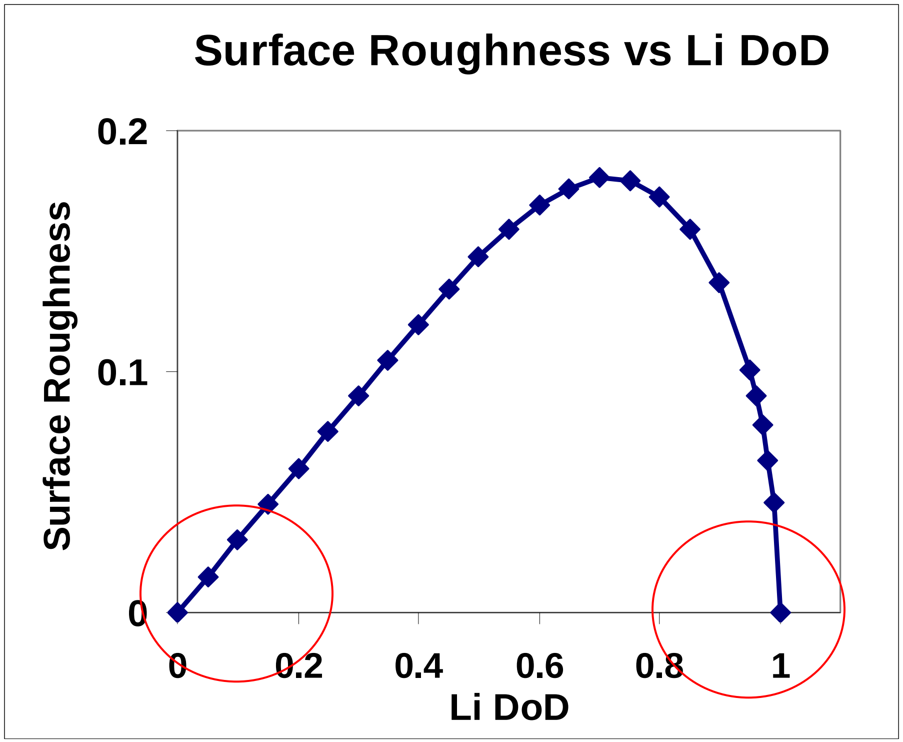
The Dynamics of Lithium Surface Roughness

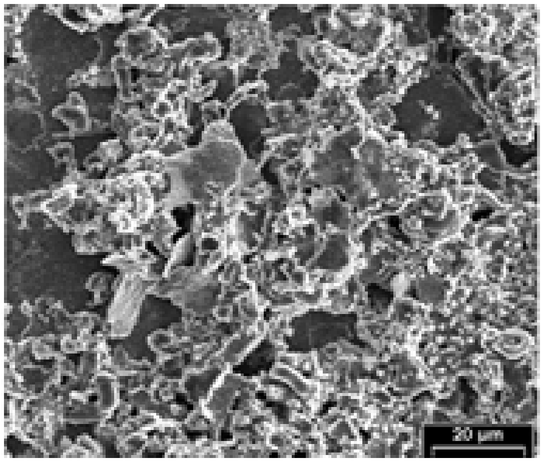
Monte-Carlo Simulation



- Initially, surface roughness increases in direct proportion to Li depth of discharge (DoD).
- Maximal surface roughness can be observed at ~50-70% of Li DoD.
- The typical scenario is cycling at low Li DoD.
- The best scenario is cycling Li anodes at 100% DoD – <u>but only with a current collector</u>.

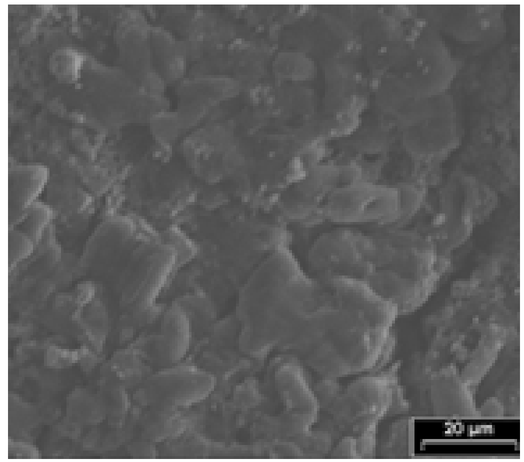
The Dynamics of Lithium Surface Roughness

Experimental Observations



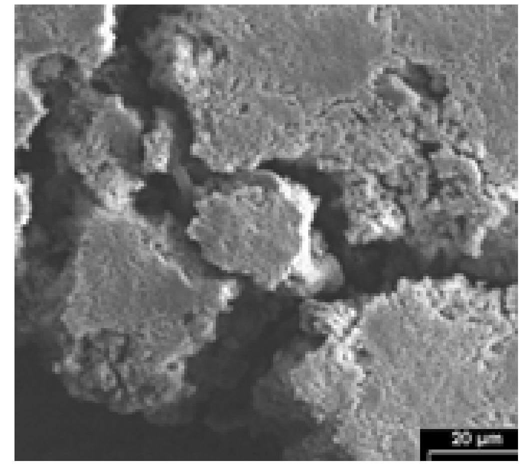
30 cycles

26% Li DoD



330cycles

100% Li DoD



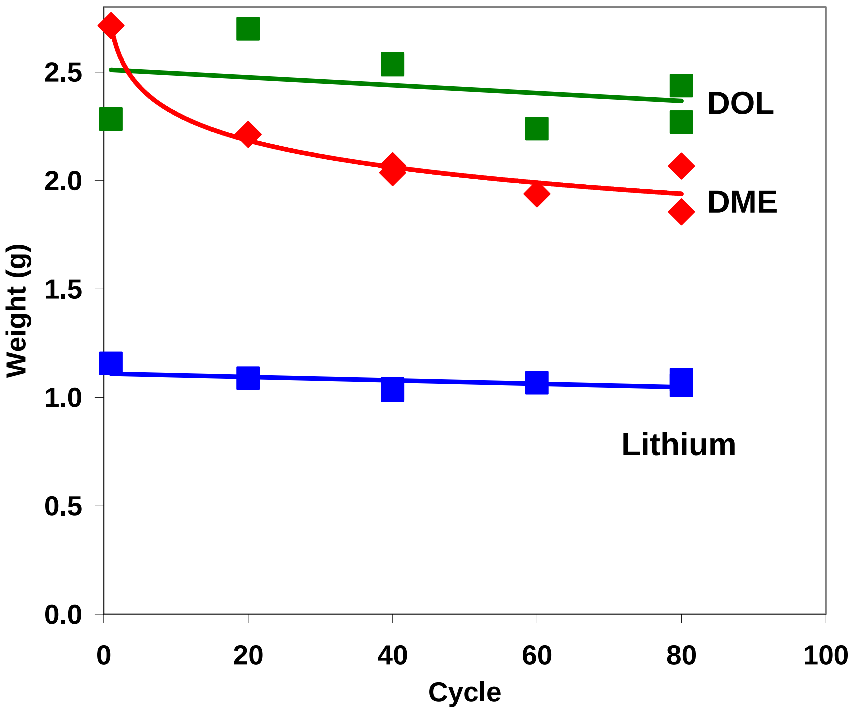
352 cycles

100% Li DoD

Cycling at 100% DOD of lithium prevents surface roughness but lithium/electrolyte depletion still occurs.

The Chemistry of Solvent Depletion
Experimental Observations

Solvent and metallic Li mass vs. Cycle Number (2.5 Ah Li-S battery).

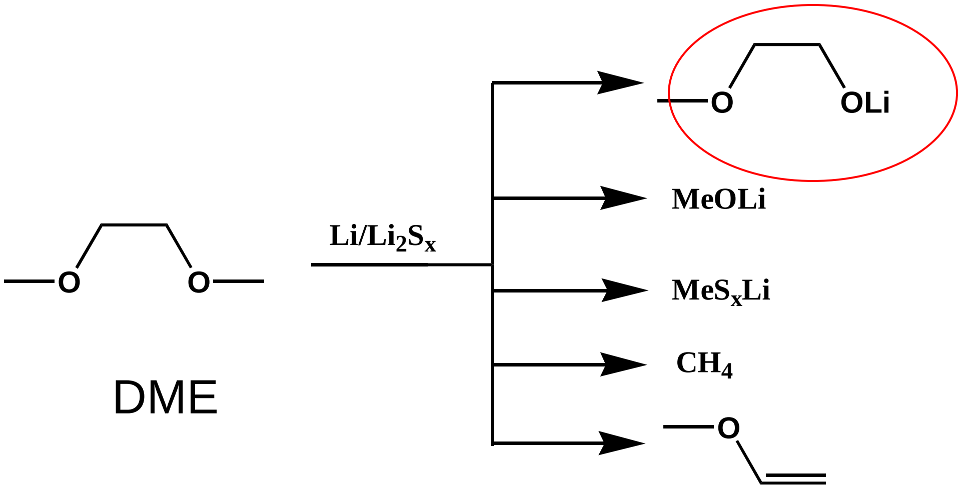


- 1,2-Dimethoxyethane(DME) is mainly responsible for depletion.
- Mass of metallic Li in the cell did not change dramatically.
- However, visually Li looks completely depleted at 60-80 cycles due to roughening and disintegration of Lithium foil.
- The slopes suggests that Lithium and DME may react in a molar ratio of 1:1 to 1:2. Several Lithium alcoholates can form by reaction with DME.

The Chemistry of Solvent Depletion

Products and Effects

Identified depletion products and their impact on battery performance.



High amount, highly soluble and highly detrimental for S cathode performance.

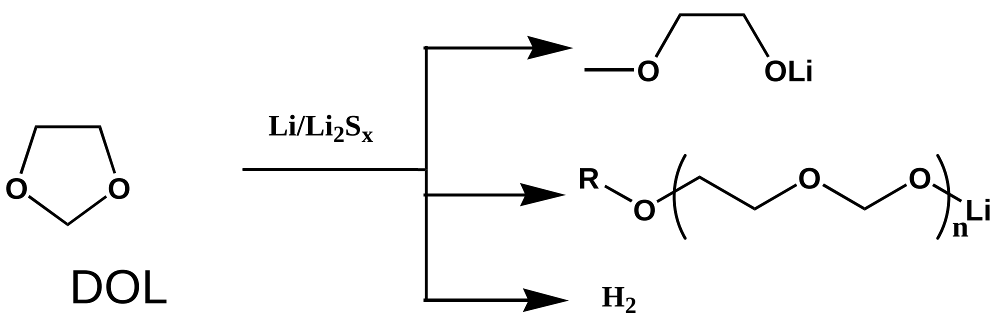
Moderate amount, low solubility, neutral.

Small amount, soluble, consumes S.

Traces.

Traces.

Identified at Sion Power



Highly soluble and highly detrimental for S cathode performance.

Increases anode polarization

Traces

Identified at Sion Power and by D. Aurbach, *J. Electrochem. Soc.*156,8. 2009.

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New Approaches Pursued by Sion in Collaboration with BASF for EV Application

- Reduction of lithium roughness.
  - Proprietary anode design.
- Development of innovative materials
  - Structurally stable cathodes.
- Materials developed by Sion/BASF
  - Physical protection of lithium with multi-functional membrane assemblies.

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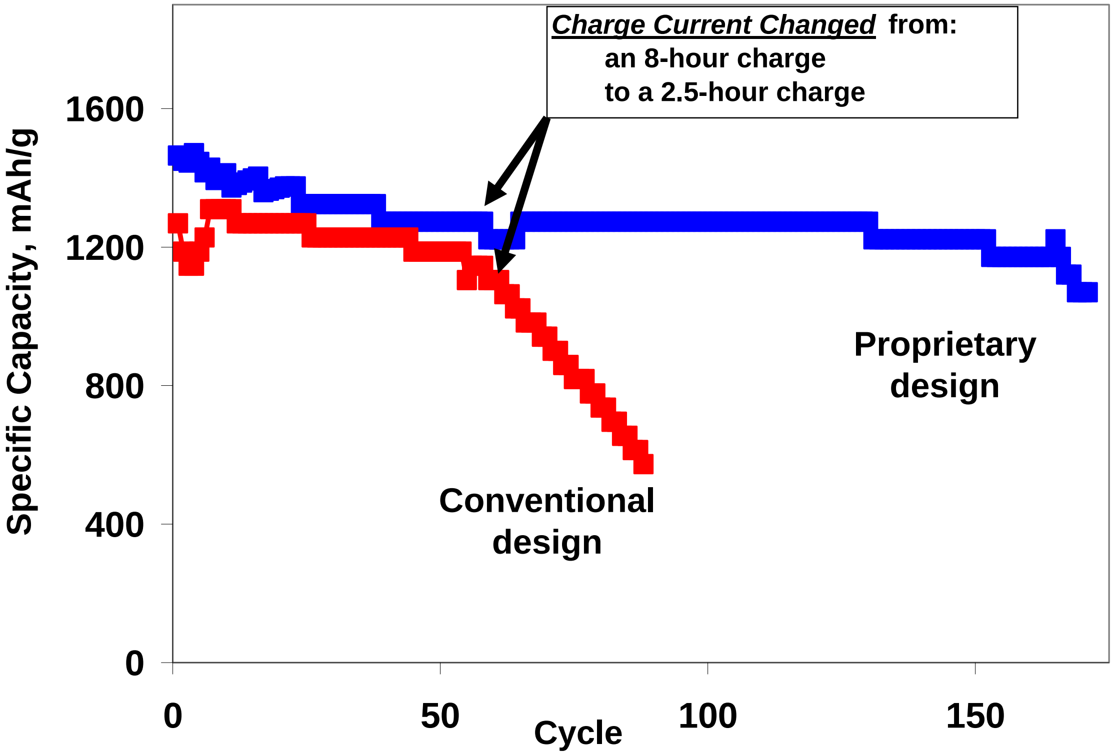
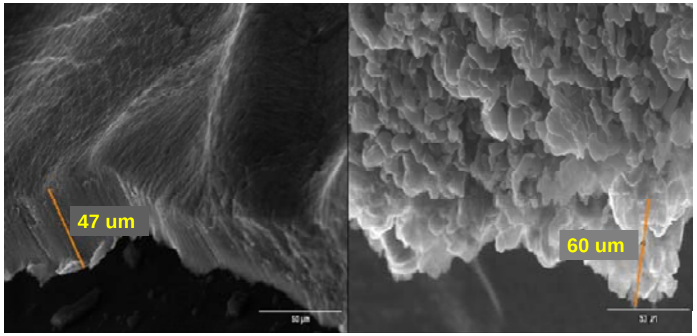
Lithium Roughness Development

Proprietary Anode Design





Proprietary design

Conventional design

Experimental batteries cycling behavior

Proprietary design allowed for increased charging rate without increase in surface roughness.

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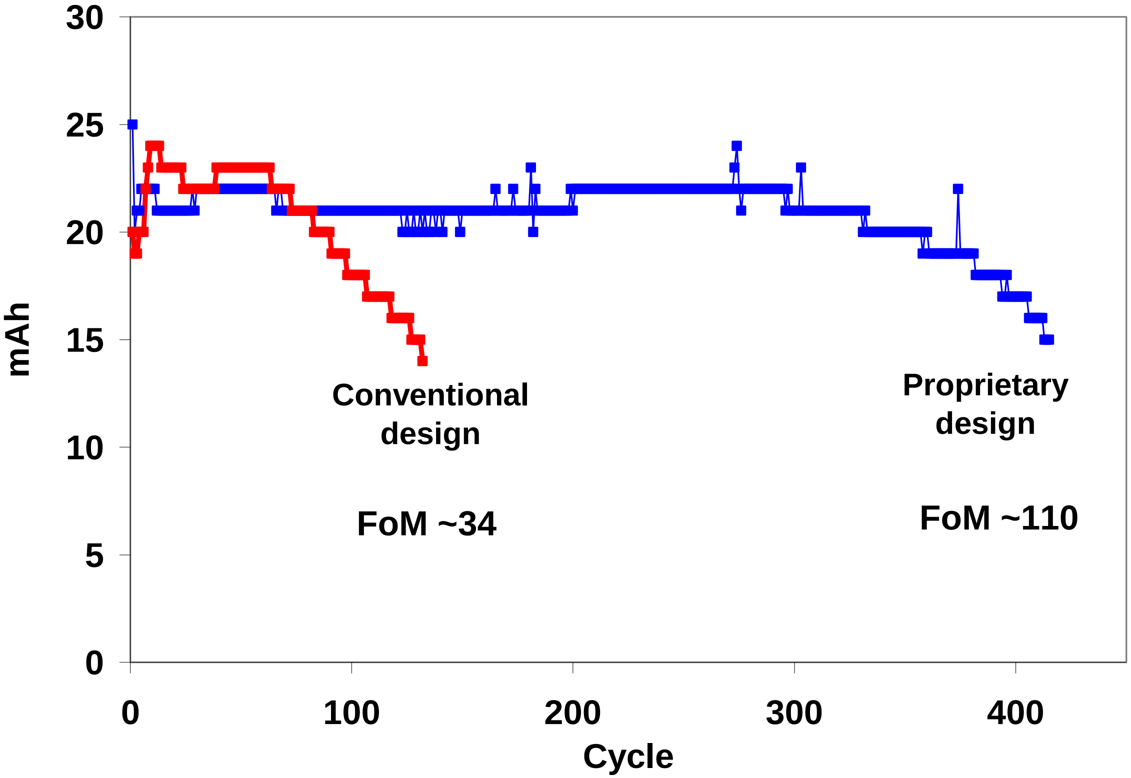
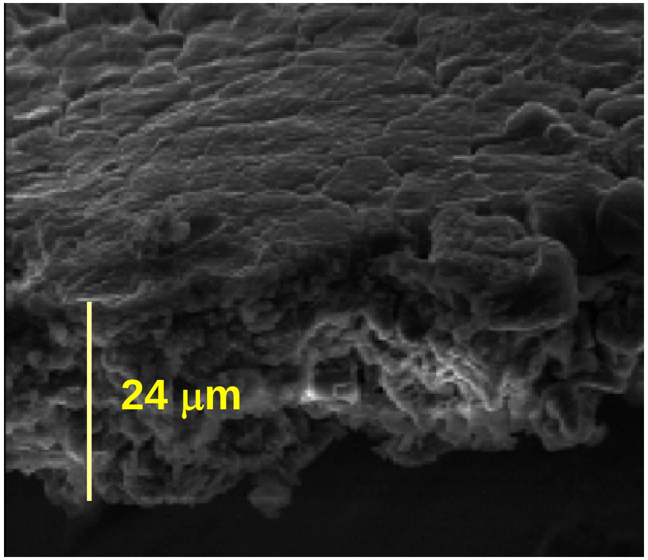
Lithium Roughness Development

Proprietary Anode Design



Experimental batteries cycling behavior



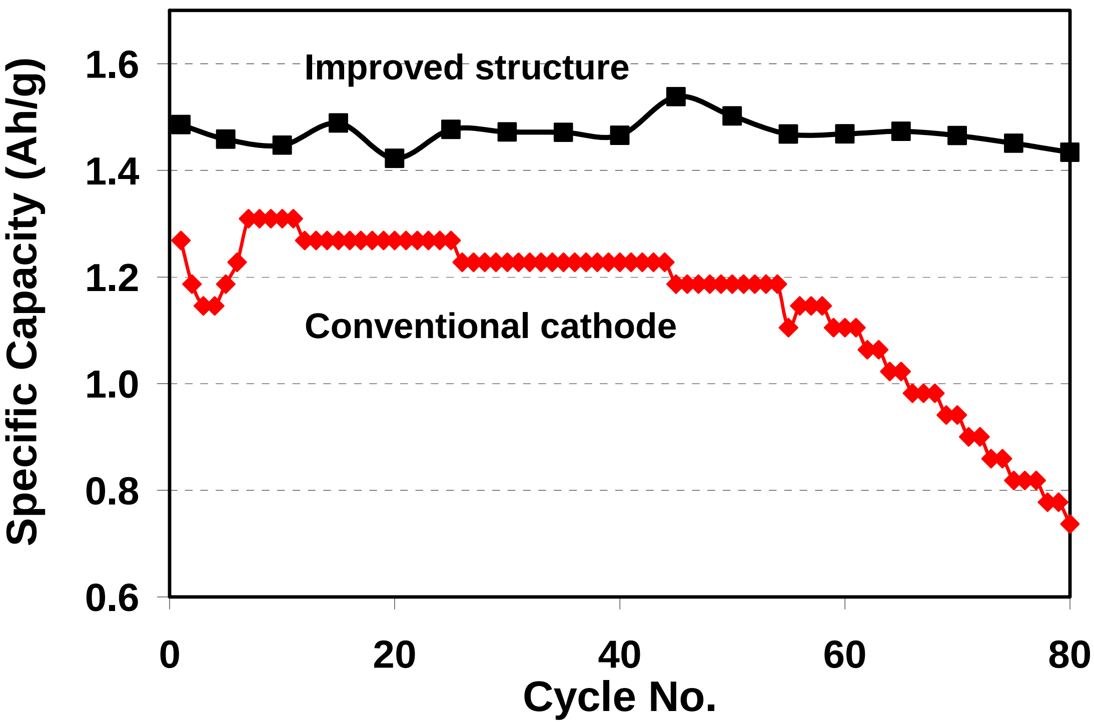
Li anode after 450 cycles. Initial and final Li thickness ~24 µm.

Li Figure of Merit (FoM) exceeds 100 at Li DoD ~26-30%.

FoM = DoD x Number of Cycles.

Development of Innovative Material

Structurally Stable Cathodes



Experimental batteries cycling behavior

- Cathode structure improvement resulted in sulfur utilization increase from 1.2 Ah/g to 1.45 Ah/g.
- This development paves the way to increasing specific energy from the current 350 Wh/kg to the 550 Wh/kg needed to achieve a 500 km EV range

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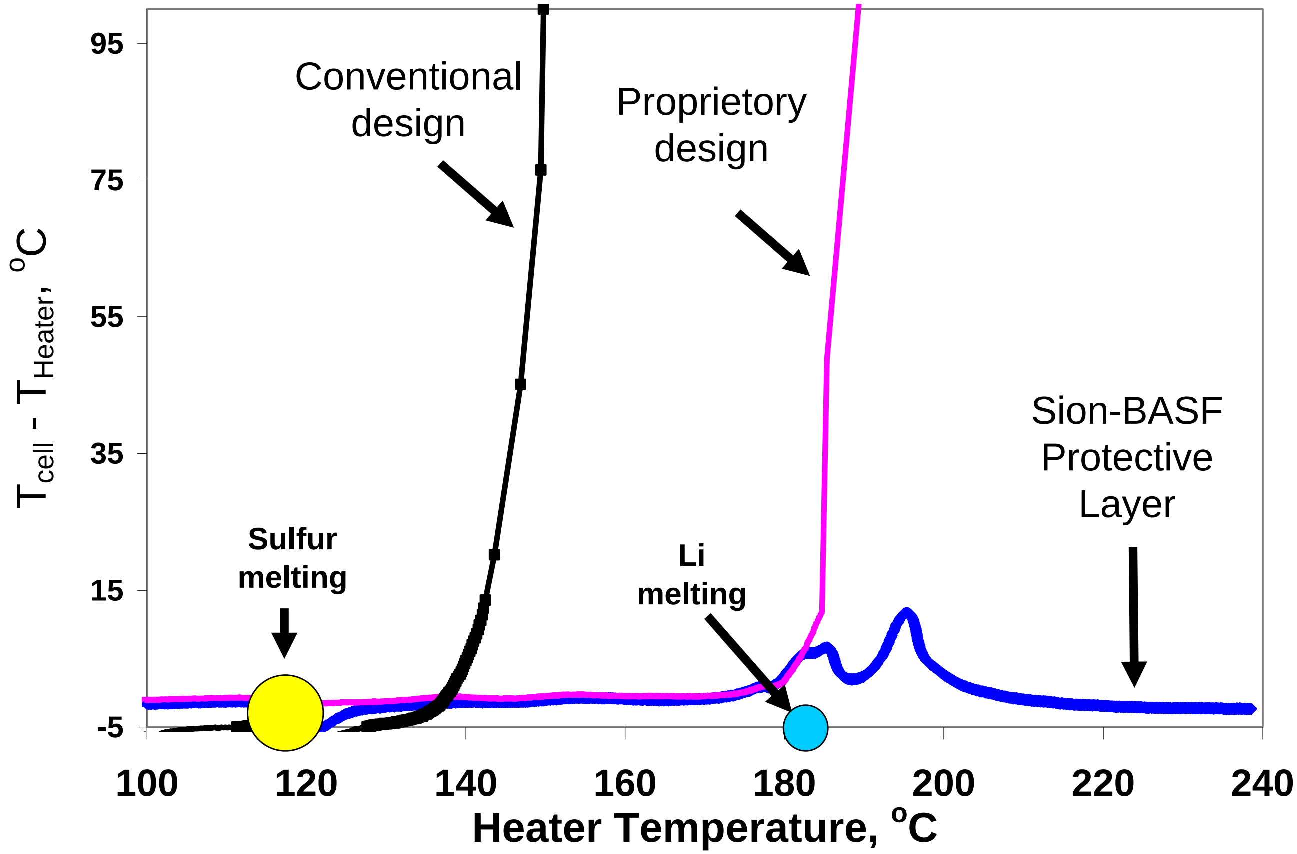
Development of Innovative Material

Multi-functional Membrane Assemblies

Thermal Ramp Test of Fully charged Li-S batteries after 20 cycles at 5 ºC/min.



With Sion-BASF protective layer on anode, there is no thermal runaway.

Conclusions

Reduction of lithium surface roughness with new anode design, and better cathode structure, resulted in:

- Recharge time reduced to less than 3 hours.
- Substantial cycle life increase if lithium surface roughness suppressed.
- Sulfur utilization increased to 87%, or 1.45 Ah/g, paving the way to 550 Wh/kg Li-S battery.

Innovative anode design, and Sion Power-BASF protective membranes, increased thermal stability of Li-S cells – eliminating thermal runaway. Batteries passed the melting point of the Li without violent events.

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Takeaway

Sion Power Corporation, in collaboration with BASF, is very optimistic that the future of all electric EV applications will be dominated by Sion Power's lithium-sulfur technology.


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