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

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Electric Vehicles (EVs), with driving range over 300 miles (500 km), require batteries with specific energy of 500 – 550 Wh/kg and the ability to cycle thousands times. With a theoretical specific energy of 2500 Wh/kg and theoretical energy density of 2600 Wh/l, the lithium-sulfur (Li-S) system is a prime candidate for future EV applications. Sion Power Corporation is working aggressively on realizing the impressive potential of the Li-S system for EV application. The aim of this presentation is to discuss:

1. Current status of Sion Power's Li-S cell technology.
2. Major failure mechanisms limiting cycle life.
3. Various approaches pursued by Sion Power towards improvement of specific energy from 350 Wh/kg to 550 Wh/kg an the cycle life.

SION Power's Li-S battery, with its high energy density (350 Wh/kg, the highest value reported for any rechargeable system), has substantially increased the flight durations of Unmanned Aerial Vehicles (UAV) [1]. With optimized cell designs, specific power over 1500 W/kg at continuous discharge and over 3000 W/kg for 10s high current pulses [2] have been realized. Figure 1 shows that current Li-S cells deliver higher energy and power density when compared to all other types of batteries. The current Li-S cells, however, have limited cycle life of 60-100 cycles.

Unlike Li-Ion cells, where solid intercalated electrodes used, the Li-S system operates with a metallic lithium anode and a soluble polysulfide cathode. Two major mechanisms limiting Li-S cycle life are: development of rough lithium morphology; and Li/electrolyte depletion. The former leads to generation of porous "mossy" Li deposits, absorption of electrolyte by porous deposits and premature Li anode disintegration. The latter leads to loss of the solvent necessary for proper functioning of the cathode. The products of these Li-solvent reactions also increase cell impedance and the rate of capacity fade.

Two approaches Sion Power is exploring to prevent depletion of lithium and electrolyte are: creating protective layers on the Li surface *in situ* by using reactive additives (chemical protection); and construction of multi-layer anode assemblies incorporating a variety of Li-protective layers (physical protection). Although the reactive additives do reduce the Li-solvent reaction rate, its potential to improve the cycle life is limited due to the slow depletion of the additives themselves. So, using chemical protection alone to improve cycle life requires the cell to carry extra mass of electrolyte components (up to 40% of cell weight) to compensate for their depletion. On the other hand, the physical protection approach – where the lithium is protected within the multi-functional membrane assembly, adding about 1 μm thickness, does not require the prohibitive extra mass of electrolyte components. These physically deposited membrane assemblies have substantially increased the thermal stability of the Li-S cell. The only obstacle preventing stable function of the membrane is its mechanical disintegration caused by the stress resulting from the roughening of the lithium underneath.

Recently Sion Power has found a novel approach to overcome this obstacle. This new approach has contributed to substantial reduction in the roughening of Li surface during cycling (Figure 2). The effectiveness of this new approach is demonstrated by the fact that the Li anode remained compact even after cycling with high charge rates ~ 1C and high surface charge capacity of 2.5 mAh/cm^2. The thickness of the lithium that was stripped and plated during this cycling was ~ 12 μm.

The new approach also substantially increased the sulfur utilization to more than 1.45 Ah/g of specific capacity (Figure 3). This improved specific capacity and reduced cell mass (resulting from the utilization of thin membrane protection) and, with improved cell design, we believe the energy density of the Li-S cell can be increased from the present value of 350 Wh/kg to 550 Wh/kg.

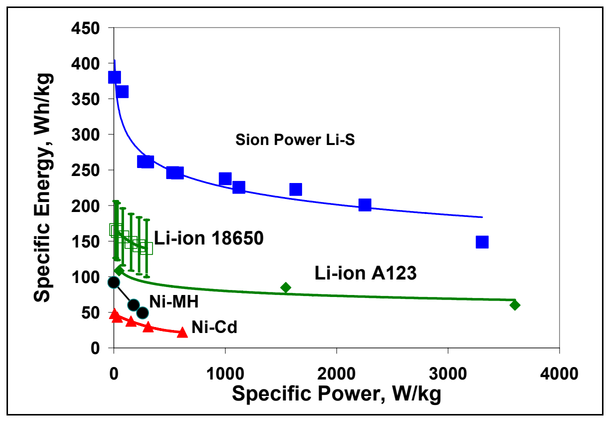
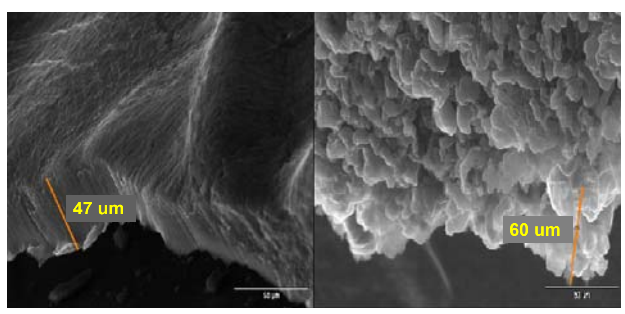


Figure 1. Ragone plots for rechargeable systems



A B

Figure 2. Lithium morphology after 50 cycles with new (A) and conventional cycling (B).

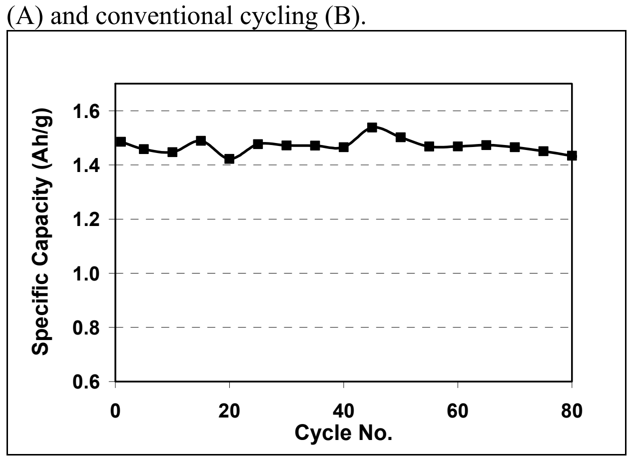


Figure 3. S specific capacity vs Cycle# in the cell with improved Li morphology.

References
1. http://news.bbc.co.uk/2/hi/science/nature/7577493.stm
2. *ECS Transactions* v 13, #19, p.53-59 (2009)
3. US Patent No. 7,354,680