

Design considerations for Practical Li-S Batteries for Electric Aviation



Donald A. Dornbusch*, Vadim F. Lvovich*, Rocco P. Viggiano*, Frederick W. Dynys*, Yi Lin§, and John W. Connell †

*NASA Glenn Research Center;
§National Institute of Aerospace;
†NASA Langley Research Center

Introduction

The 2018 Strategic Implementation Plan sets forth the NASA Aeronautics Research Mission Directorate (ARMD) vision for aeronautical research aimed at the next 25 years and beyond. It encompasses a broad range of technologies to meet future needs of the aviation community. Two key areas of focus are the transition to ultra-efficient subsonic transports as well as the transition to safe, quiet and affordable vertical lift air vehicles. In support of these technology areas, NASA has been researching hybrid-electric as well as fully electric aircraft designs.



Both designs necessitate the development of higher energy density battery systems, while higher energy density batteries pose a greater safety risk. Next generation chemistries such as lithium-sulfur batteries have been proposed as a potential enabling technology owing to its high theoretical energy density.

However, there are immense technical challenges facing their development, including the development of high utilization cathodes and thin electrolyte layers, and prevention of soluble intermediates. Through appropriate material choices, thin and scalable composites can be manufactured utilizing traditional manufacturing techniques to produce components with practical weights to achieve high specific energy batteries.

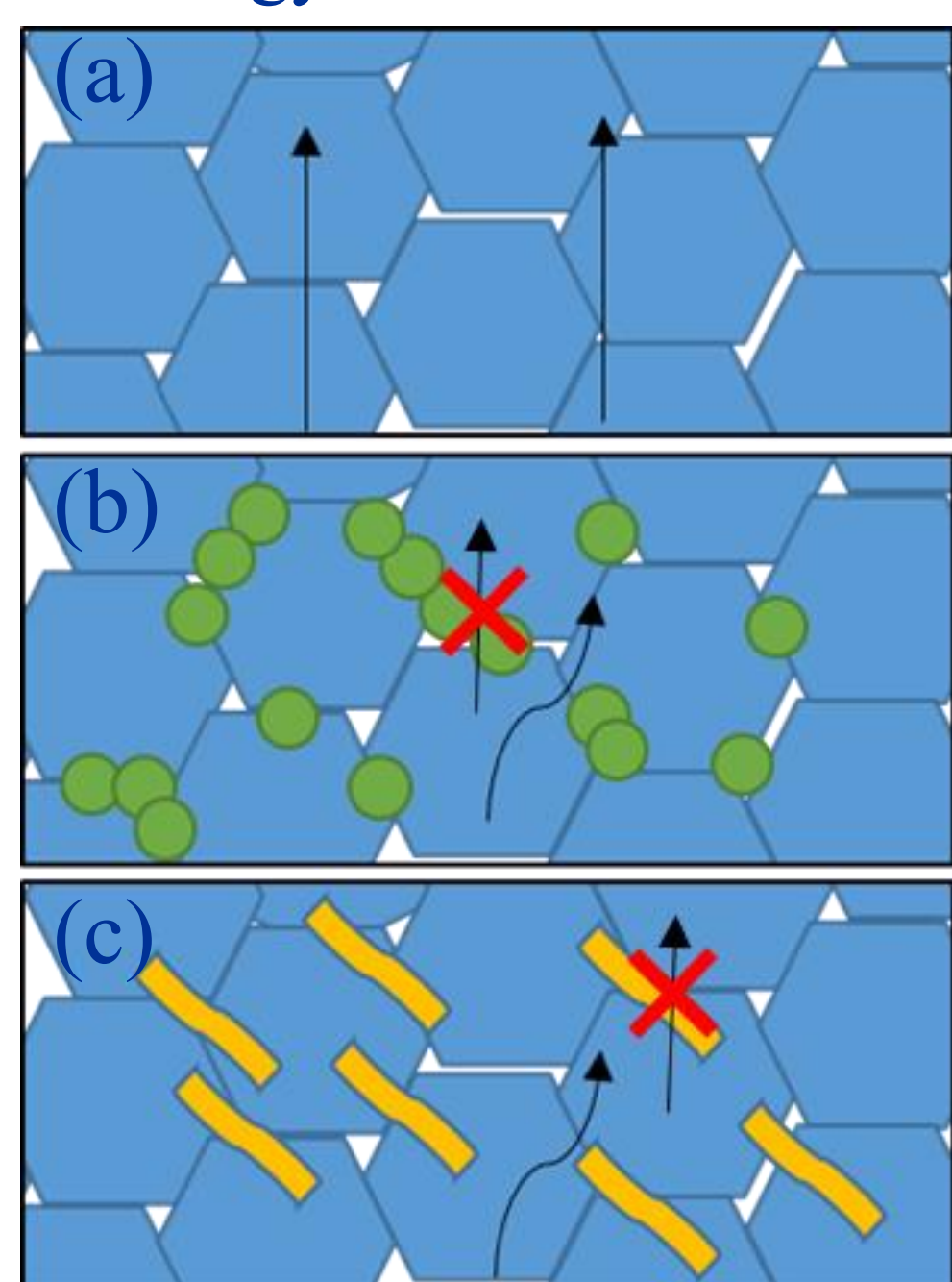


Figure 1: Depiction of Li transport through densified solid-state electrolyte for pure (a), composite with PTFE powder binder (b), and composite with solution deposited Styrene-Butadiene-Styrene (SEBS) rubber binder (c).

Motivation

Solid-state electrolytes (SSE) show promising properties such as low flammability and wide temperature range making them ideal for applications requiring a high degree of safety and temperature tolerance. Additionally, SSE prevent dissolution of sulfide intermediates and may be an enabling technology for lithium-sulfur chemistry. To compete with current lithium-ion technology, the solid-state lithium-sulfur battery must be manufactured with optimal dimensions that maximize active material loading and minimize inactive cell components such as the SSE separating layer. Thin sulfide-polymer composite SSE layers contribute minimal parasitic mass and can be produced through a scalable tape-casting process to achieve $\sim 35 \mu\text{m}$ thin films maintaining 0.2 mS/cm conductivity.

Results

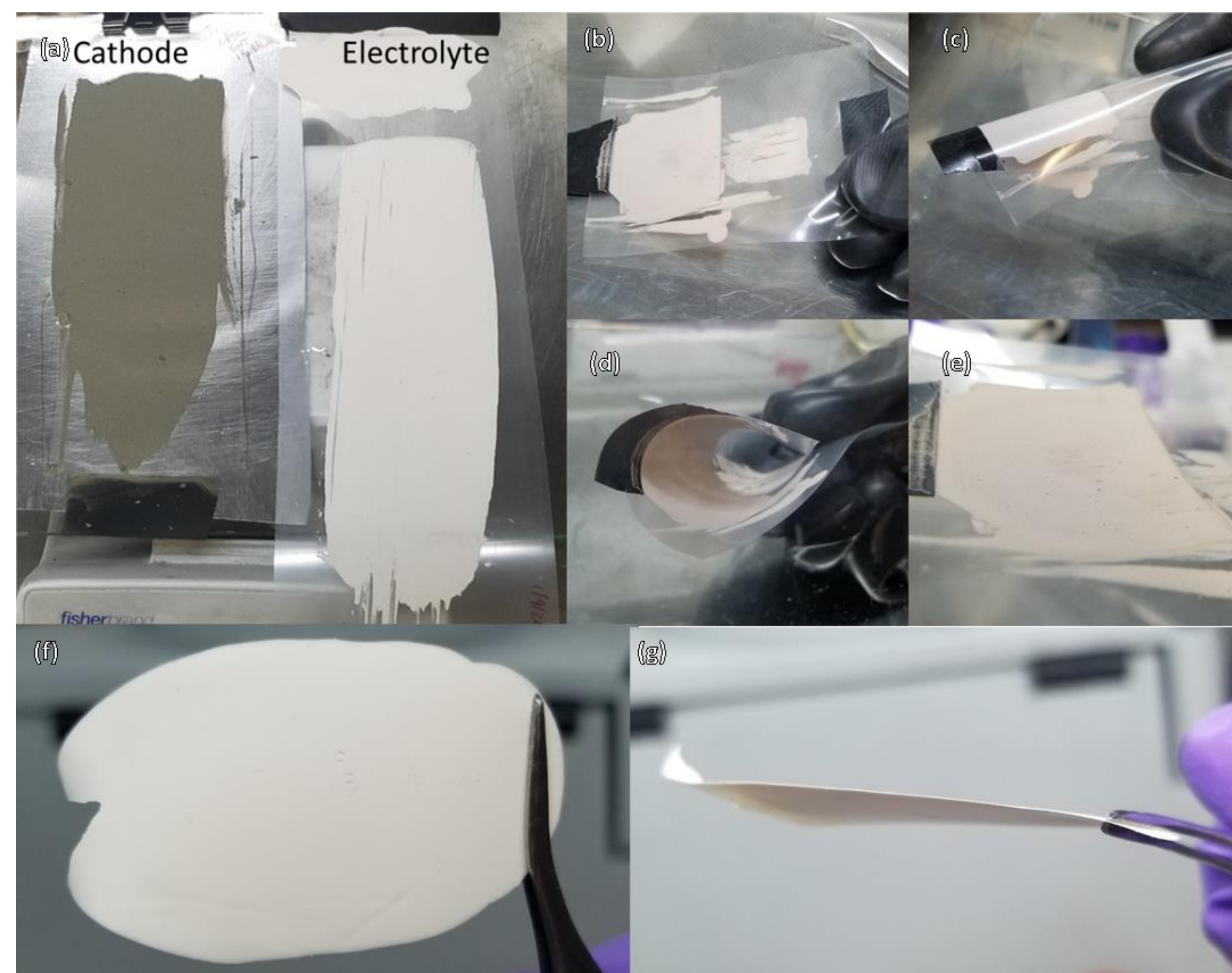


Figure 2: Tape-cast 7.5cm wide composite cathode and electrolyte films on aluminum and PET substrates, respectively (a) and the flexibility of adhered films on PET substrate before (b), during rolling (c)(d), and after release (e). Freestanding SSE-polymer composite films obtained from casting on a PTFE substrate followed by delamination (f) and (g).

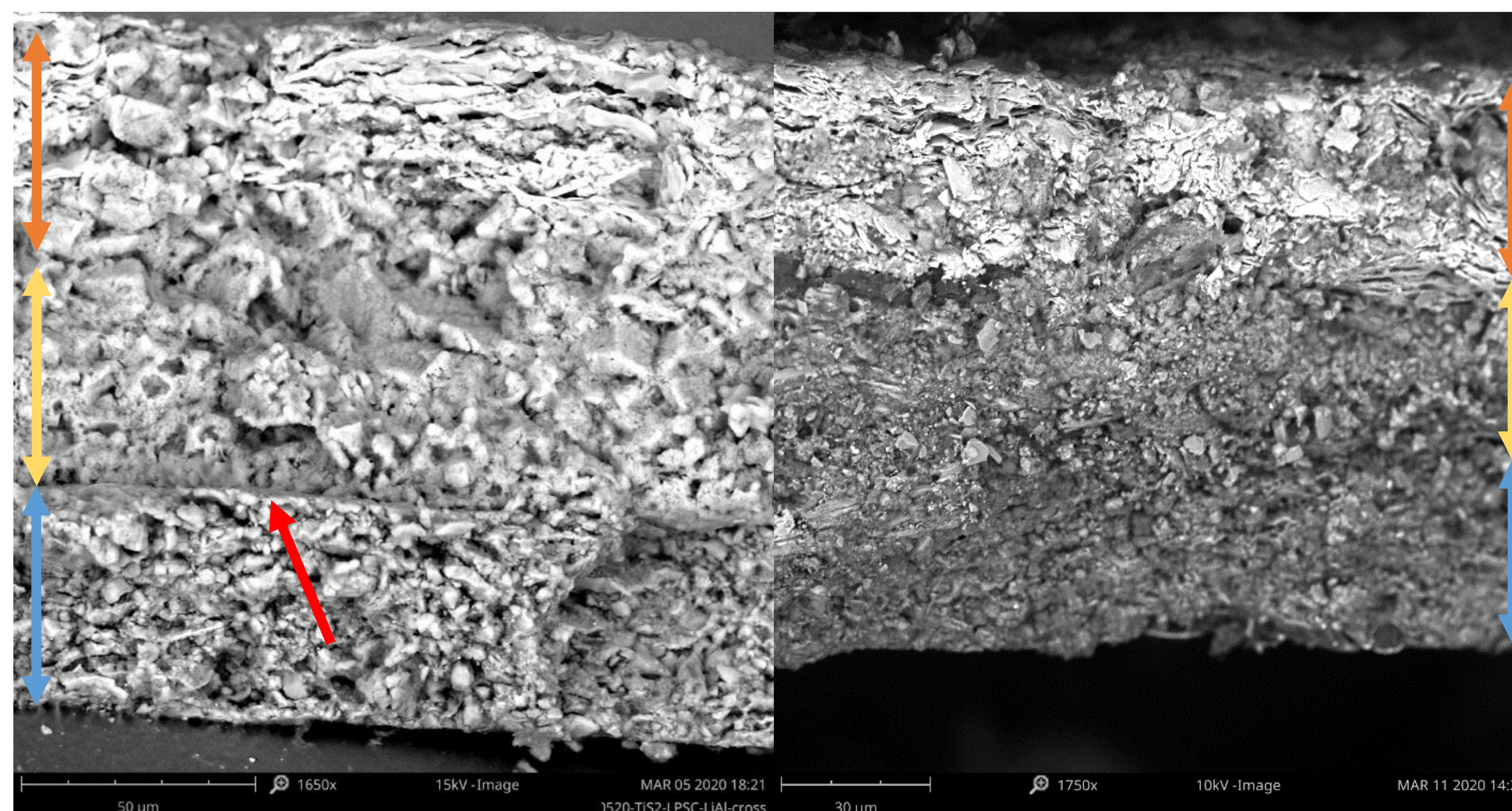
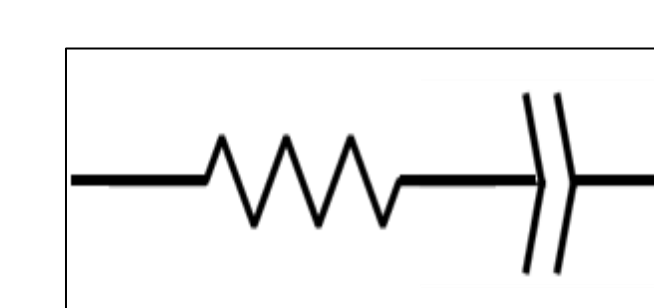
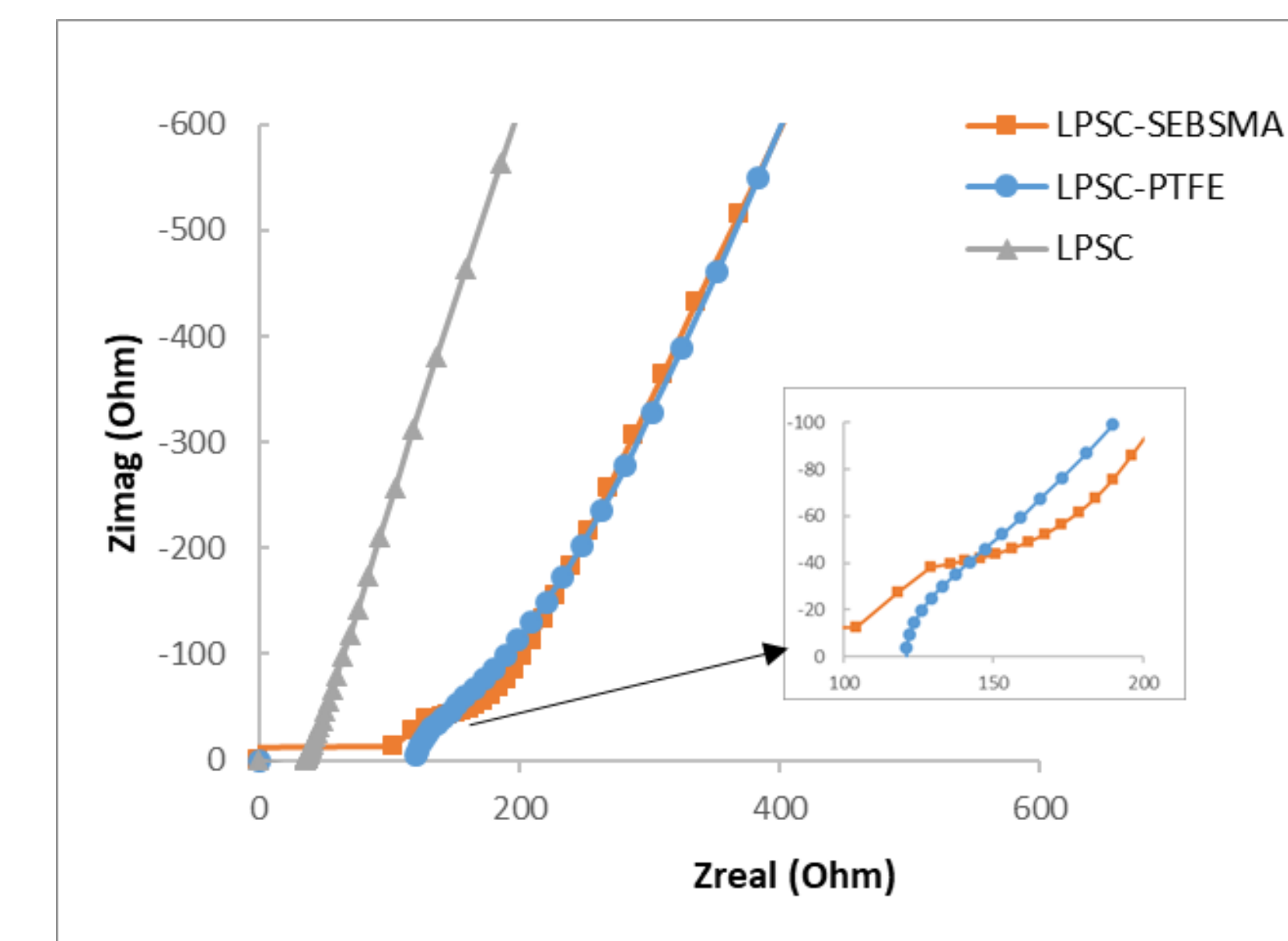


Figure 3: Full stack assembly showing LiAl-Li₆PS₅Cl composite anode (blue, lower) Li₆PS₅Cl-SEBS composite (yellow, middle) and TiS₂-Li₆PS₅Cl-SEBS composite cathode (orange, top). The red arrow indicates poor adhesion between two layers which disappears after improvement in processing conditions. Powder lithium-aluminum alloy (LiAl) was used as anode due to its ease of processing in a tape-cast composite compared to lithium metal.

Results



| Electrolyte | Resistance (Ohm) | Conductivity (S/cm) |
|-------------|------------------|---------------------|
| LPSC | 35 | 1.36E-03 |
| LPSC-PTFE | 159 | 2.99E-04 |
| LPSC-SEBS | 168 | 2.83E-04 |

Figure 4: Electrochemical Impedance Spectroscopy for pure and binder containing SSE with stainless steel blocking electrodes. The conductivity retention is $\sim 20\%$ of the pure sample due to incorporation of a binder phase that can block transport channels. The corresponding equivalent circuit used to calculate the conductivities (bottom left).

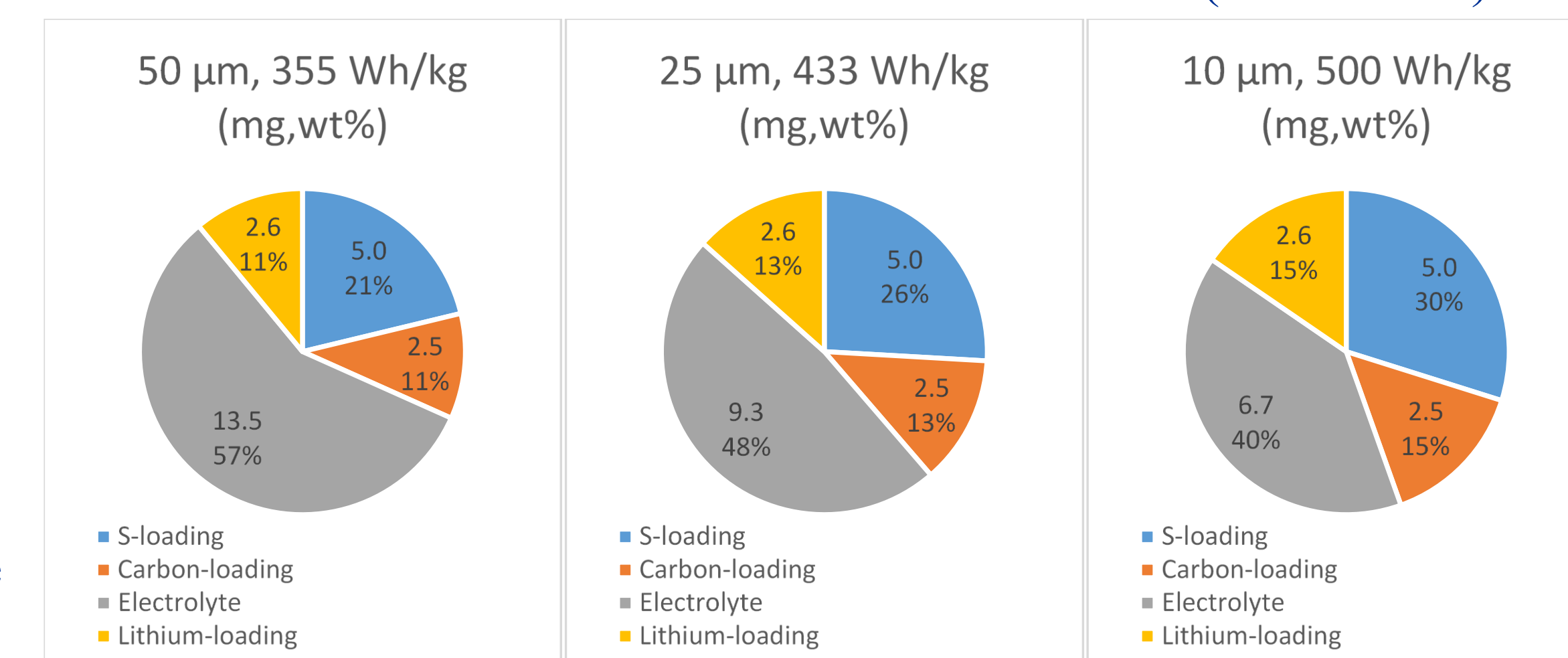


Figure 5: Prediction of specific energy for an idealized cell utilizing tape-cast LPSC SSE composites for 50, 25, and 10 micron separating layer. Assuming a cathode with S:SSE:C ratio of 2:2:1 and 20% excess lithium anode. The electrolyte contributes significant parasitic mass to the cell weights even down to 10 μm .

Conclusions

- Lithium conducting Li₆PS₅Cl composite electrolytes could be manufactured with thicknesses between 25-50 μm through a scalable process.
- Achieved thicknesses were in the practical range to make the chemistry competitive with current lithium-ion cells.
- Binder impacted conductivity, but 20% was retained. Significant reduction in thickness will lead to overall improvements in energy and power capability.

Next Steps

- Optimization of cathode microstructure to achieve a high active material utilization.
- Validate this approach will enable high energy and high power batteries with improved safety over traditional electrolytes.