



Next Generation Batteries for Electric Aviation and Space

Donald A. Dornbusch¹, Yi Lin², William Huddleston³, Vesselin Yamakov⁴, Rocco P. Viggiano¹

¹ - NASA Glenn Research Center, Cleveland, OH 44135, USA

² - NASA Langley Research Center, Hampton, VA 23681, USA

³ - HX5, LLC, Cleveland, OH 44315, USA

⁴ - Analytical Mechanics Associates Inc, Hampton, VA 23666

Three futuristic aircraft designs are shown against a blue sky with white clouds. The top aircraft is a white jet with blue and red accents and NASA logos. The bottom-left aircraft is a white jet with blue accents and NASA logos. The bottom-right aircraft is a white, sleek, delta-wing aircraft with two engines and a NASA logo.

49th International Conference and Expo on Advanced Ceramics and Composites (ICACC2025)

Presenter:

Dr. Donald A. Dornbusch-NASA GRC

donald.dornbusch@nasa.gov

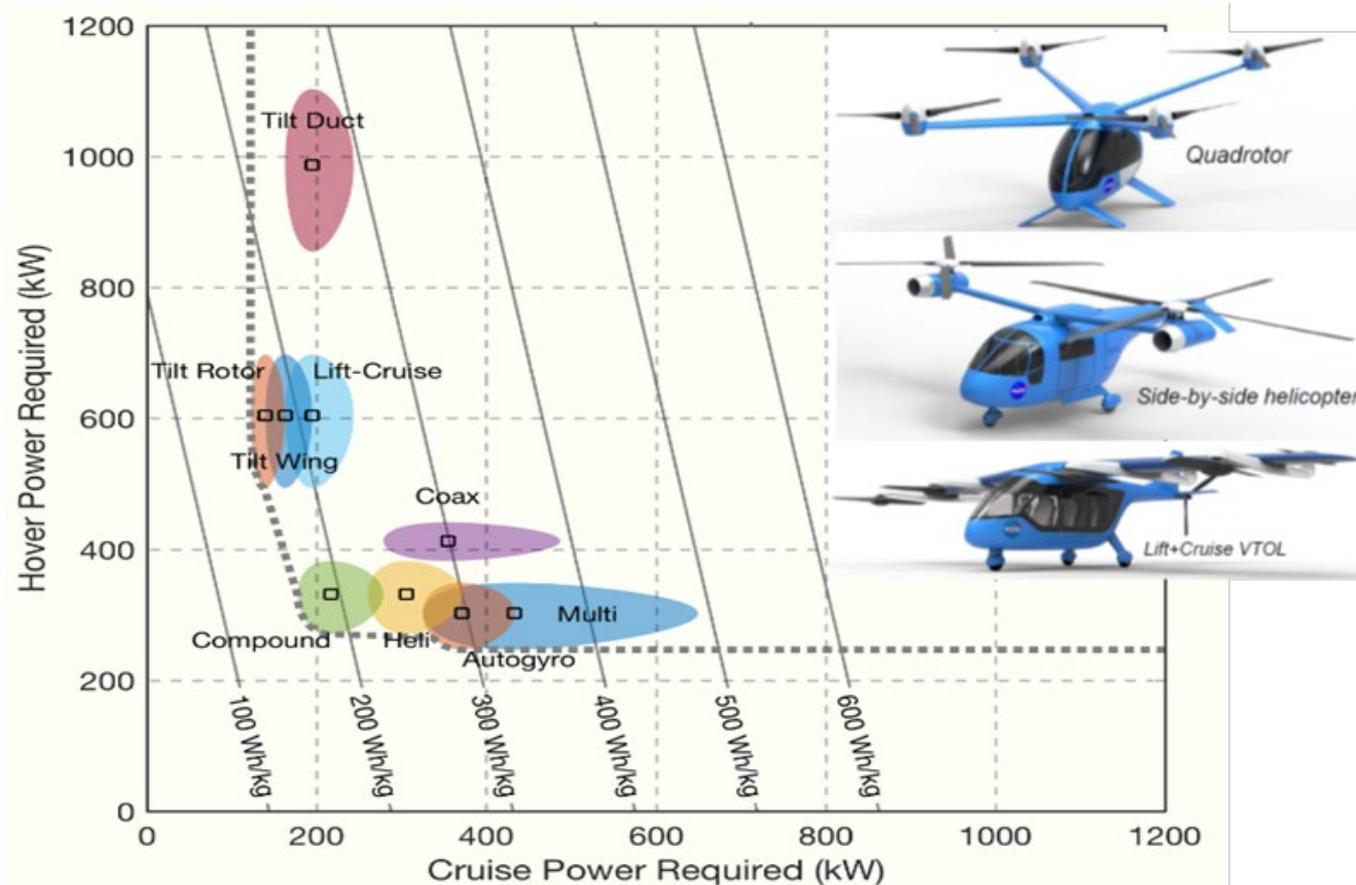


Introduction – Electrified Aviation



- Electric and hybrid electric aircraft systems can lead to higher efficiencies, safer designs, and quieter operation
- Current battery technology is insufficient to achieve the requirements for electric aviation:
 - Energy, Power, and Safety
- Increasing energy density of batteries packs more energy within a fixed space leading to greater risk

Aircraft Requirements



- Aircraft design significantly impacts power & energy requirements



Solid-State Electrolytes

Advantages:

- Solid-state electrolytes = low volatility
- Wide temperature tolerance

Disadvantages:

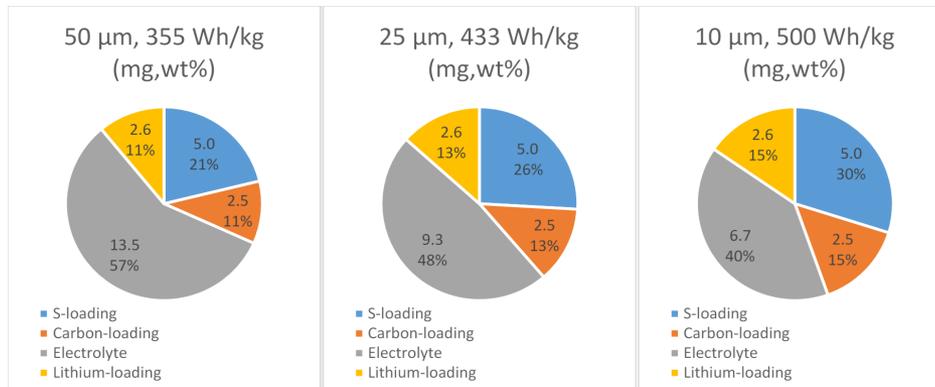
- Difficult to manufacture
- Interface issues
 - Solid-Solid contact vs Liquid-solid
- High density vs liquid (g/cm³)



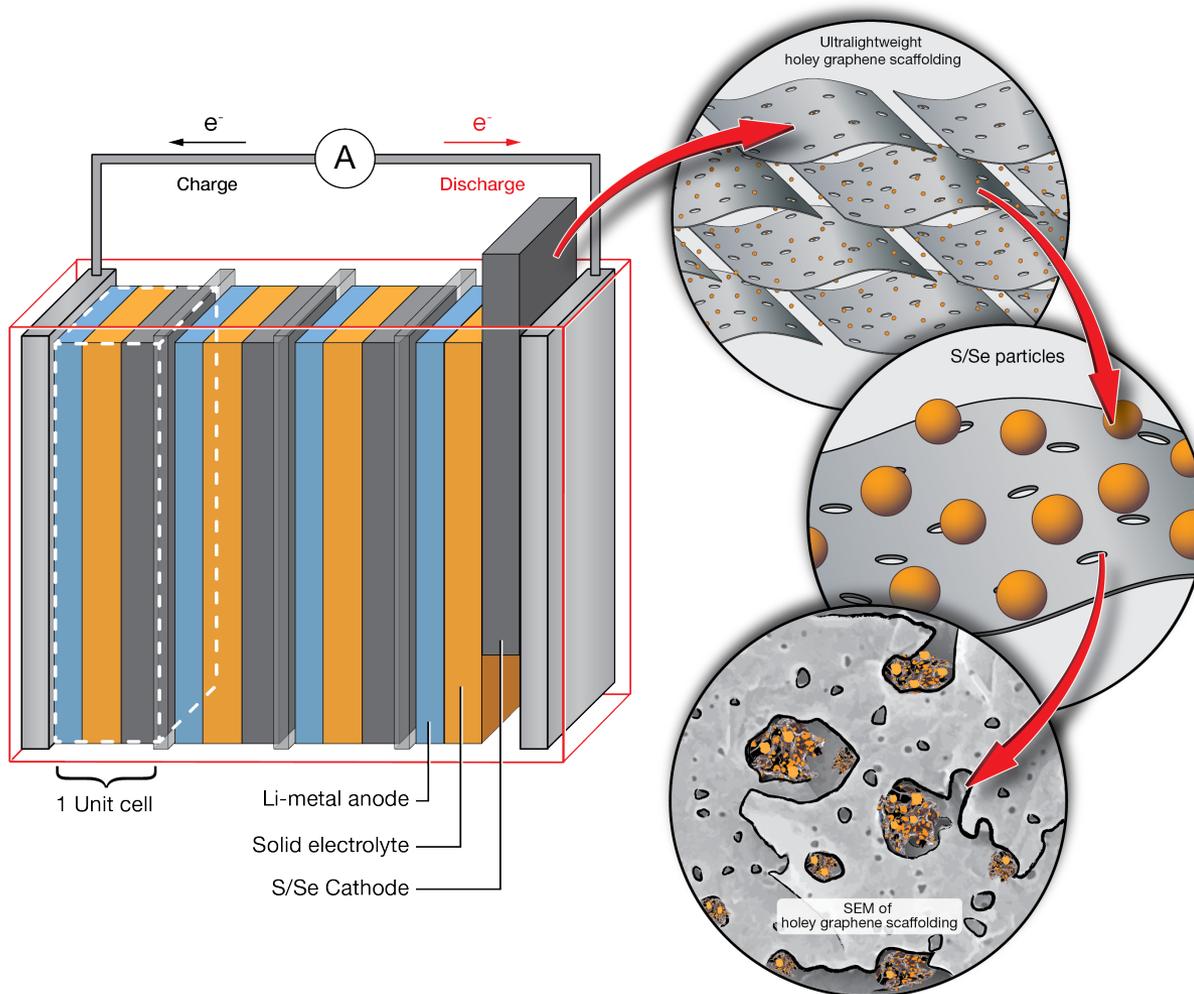
Material Selection

- **Solid-Electrolyte (density)** 25 μm separator:
 - Polymer ($\sim 1.2\text{g/mL}$) \rightarrow 3 mg/cm^2
 - Sulfide ($\sim 1.7\text{g/mL}$) \rightarrow 4.25 mg/cm^2
 - Oxide ($\sim 5.6\text{g/mL}$) \rightarrow 14 mg/cm^2

Oxides, such as LLZO, must be x3.3 times thinner than corresponding sulfide to achieve same weight penalty
- **Lithium-Sulfur**
 - Lithium metal is an ideal anode material
 - Lightweight (3860mAh/g), low potential, metallic
 - Sulfur has high capacity (1675mAh/g)
 - Reasonable potential above lithium ($\sim 2\text{V}$)
 - Dissolution prevented in a solid-electrolyte
- **Impact of Solid-Electrolyte (Sulfide):**
 - Substantial gains in energy projected by reducing separating layer thickness

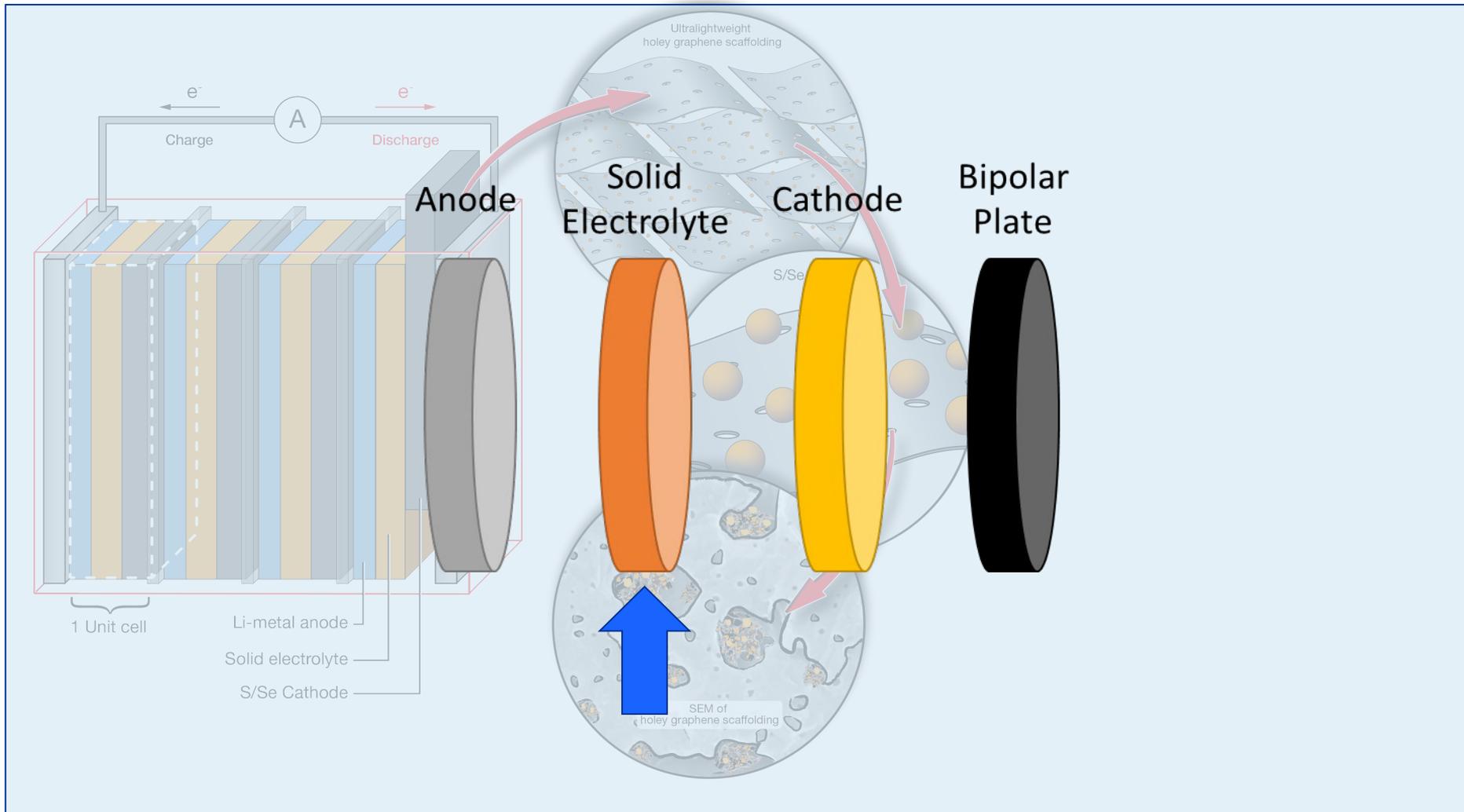


Cell Design



- Multilayered system
- Anode: Lithium Metal
- Separator: Solid Electrolyte-Polymer composite
- Cathode: Sulfur-Carbon-Electrolyte Composite

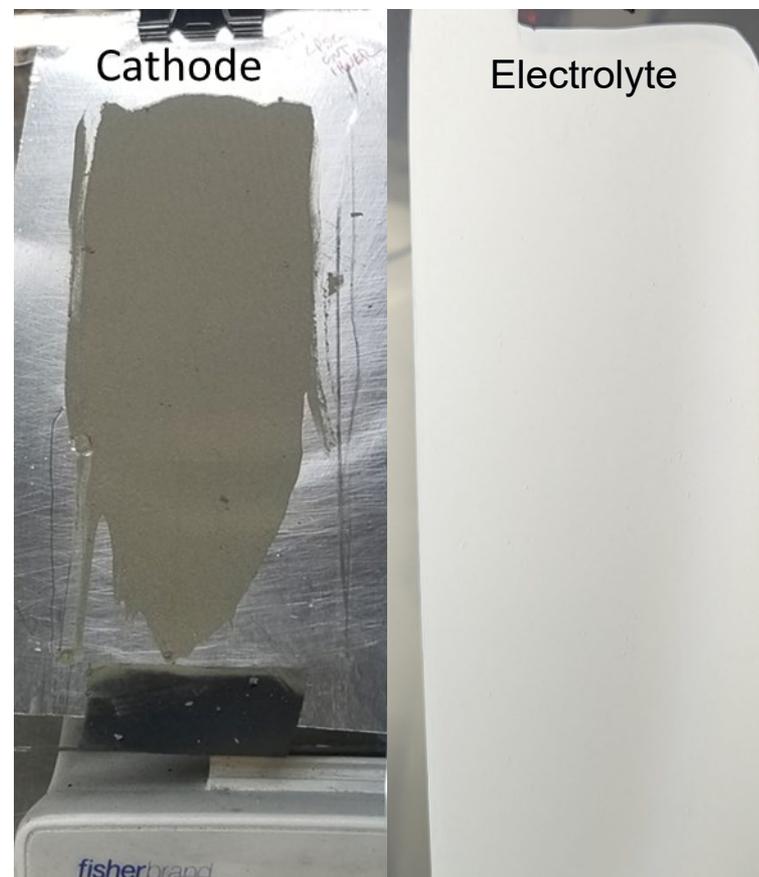
Cell Design



Manufacturing Thin Electrolytes

Sulfide ($\text{Li}_6\text{PS}_5\text{Cl}$)-Polymer Composites

- Tape-casting produces thin electrolytes
- Traditional lithium-ion manufacturing technique
- Utilizing inert binder (3-5wt%) to achieve well adhered films
- Capable of producing multi-phase cathodes
 - (Active-Carbon-Electrolyte-Binder)





Improved mechanical properties

Pure LPSC (~200 μm)

Mylar Supported

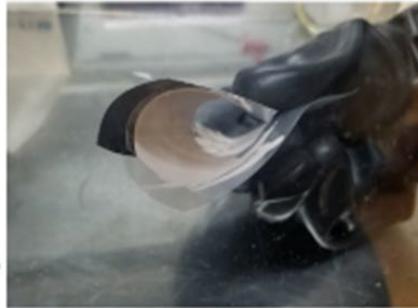
Free-standing

Flexibility test: ~2"x2" tape-cast electrolytes

Dried SSE film



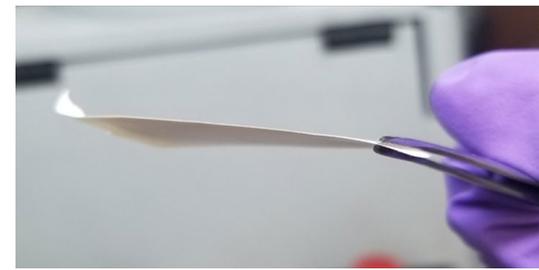
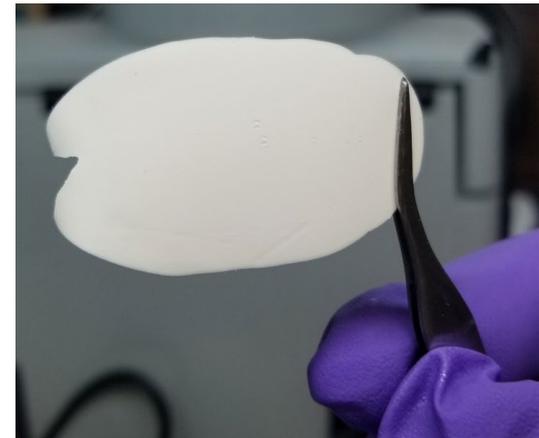
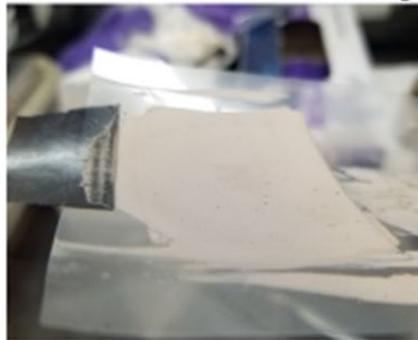
Folded SSE film – Side View



Folded SSE film – Top View



Unfolded SSE film – No visible damage

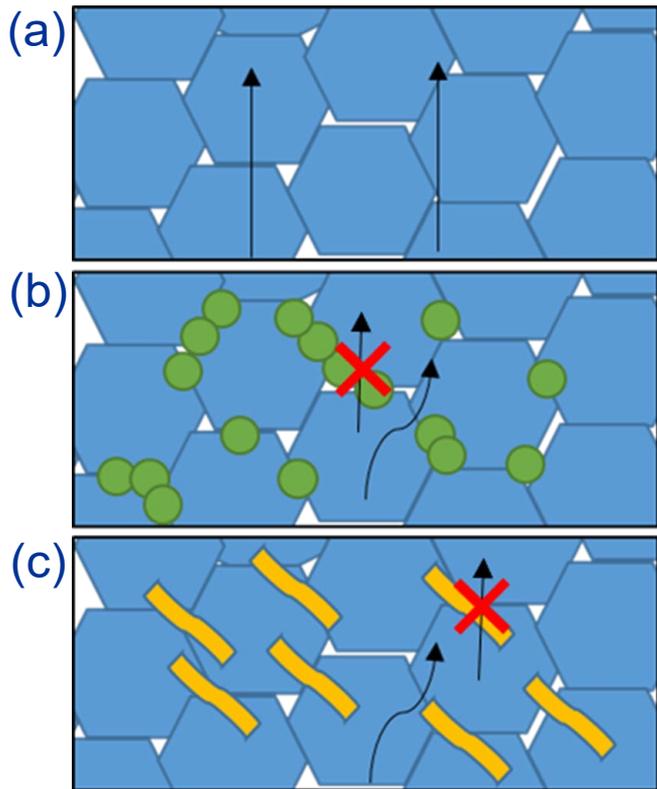


Bent or rolled over

Shape rebounds undamaged

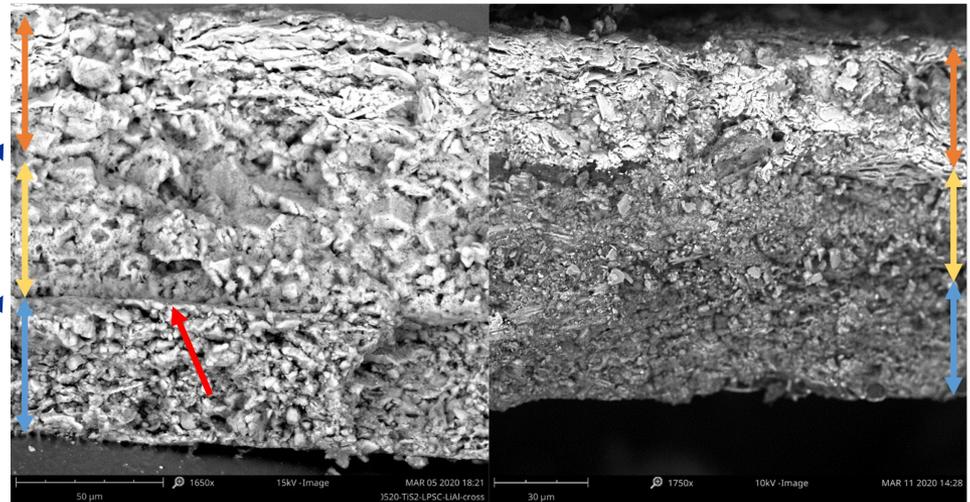
Substantially improved flexibility over pure glass electrolytes

Glass-Polymer Composite Electrolytes



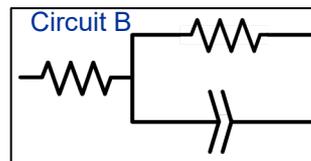
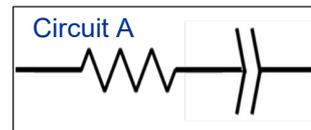
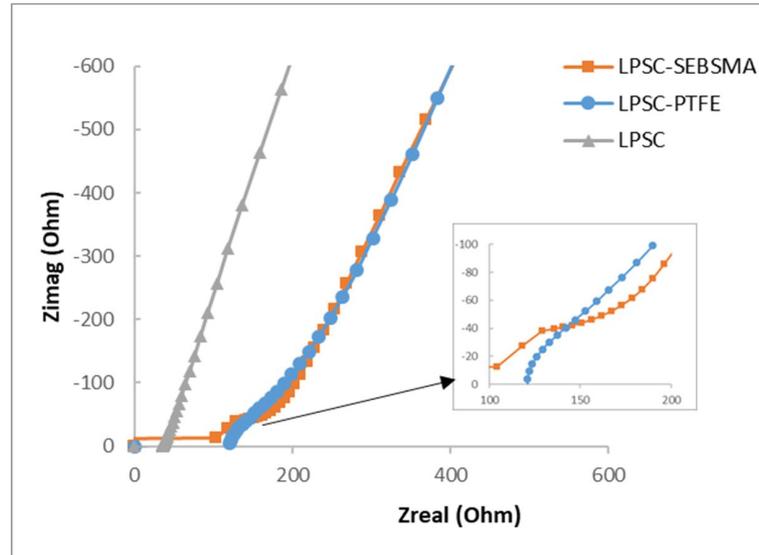
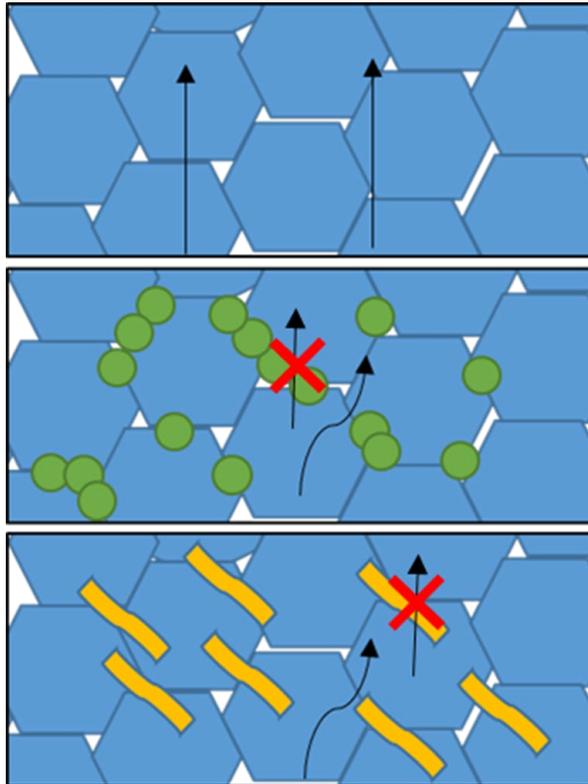
Depiction of Li transport through densified solid-state electrolyte for pure (a), composite with PTFE powder binder (b), and composite with solution deposited Styrene-Butadiene-Styrene (SEBS) rubber binder (c).

- Introduction of a passive phase
 - Conduction pathways change



- Binder & processing selections dramatically impact layer adhesion between multiple layers

Impedance Data



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

- Increase in impedance through electrolyte layer due to binder phase
- Ionic conductivity still retains ~20% of pure LPSC



Limitations of binder-based systems

- Reactivity of LPSC with polar solvents forces the use of nonpolar solvents
 - Nonpolar solvents are limited to low polarity binders with weaker adhesion to polar LPSC surfaces
- Below $30\mu\text{m}$ films remain fragile



Limitations of binder-based systems

- Reactivity of LPSC with polar solvents forces the use of nonpolar solvents
 - Nonpolar solvents are limited to low polarity binders with weaker adhesion to polar LPSC surfaces
- Below 30 μm films remain fragile

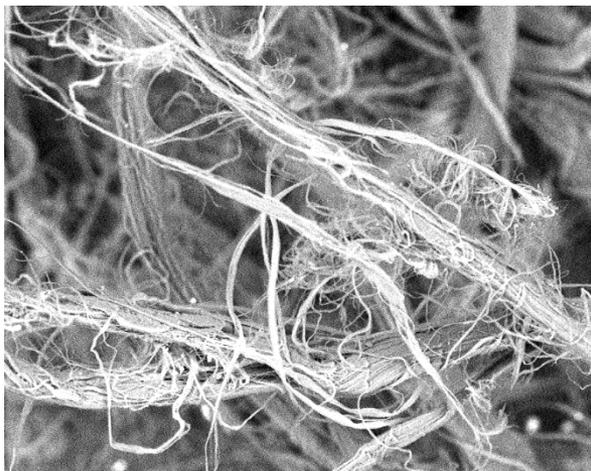
Possible solutions:

- ➔ Introduce a filler material to further strengthen the composites
- Explore alternate binders/processing techniques



Fiber-based fillers

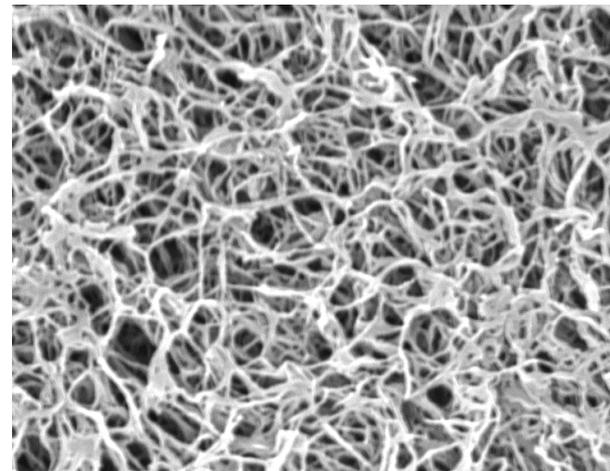
Polyaramid(Kevlar)



Nanoglass



NASA aramid nanofibers



Fiber candidates:

Kevlar – high strength polymer fibrils (wide distribution)

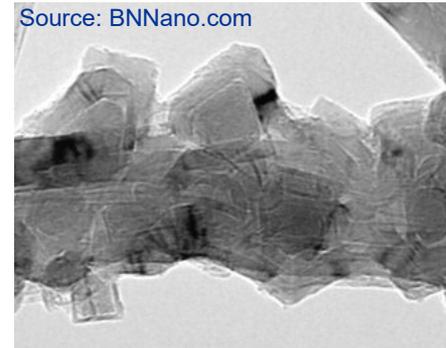
Nanoglass – high aspect ratio (700nm x 100's μm)

Aramid nanofibers– ultra fine fiber, branched network?

BNNanobarbsTM – insulating analog to CNT (very small, nm x nm)

Boron Nitride NanobarbTM

Source: BNNano.com



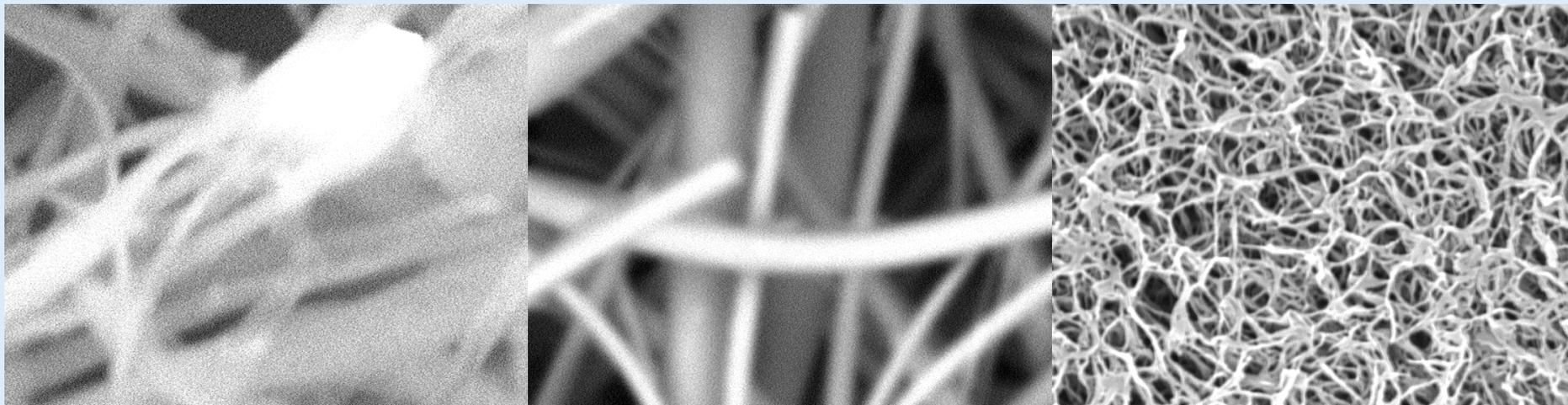


Fiber-based fillers

Polyaramid(Kevlar)

Nanoglass

NASA aramid nanofibers



Adjusted to same magnification, ANF are clearly smaller than Kevlar and Nano glass fibers

Fiber candidates:

Kevlar – high strength polymer fibrils (wide distribution)

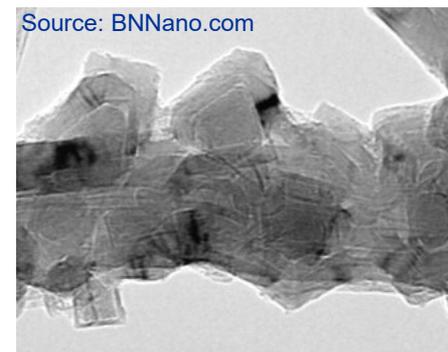
Nanoglass – high aspect ratio (700nm x 100's μm)

Aramid nanofibers– ultra fine fiber, branched network?

BNNanobarbsTM – insulating analog to CNT (very small, nm x nm)

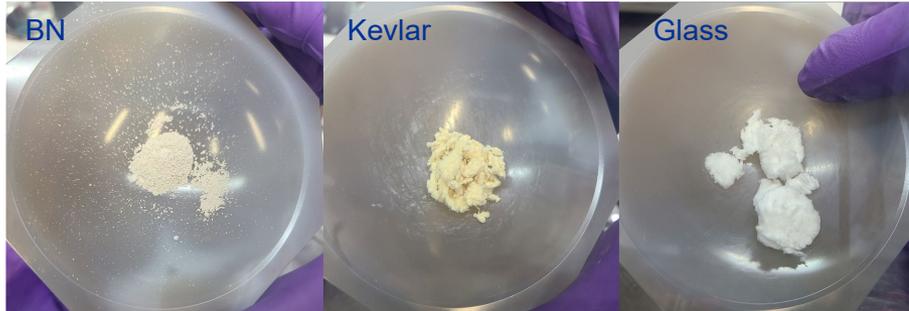
Boron Nitride NanobarbTM

Source: BNNano.com



Filler Results

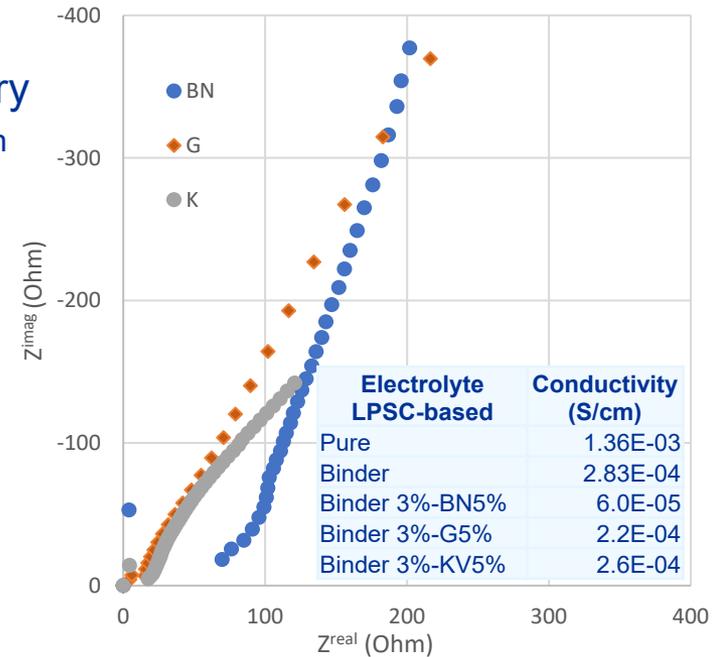
- Fillers were added at 5wt% to LPSC-Binder-Toluene slurry
 - Alternating centrifugal mixing and sonication to ensure even dispersion
 - Tape cast onto mylar substrate
 - Dried at 60°C



- Fibrous additives dramatically increased the slurry viscosity
 - Viscosity ranged from BN < Nanoglass < Kevlar
 - Kevlar viscosity greatly increased after sonication
 - Bundle unwrapping and/or stronger interaction with binder

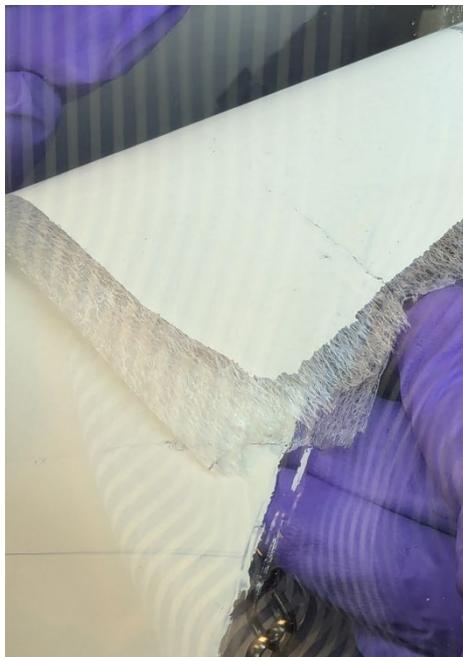
- Impact on conductivity
 - Largest drop observed for BN, which suggests stronger interference between electrolyte particle-particle contacts within the composite.
 - Larger fibers retained more conductivity, close to filler-free composites, indicating less contact interference between LPSC particles.

- Mechanical stability
 - All three materials showed substantially improved stability
 - The samples even showed flexibility after densification.

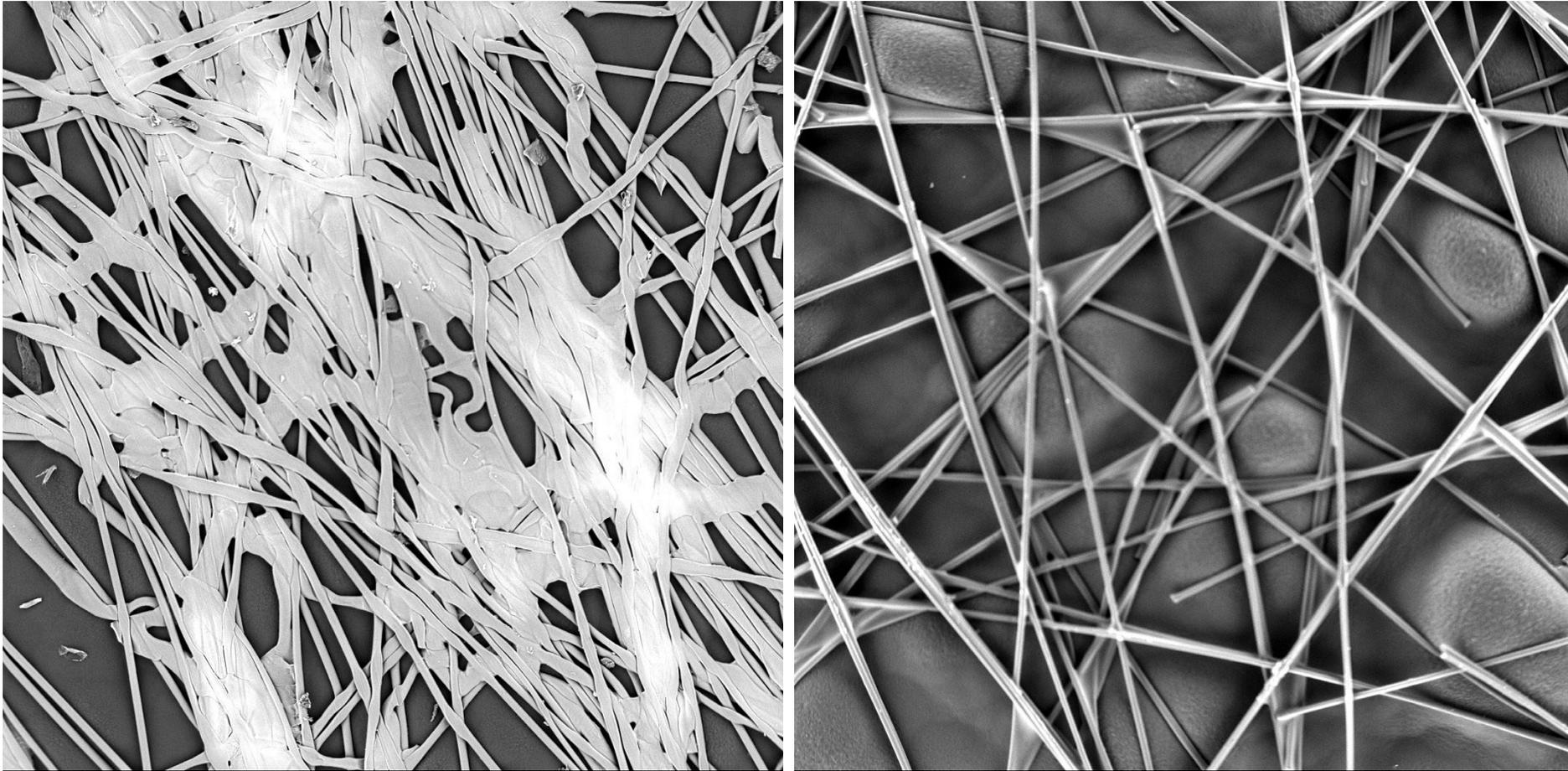


Microfiber Veils Composites

- LPSC-binder slurry can be incorporated into microfiber veils
- Improves mechanical strength through long-range mechanical scaffold
- Dispersed fillers can influence viscosity, while microfiber veils do not
- Uniform integration into veil network requires appropriate wettability from slurry



Commercial Microfiber Veils



- Two commercial microfiber veils
- Similar open area, areal weight, differing morphologies



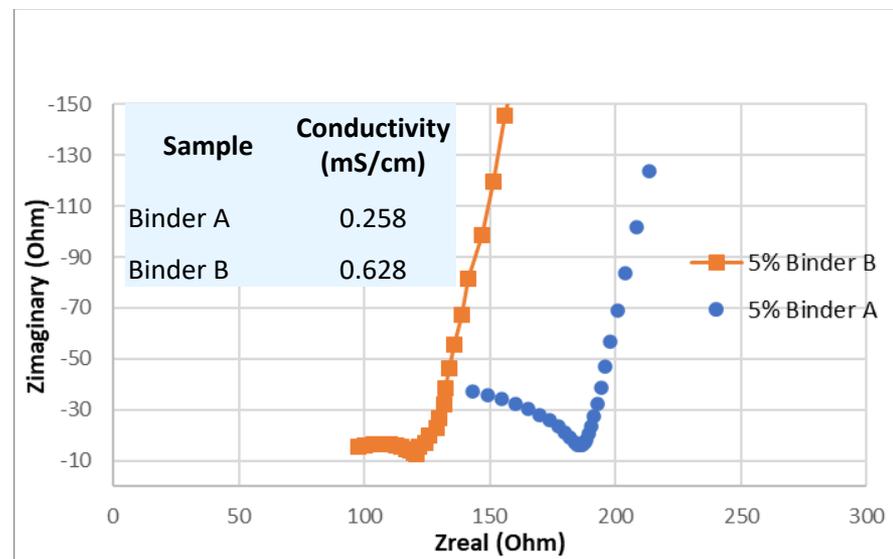
Limitations of binder-based systems

- Reactivity of LPSC with polar solvents forces the use of nonpolar solvents
 - Nonpolar solvents are limited to low polarity binders with weaker adhesion to polar LPSC surfaces
- Below 30 μm films remain fragile

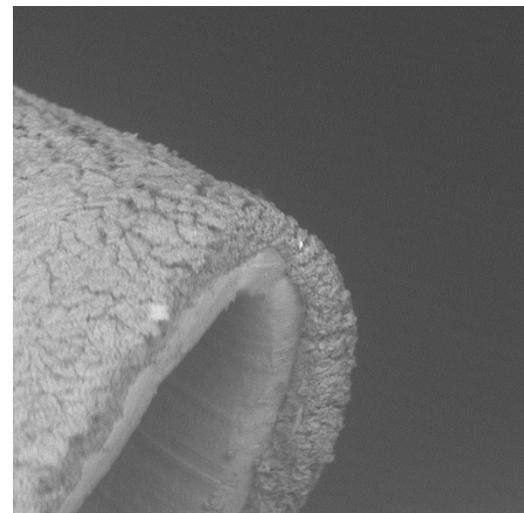
Possible solutions:

- Introduce a filler material to further strengthen the composites
- ➔ Explore alternate binders/processing techniques

Exploring advanced binders



- New binder candidates
 - Improved viscoelastic fluid behavior
 - Remarkable flexibility leading to minimal cracking damage
 - Minimized impact on ionic conductivity

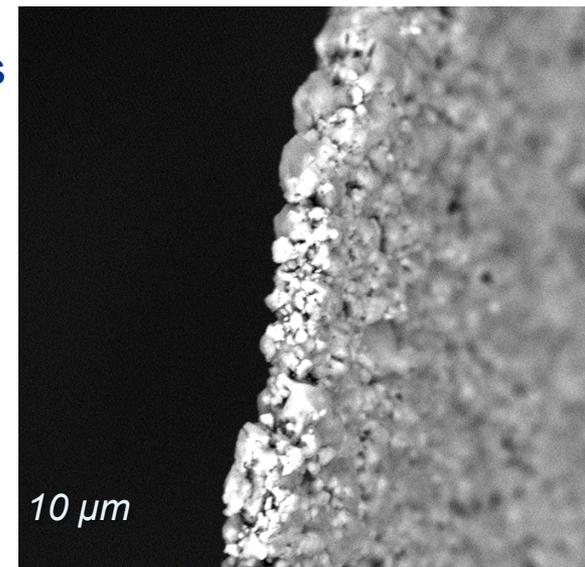


Conclusions

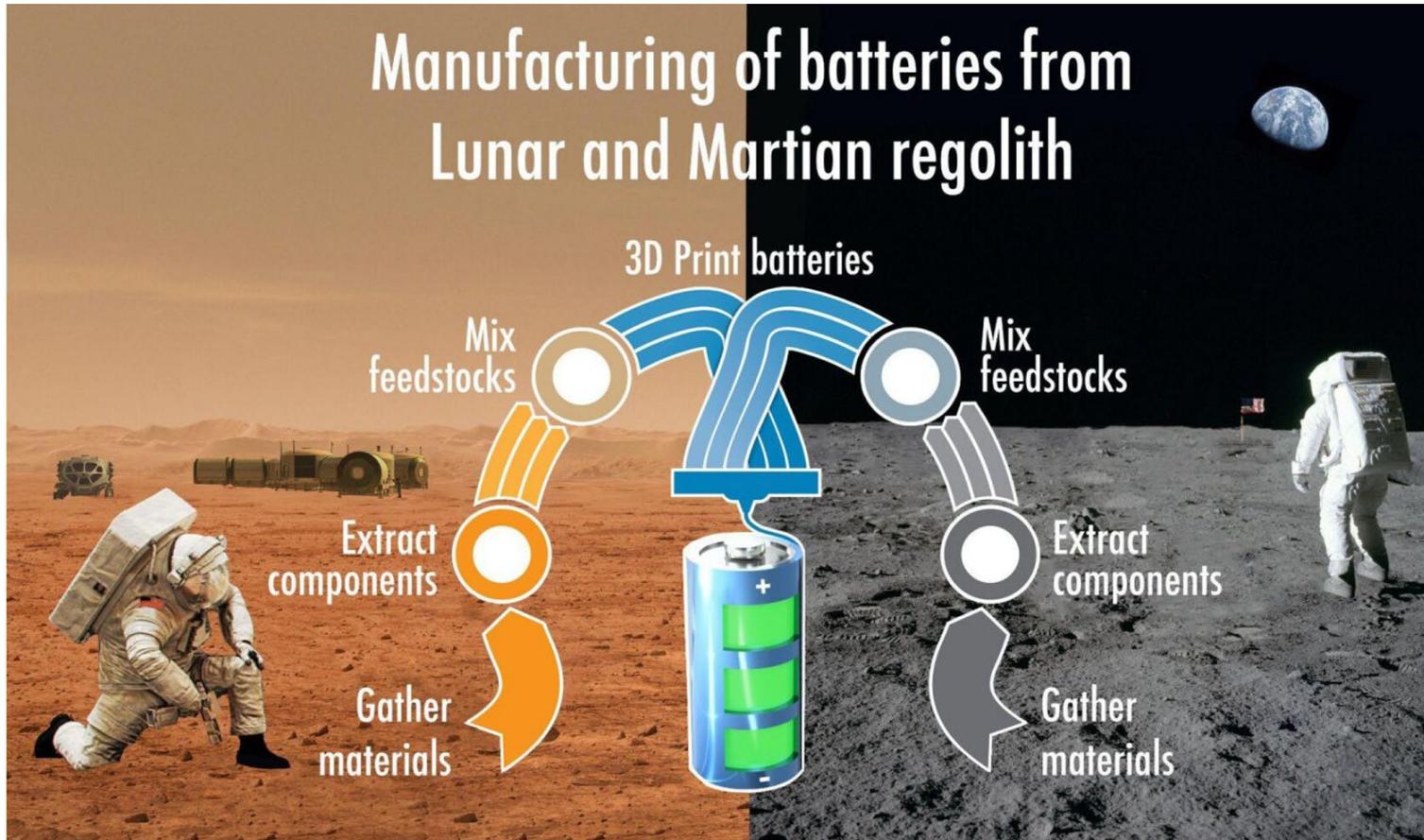
- Lithium conducting $\text{Li}_6\text{PS}_5\text{Cl}$ composite electrolytes can be manufactured with thicknesses between 25-50 μm through a scalable slurry-process.
- Binder-filler-solvent have a strong impact on ionic conductivity
- Manufacturing advancements push towards more practical thicknesses that are required to be competitive with current lithium-ion separators.
- Advanced binders/fillers allow for $\sim 50\%$ ionic conductivity retention.
 - Binder chemistry has a strong impact on interfacial resistance
 - Filler length influenced conductivity losses

Future Direction

- Continued optimization of polymer and filler loadings to improve conductivity and mechanical stability
- Study electrode compatibility



Beyond Aeronautics: Space



ACS Energy Lett. 2023, 8, 1042–1049

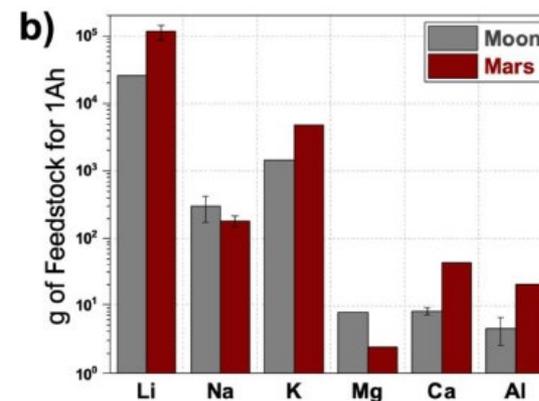
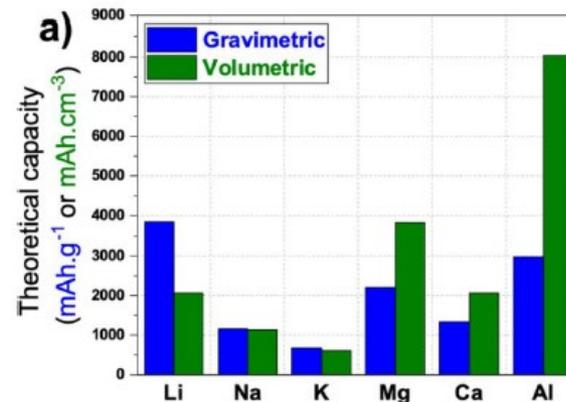
- Lunar derived materials for sustained habitation on the Moon and Mars



Lunar & Martian Abundance

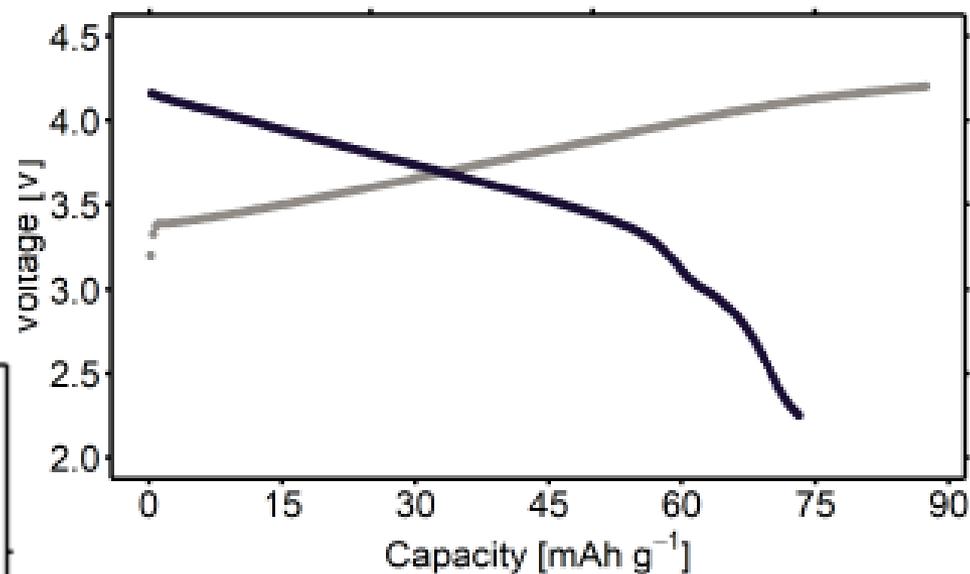
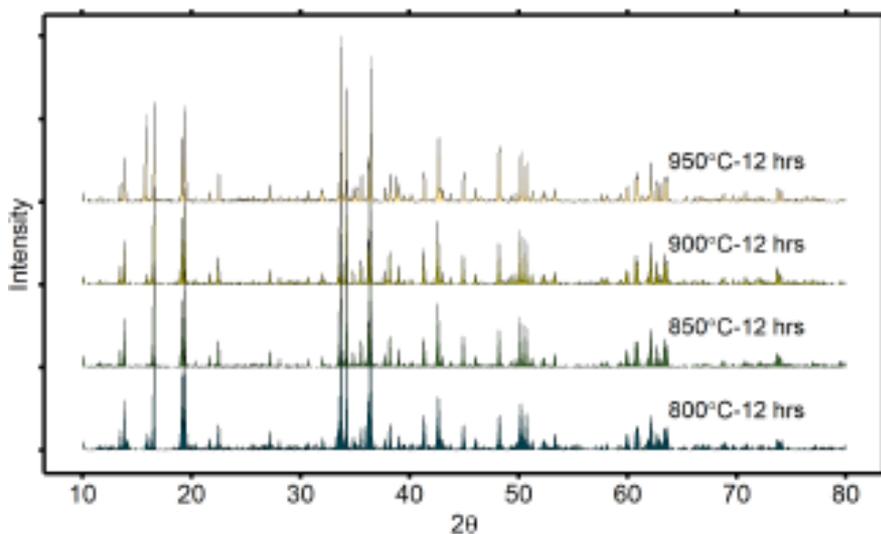
Table 1. Bulk Composition of Lunar, Martian, and Terrestrial Soil^a

Element	Moon (refs 17–19)	Mars (refs 20, 21, 24)	Earth (refs 25, 26)
Li (ppm)	10	1.8–3	18
Na (ppm)	2000–3000 (average); 5000 (Maria region)	5770	23 600
K (ppm)	1000	309	21 400
F (ppm)	70	20–30	525
Cl (ppm)	50	30	472
P (ppm)	800	675	757
V (ppm)	130	130	98
Mg (wt%)	5.5	18.5	2.2
Ca (wt%)	10 (highland); 8 (Maria Region)	1.7	3.9
Fe (wt%)	26 (highland); 15 (Maria region)	14.1	4.3
Mn (ppm)	200 (highland); 2000 (Maria region)	2250	716
Al (wt%)	13 (highland); 5 (Maria region)	1.6	8.0
Cu (ppm)	8	2	25
Si (wt%)	21	20.5	28.8
Ni (ppm)	200	330	56
Co (ppm)	40	71	24
Ti	1 wt% (average); 5 wt% (Maria region)	832 ppm	4010 ppm (0.4 wt%)
Zr (ppm)	100–400	7.5	203
C (ppm)	<100	2960	200–1990



- Elemental abundance driven material discovery
- Different geological processes affect elemental distributions
- *Make it don't take it*

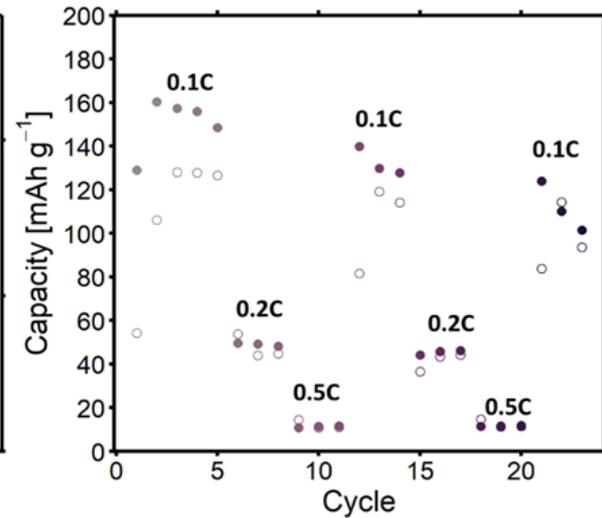
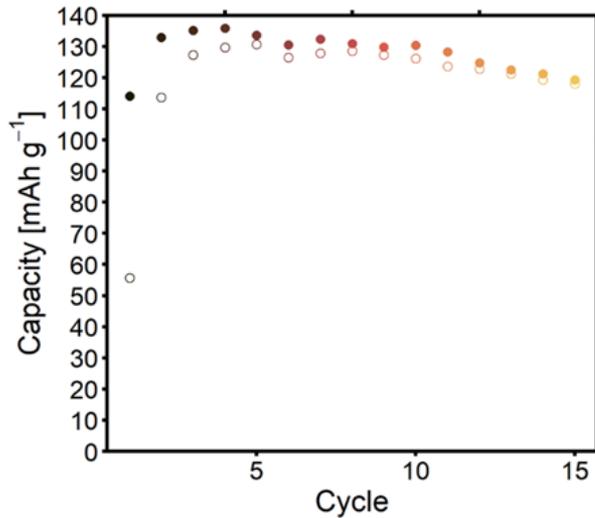
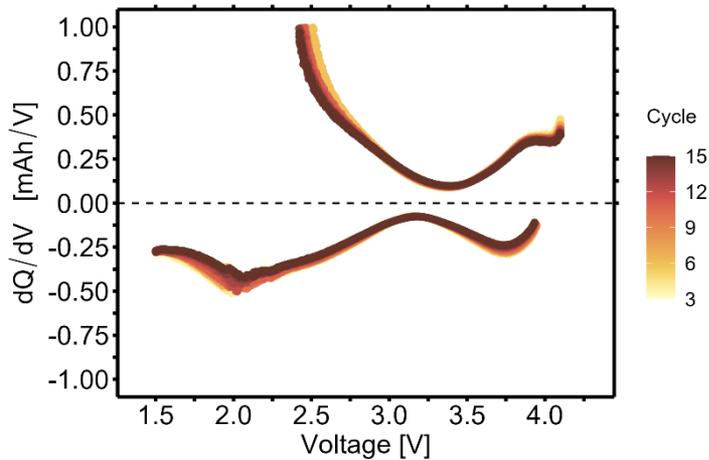
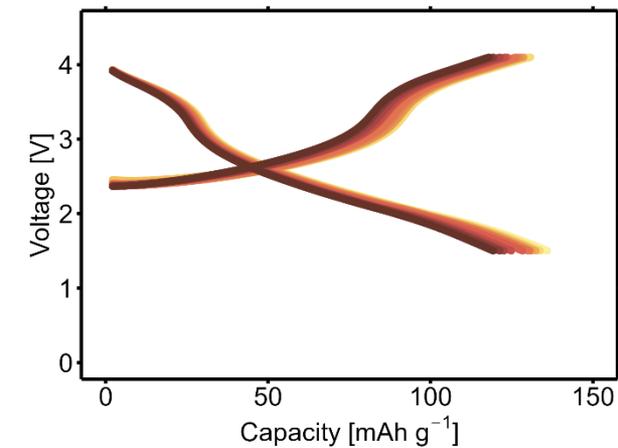
Sodium Ion cathodes designed for In-Situ Resource Utilization on the Moon & Mars



- NaMn_xFe_yTi_zO₂ design space
 - Investigation of other dopants
- Synthesis and processing conditions
- Electrochemical Testing



Sodium Ion cathodes designed for In-Situ Resource Utilization on the Moon & Mars



- $\text{NaMn}_x\text{Fe}_y\text{Ti}_z\text{O}_2$
- Good cyclability
- Moderate rate capability



Conclusions

- NASA has many unique considerations when developing energy storage devices
- Electric aviation demands ultra-high performing next generation batteries
- Sustained habitation on the Moon and Mars need alternate chemistries based on elemental availability
 - Environmental extremes vary greatly compared to Earth
- Safety and reliability remain critical



Next Generation Batteries for Electric Aviation and Space

Donald A. Dornbusch¹, Yi Lin², William Huddleston³, Vesselin Yamakov⁴, Rocco P. Viggiano¹

¹ - NASA Glenn Research Center, Cleveland, OH 44135, USA

² - NASA Langley Research Center, Hampton, VA 23681, USA

³ - HX5, LLC, Cleveland, OH 44315, USA

⁴ - Analytical Mechanics Associates Inc, Hampton, VA 23666

Three futuristic aircraft designs are shown against a blue sky with white clouds. The top aircraft is a white jet with blue and red accents and NASA logos. The bottom-left aircraft is a white jet with blue accents and NASA logos. The bottom-right aircraft is a white, sleek, delta-wing aircraft with two engines mounted on the wings and a NASA logo on the nose.

49th International Conference and Expo on Advanced Ceramics and Composites (ICACC2025)

Presenter:

Dr. Donald A. Dornbusch-NASA GRC

donald.dornbusch@nasa.gov



Acknowledgments

This project was funded through Transformational Tools and Technologies (TTT) and Convergent Aeronautics Solutions (CAS) programs under the Transformative Aeronautics Concepts Program (TACP).

Next Generation Solid-State Batteries for Electric Aviation

Donald A. Dornbusch¹, Yi Lin², William Huddleston³, Vesselin Yamakov⁴, Rocco P. Viggiano¹

¹ - NASA Glenn Research Center, 21000 Brookpark Rd., Cleveland, OH 44135, USA

²- NASA Langley Research Center, Hampton, VA 23681, USA

³-NASA NPP/Oak Ridge Associated Universities, USA

⁴ – Analytical Mechanics Associates Inc, Hampton, VA 23666

Presenter:

Dr. Donald A. Dornbusch-NASA GRC

donald.dornbusch@nasa.gov