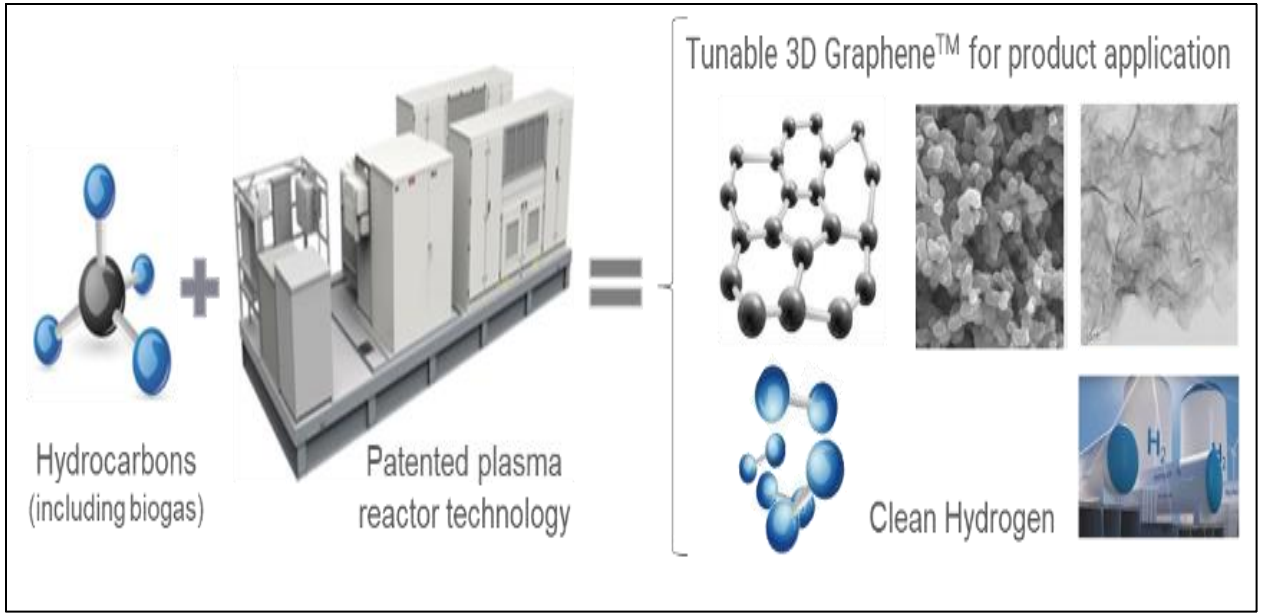
Lyten's Lithium-Sulfur Technology

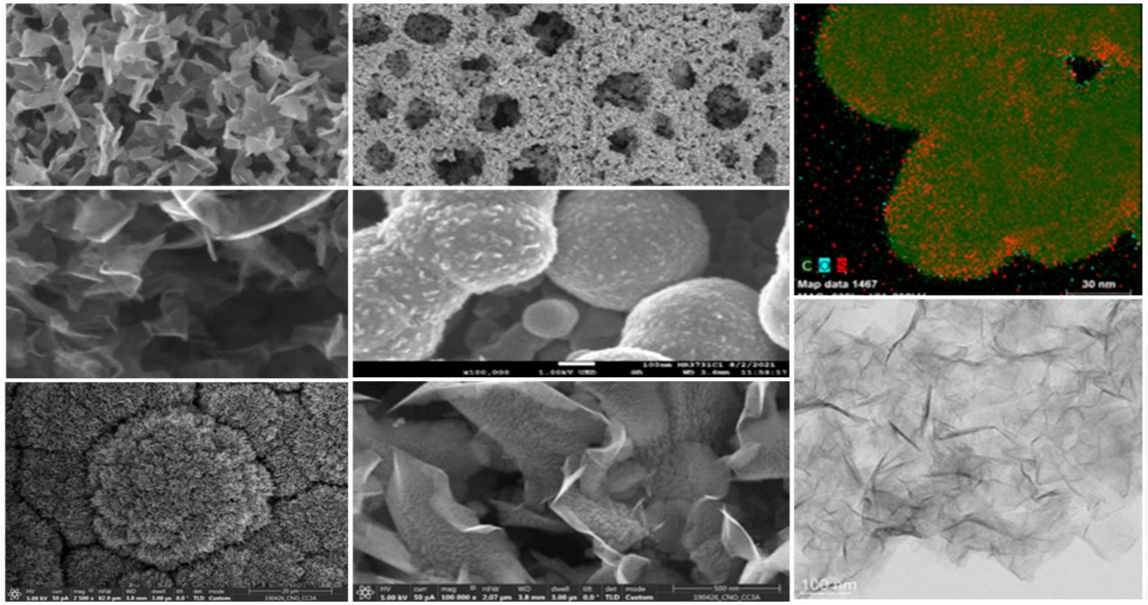
Ratnakumar Bugga, Celina Mikolajczak, Arjun Mendiratta, Karel Vanheusden, Yongtao Meng, Babu Ganguli, Jeffrey Bell, Zack Favors, and Dan Cook

SPACE POWER WORKSHOP (SPW)
April 29, 2025 - May 01, 2025
Torrance CA

- Founded 2015 – Produce Lyten 3D Graphene™
- Leader in 3D Graphene Patents (>500 patent matters)
- >$500M Raised; finishing Series B
- Initial Applications of Lyten 3D Graphene™
  - Lithium-Sulfur Batteries
  - Composites
  - Sensors
  - US Government Applications
- 145k ft^2 Facilities in Silicon Valley
  - 3D Graphene Fab (2022)
  - Pilot Cell Production Line (2023)
  - San Leandro (2024)
- > 315 employees; >70% advanced degree holders

LYTEN 3D Graphene™





- A family of 3D Graphenes developed and being produced with customized nanostructure and morphological features for different applications (Li-S batteries, composites, sensors etc.)
- Offers high conductivity, good mechanical strength and flexibility, a highly tunable morphology, optimum surface area, pore size, pore distribution and tap density through process controls.

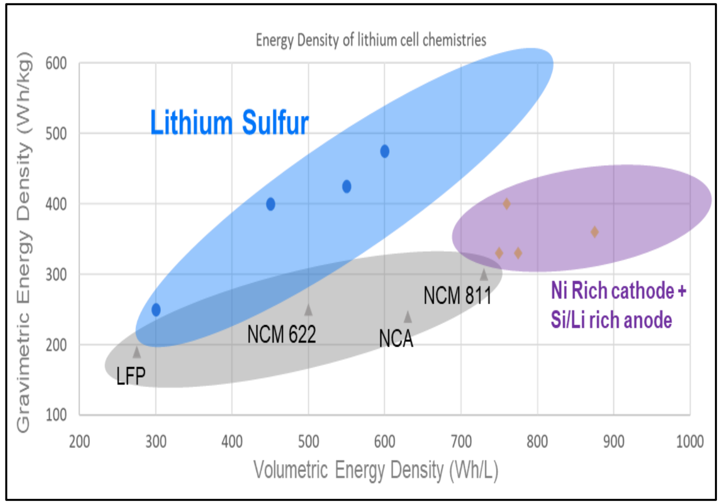
LITHIUM SULFUR- HIGH ENERGY AND SUSTAINABLE

LYTEN

Key Challenges for Traditional LIBs

- Cell performance reaching its fundamental limits (300 Wh/kg)
- Predominantly foreign-sourced active materials causing supply chain issues and unstable (increasing) pricing
- Cobalt and nickel shortfall in coming years
- China has overwhelming dominance in the processed materials and also cell and battery manufacturing
- Safety concerns from thermal runaway are still prevalent

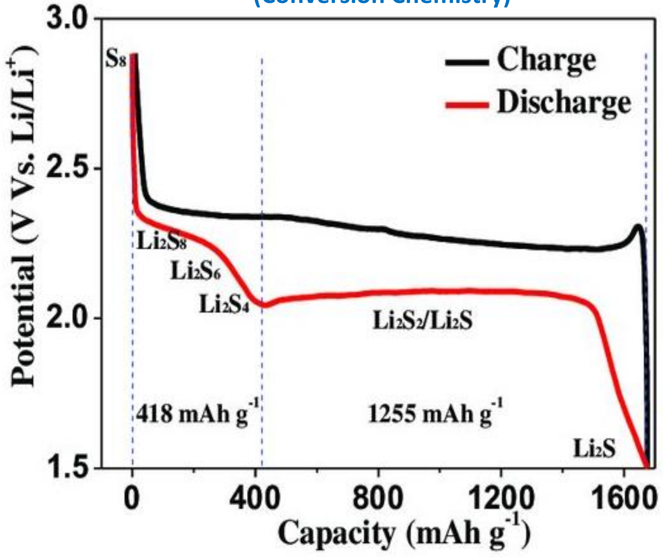
Li-S vs Li-Ion and Li-NMC Batteries



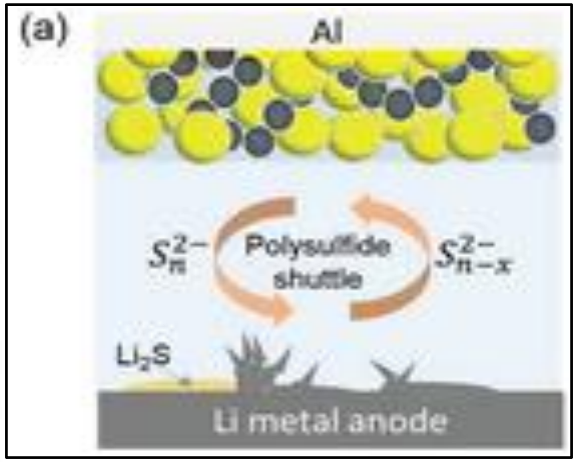
Key Advantages of Lithium-Sulfur Batteries

- Higher specific energy (Sulfur has <u>8x</u> specific capacity vs. LIB cathode). At maturity, 600 Wh/kg and 800 Wh/L possible
- Robust domestic supply chain, free from nickel/cobalt/graphite
- Abundant, low-cost materials: sulfur and carbon
- Inherently safer than LIB due to unique chemistry
- Lyten architecture has a possible path towards low or neutral carbon footprint.

Li-S Cell Voltages (Conversion Chemistry)



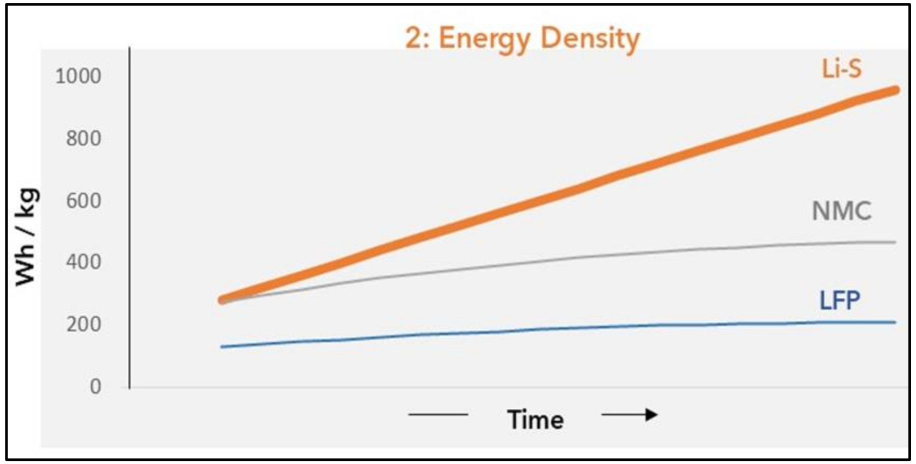
Polysulfide Shuttle

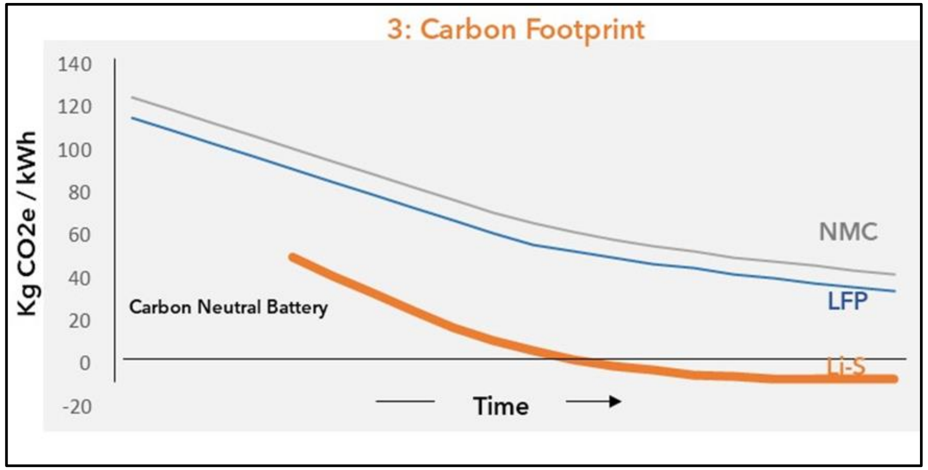


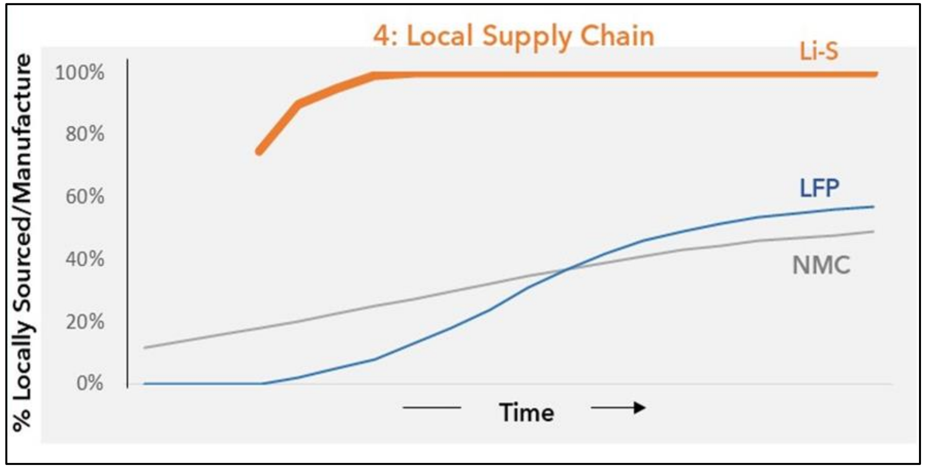
Mitigating Polysulfide shuttle is one of the major challenges

Li-S to Accelerate Widespread Electrification

Advantages of Li-S over Li-Ion Battery Systems



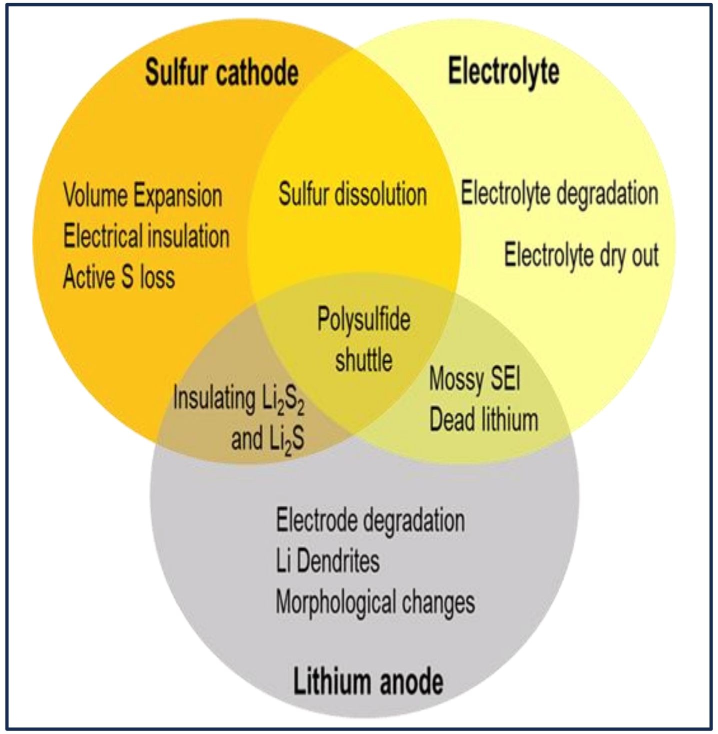




- **Lower cost and smaller carbon footprint and high specific energy compared to NMC and LFP systems and free of supply chain issues**

How Lyten Has Overcome the Challenges

Polysulfide Shuttle and Beyond



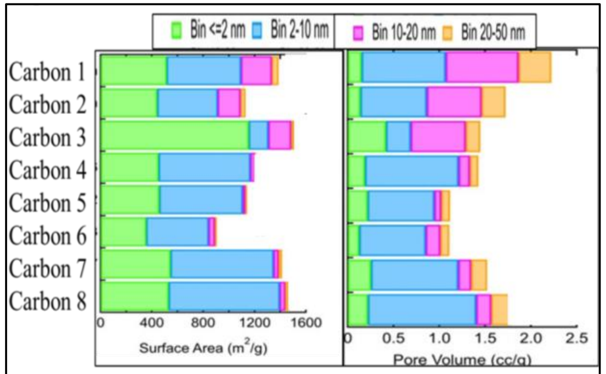
3D Graphene Tuning	Sulfur-infused 3DG cathode with nanopores restraining polysulfides by physisorption
3DG-S Cathode	High areal capacity (>4 mAh/cm^2) cathodes on commercial coaters (aqueous binders)
Composite anode with Protective coatings)	New Li-based multi-component anodes with proprietary surface coatings for reduced corrosion and dendritic failures
Proprietary Electrolyte	New stable electrolytes enabling long life and low electrolyte quantities (E/S)
Customized Separator	Coated separators for restricting polysulfide crossover
Optimized Cell Design	Efficient cell designs in both pouch and cylindrical (18650/21700) formats
New Formation and Test Protocols	Asymmetric cycling with slow charge rates helps Li anode cycling

HOW LYTEN Li-S CELL WORKS

3D GRAPHENE™- SULFUR CATHODES

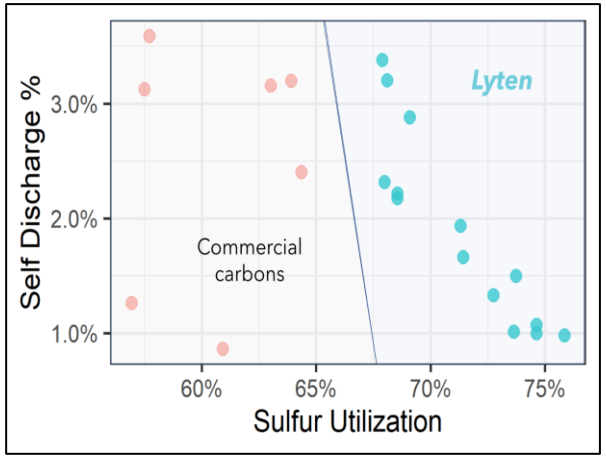
- Lyten 3D Graphene (3DG) forms the primary structure of the cathode.
  - Tuned through synthesis and post-synthesis processing to achieve the desired hierarchical pore structure (nano/micro) for efficient physisorption of polysulfides (cf. Nazar et al 2009).
    - Chemical environment may be tuned with aliovalent doping and functionalization to enhance polysulfide affinity and kinetics.
- Lyten 3DG outperforms commercial carbons with enhanced sulfur utilization and low self-discharge.
  - High areal-capacity cathodes fabricated with optimum macro-porosity using spray-dried 3DG-S cathode active material (CAM) and aqueous binder on standard coater.
    - Coatings to mitigate polysulfide release
    - Catalysts and multifunctional additives are incorporated as needed

3DG Tuning

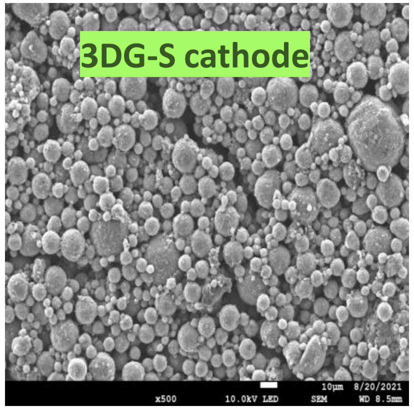


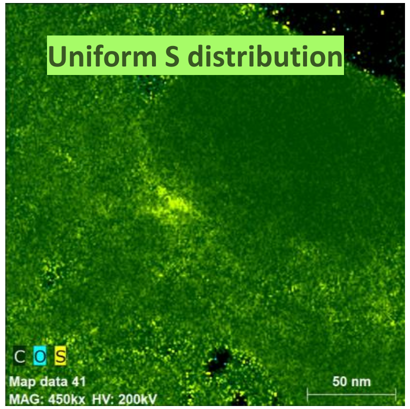
Morphological features of eight different carbons for example with the weight loss from TGA

3DG vs. Commercial Carbons



3DG-S Cathodes (Aqueous Binder)

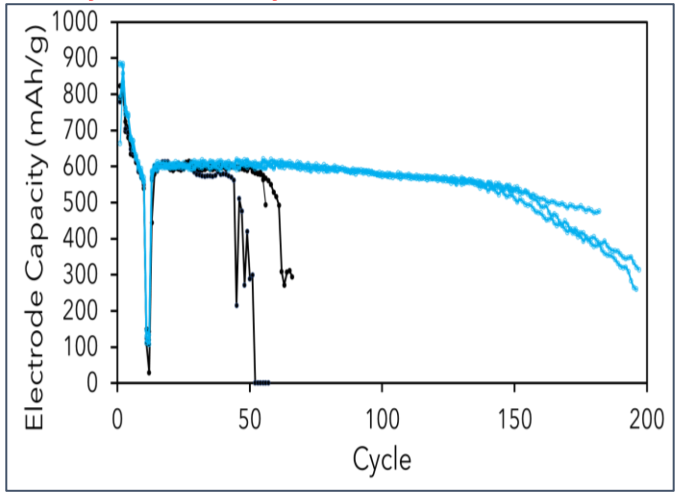




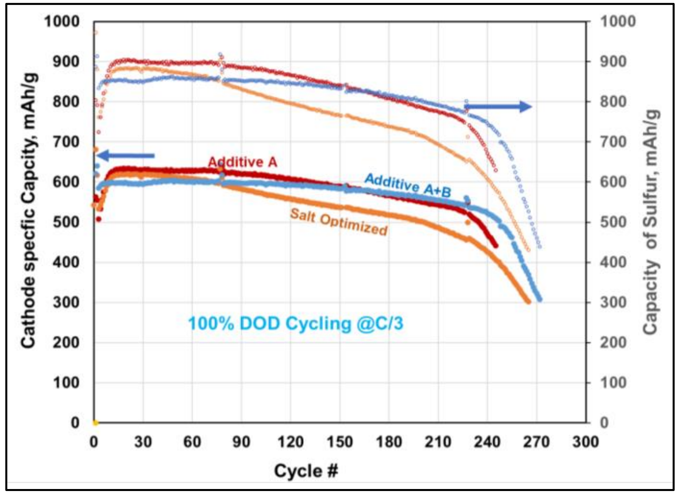
Lyten Li-S Electrolyte Designs

- Challenges in the electrolyte design:
  - Stability/compatibility with Li (highly solvating electrolytes more reactive)
  - Adequate solvation of polysulfides at low E/S;
  - Solvating or sparingly solvating electrolytes?
  - Polysulfide effects (viscosity, conductivity, wetting)
- Advanced electrolytes using mixed solvents and salts (cf: High entropy electrolytes).
  - Synergistic effects
  - Stable SEI formation
- Lyten advanced electrolytes enable operation at low E/S and deliver high specific energy.
- New Gel Polymer Electrolytes (GPE) developed using Electrospinning
  - Improved chemical and thermal stability
  - Lower E/S possible
  - Enable Semi-solid architecture

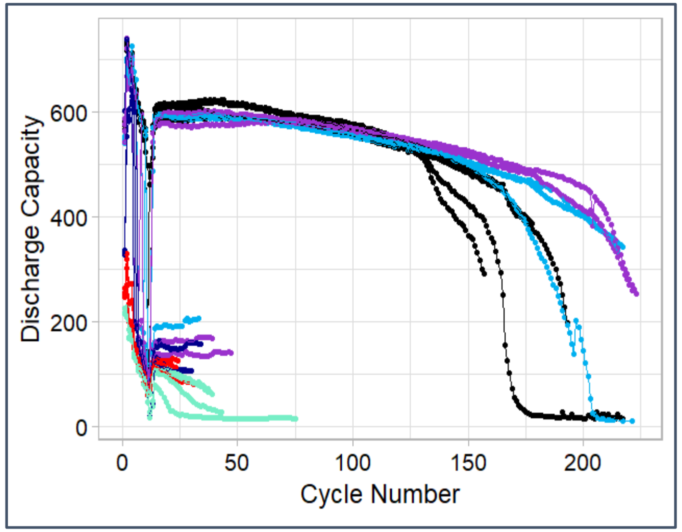
Lyten Electrolyte vs. Literature Standard



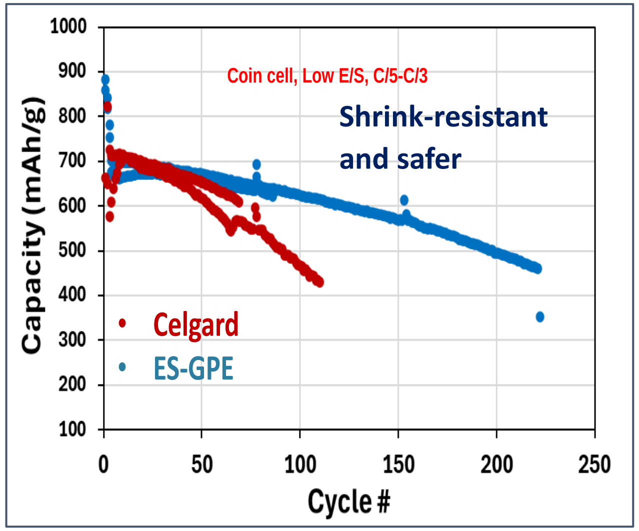
Optimization of Salts and Additives



Optimization of Salt Content



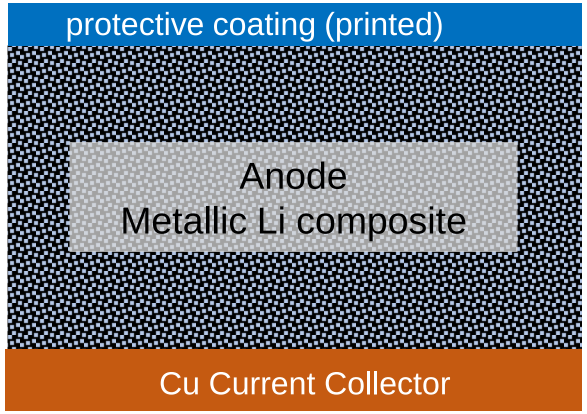
Electrospun GPE vs Standard Separator

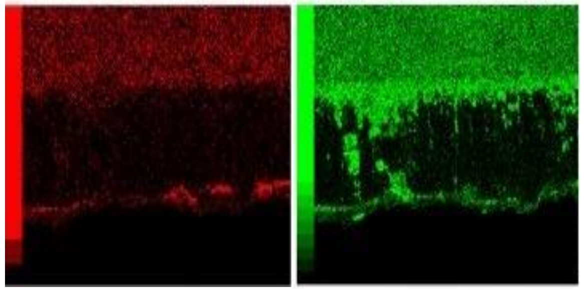


LITHIUM-BASED ANODES

- New Protective Coatings on Li composite anode

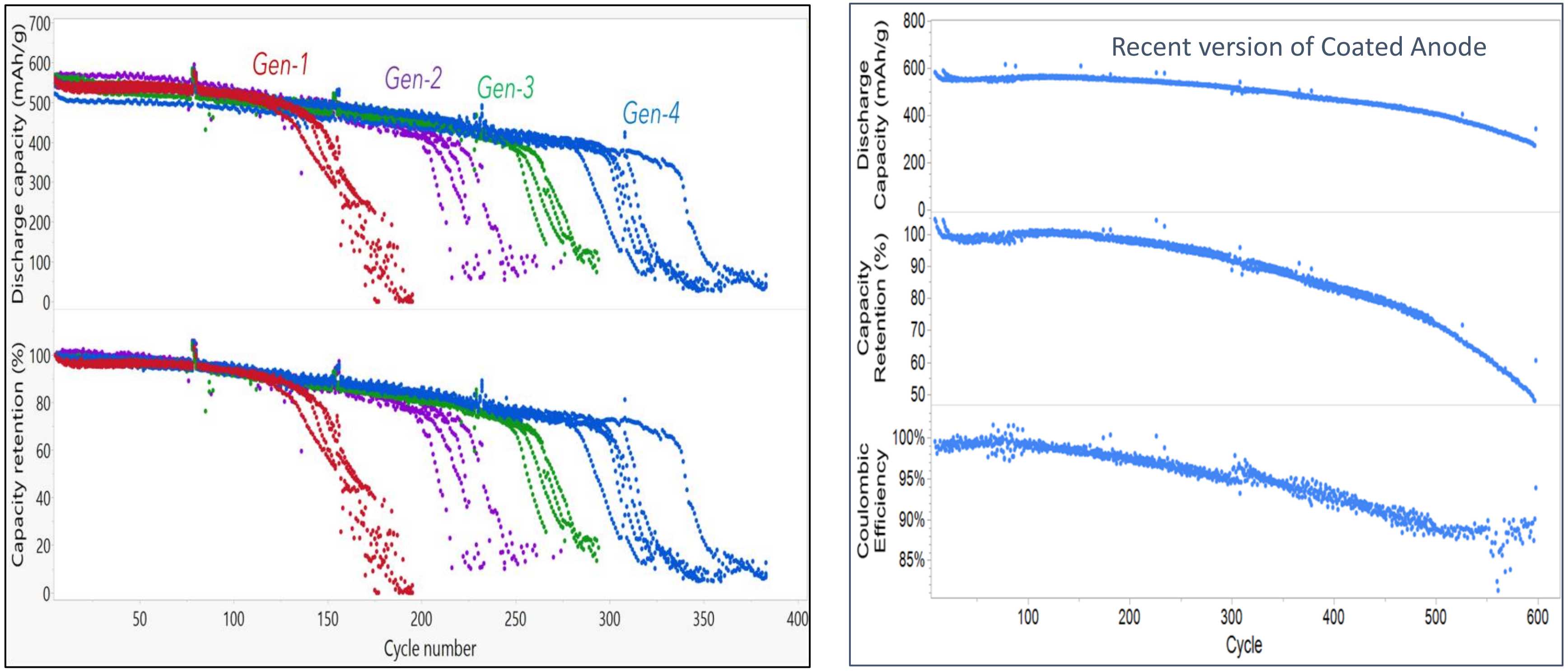
Schematic of Lyten Anode





SEM / EDS of Anode + Coatings

Cycle Life @ C/3,100% DoD with Different Anode Designs

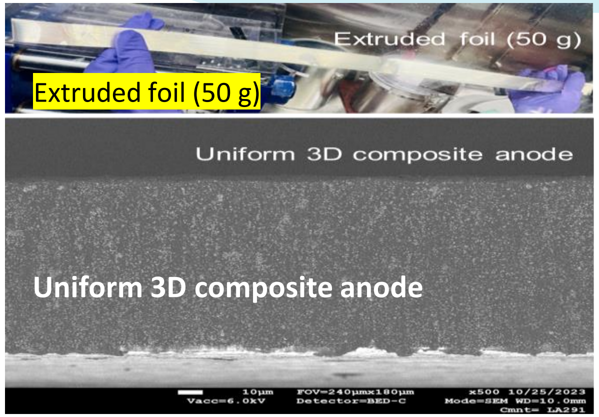


- **Composite anode with protective coating improves cycle life by 2-3 times vs. Li.**

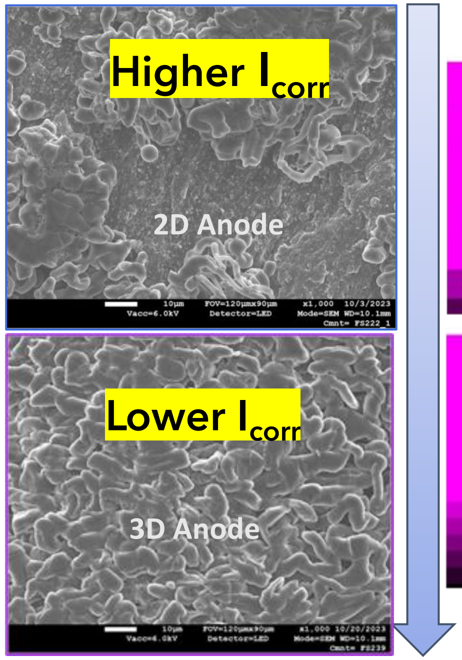
LYTEN 3D ANODES

- 3D anode shows lower corrosion currents (and increased stability) from Tafel.
- SEI on the 3D anode is more compact compared to the baseline 2D anode.
- 3D anode showed better reliability and stability compared to the baseline.
- 3D anode can potentially reduce Li usage by 40 wt%, which reduces the supply chain constraints and environmental impact/
- Demonstrated good cycle life vs LFP an cathode.

Fabrication of 3D Anodes

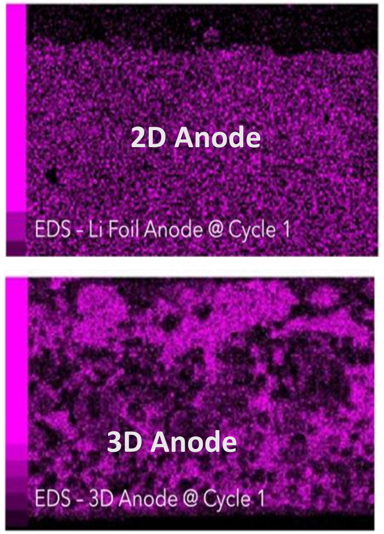


SEM

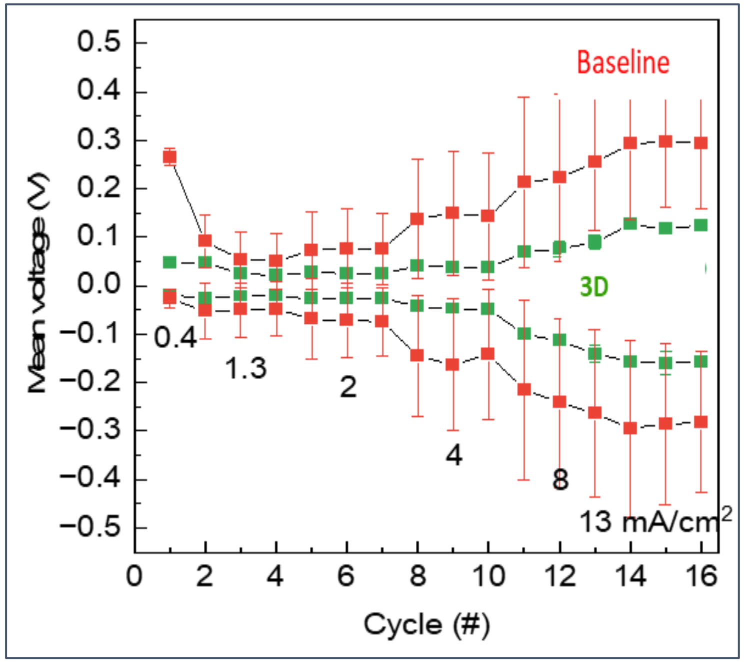


Less reactivity

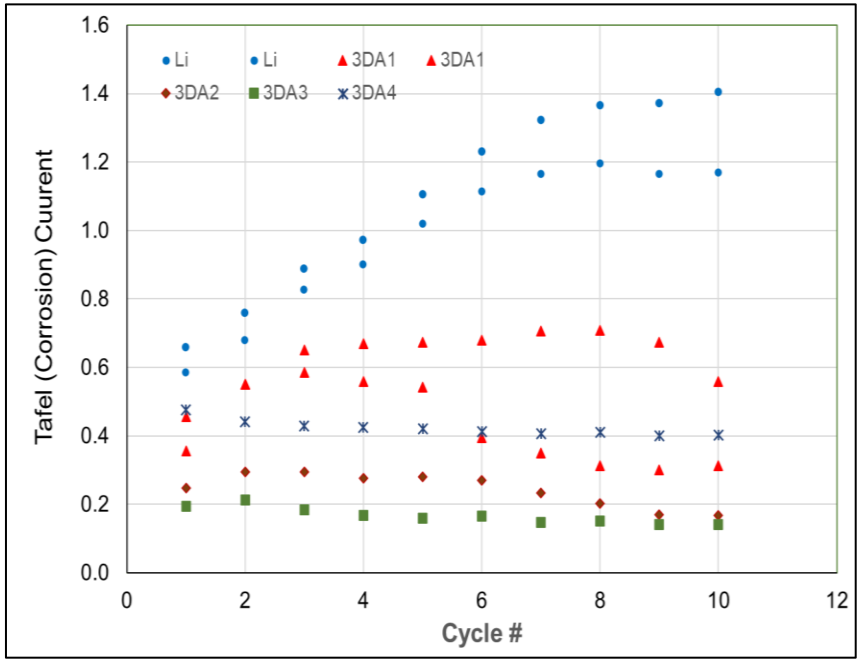
Li inside 3D Anode



High-Rate Capability of 3D Anodes

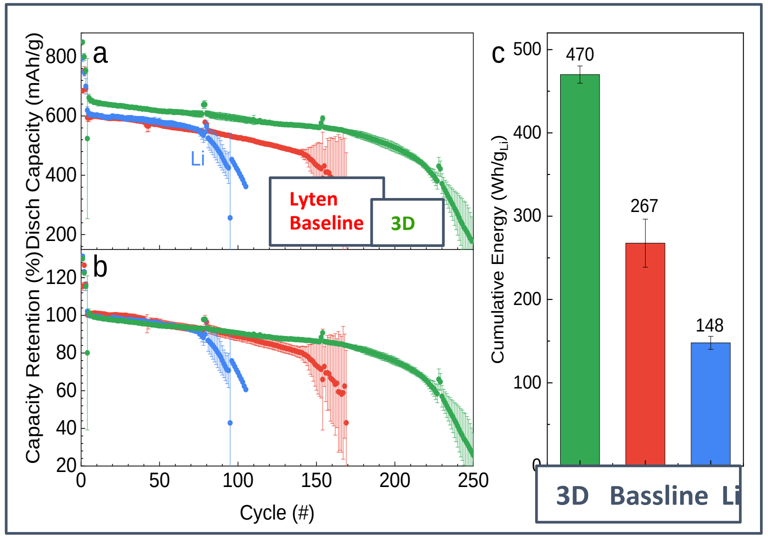


Tafel Currents of 3D Anodes

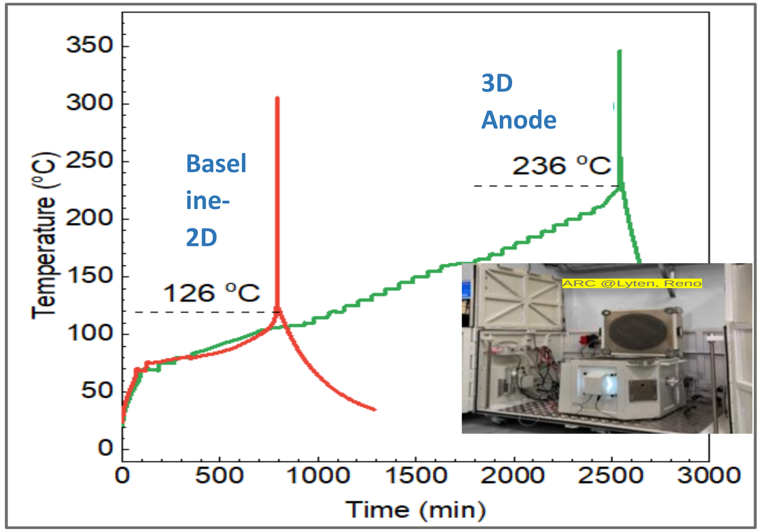


LYTEN 3D ANODES

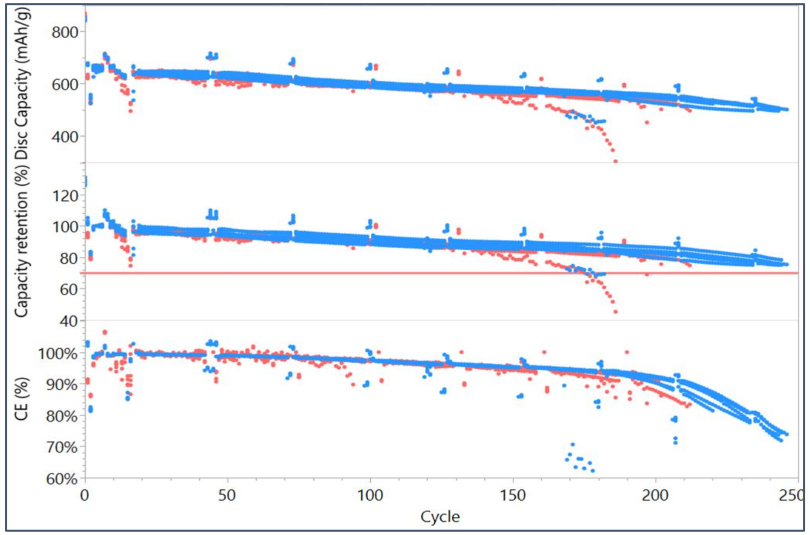
• Li-lean Low-cost Anodes



SAFETY TESTING OF 3D ANODE CELLS



3D ANODE IN POUCH CELLS



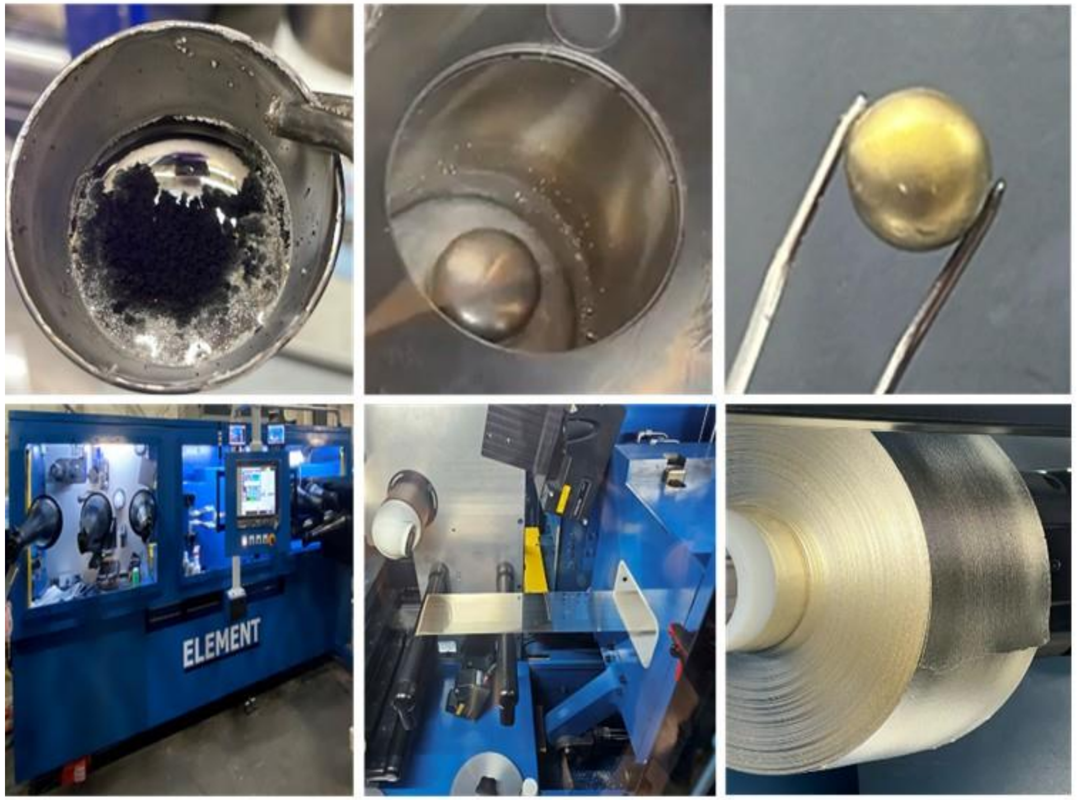
- 3D anode improves the cycle life of Li-S cells than the baseline 2D anode.
- Multiple designs have been demonstrated that can function as well even with 30-45% less Li (benefits in cost and material availability)

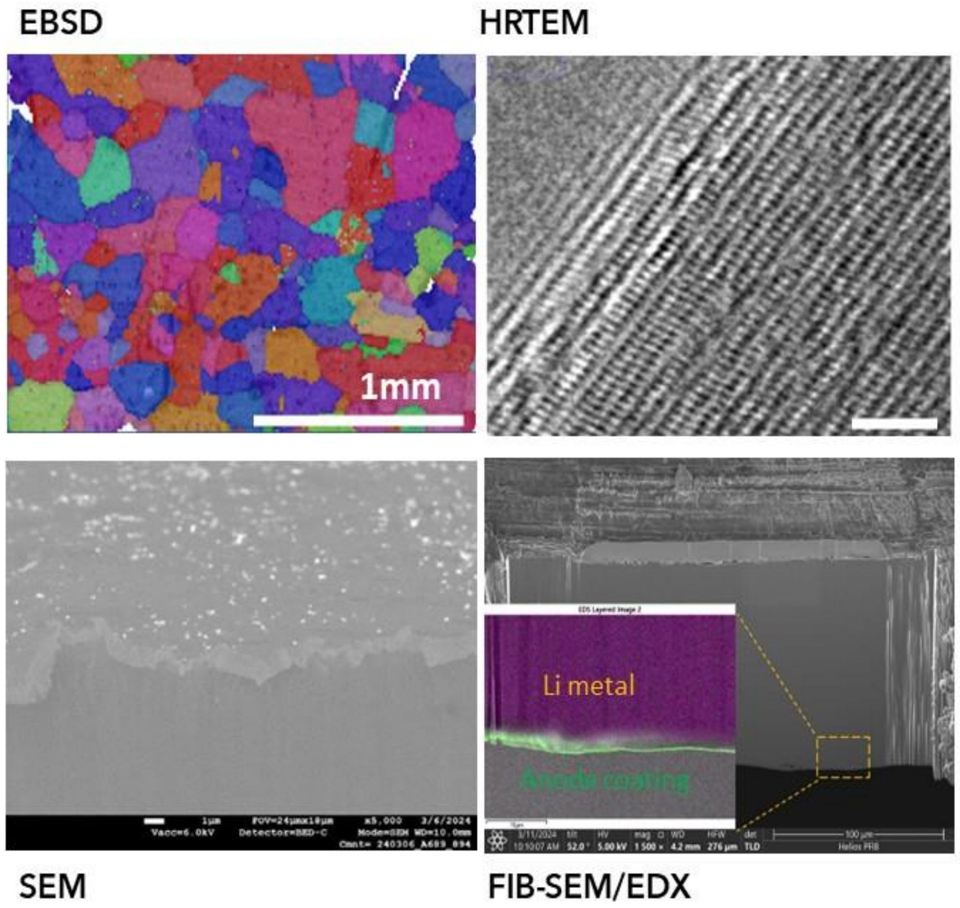
- Thermal runaway onset temperature pushed from 126ºC to 236ºC by the 3D anode.
- 3D anode seems plays a critical role in improving the safety of Li-S cells.

- Improved cycle life with 3D anode in pouch cells.
- Expected to be amenable to high power and fast charge

Continued Development of Anode

- Developed in-house Li ingots melting, purification, alloying, casting, extruding, and rolling capability.
- Advanced in-house characterization tool: EBSD, TEM, SEM, FIB, XPS. etc.





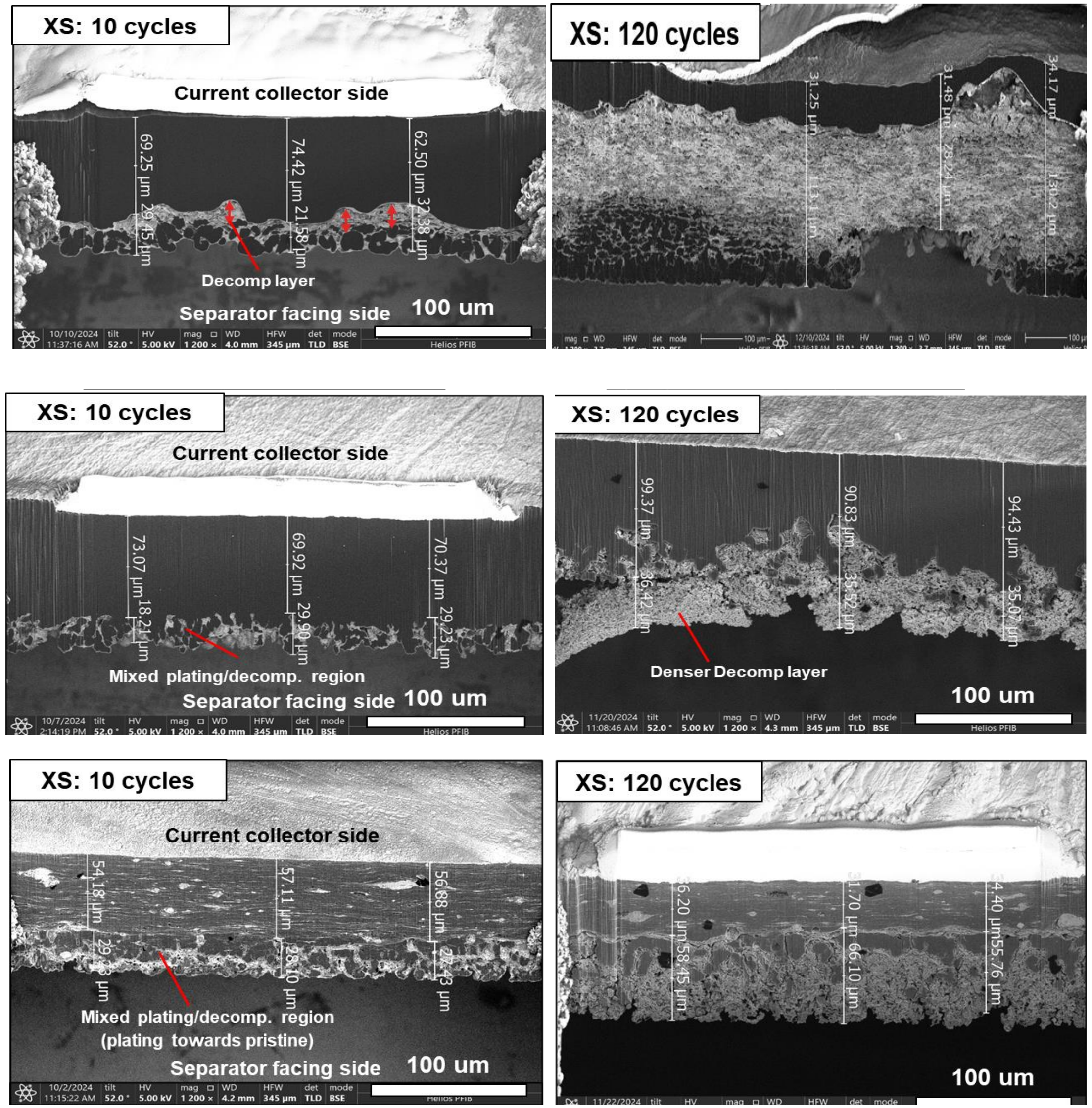
FIB Cross Section Analysis of the Anodes

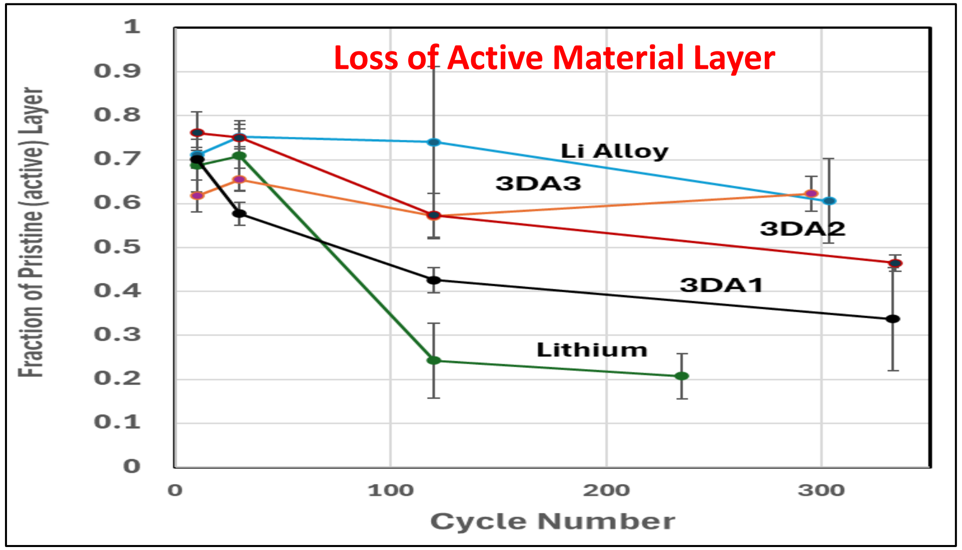
Loss of Active Layer and Growth of Decomposition

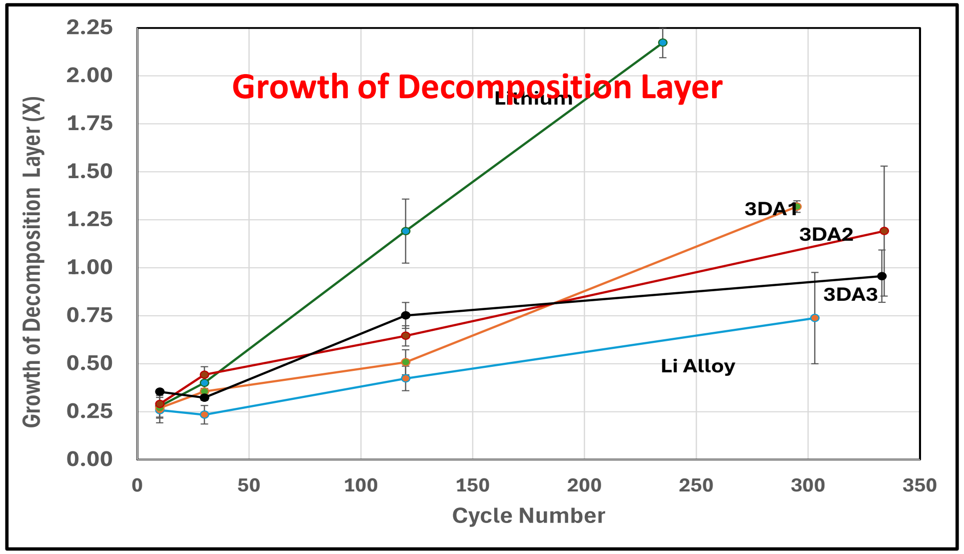
Lithium

Lithium Alloy

Li 3D Anode





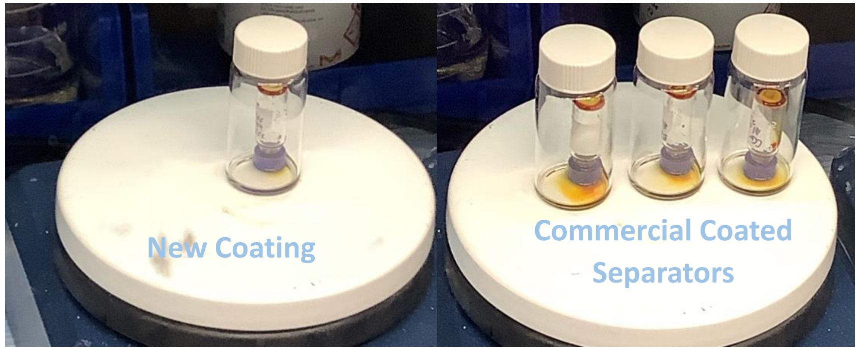


- Lyten anodes (including 3D) show reduced loss of active layer and growth of decomposition layer compared to bare lithium

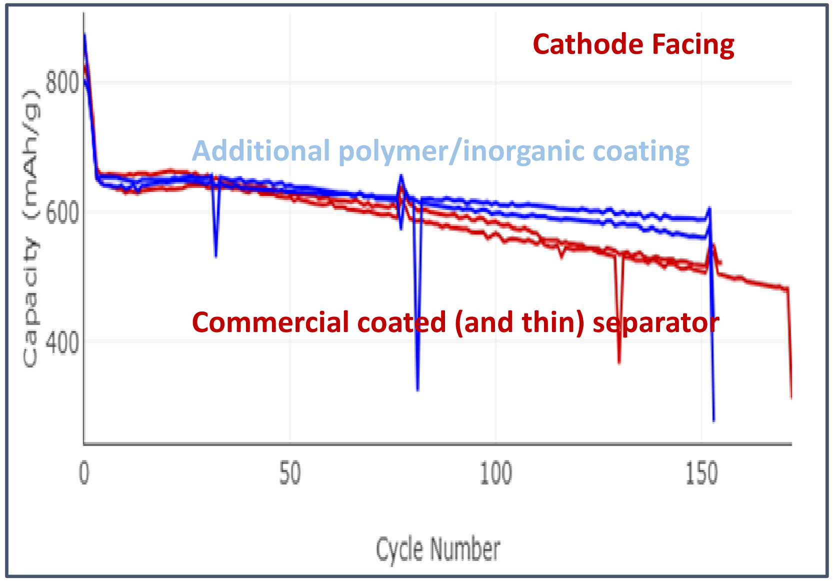
LYTEN-MODIFIED COMMERCIAL SEPARATORS

- Polymeric/ceramic coating on commercial polyolefin separators
  - Improve cell safety by reducing thermal shrinkage and minimize TR-related failure.
  - Reduce polysulfide crossover and minimize shuttle effects
  - Develop new coatings and evaluate commercial coated separators.
  - Commercial separators on the anode side significantly improves cycle life

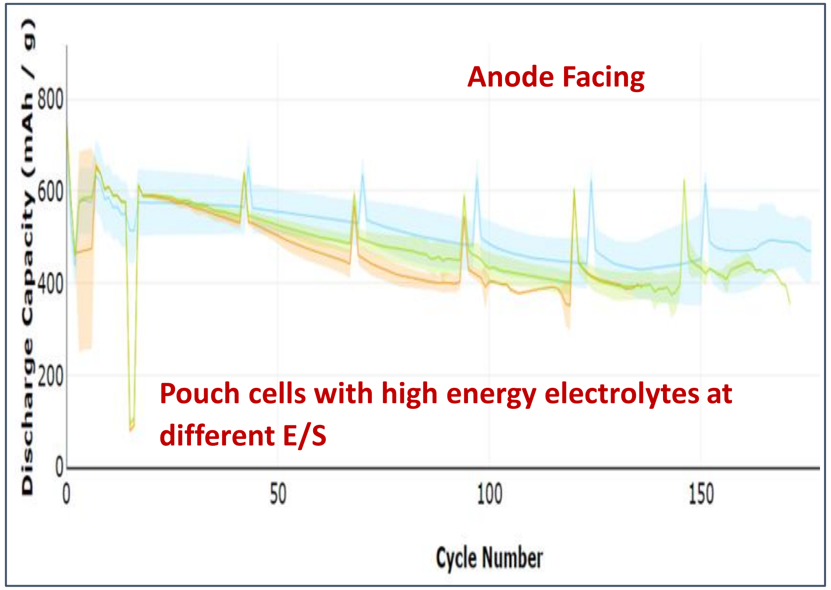
Polysulfide Absorption



Electrospun Polymer/Inorganic Coating

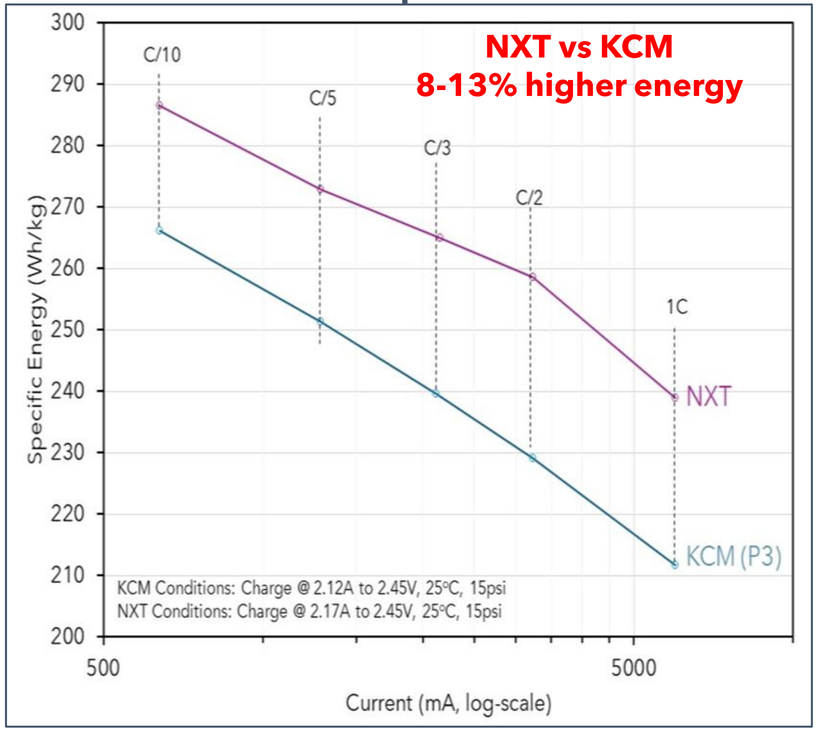


New Polymer/Inorganic Coating

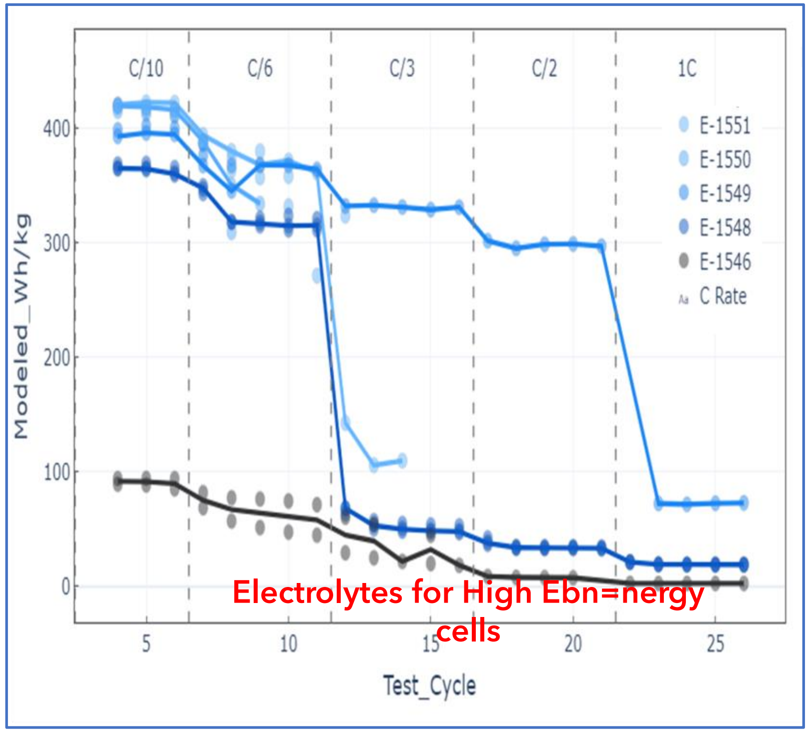


Recent Component Developments

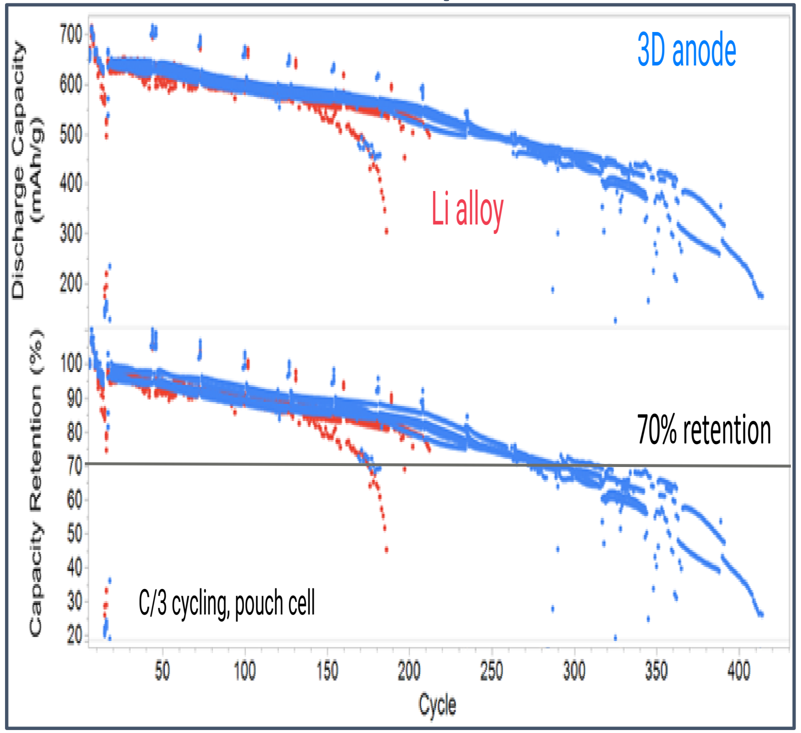
Cathode Improvements



Electrolyte Development

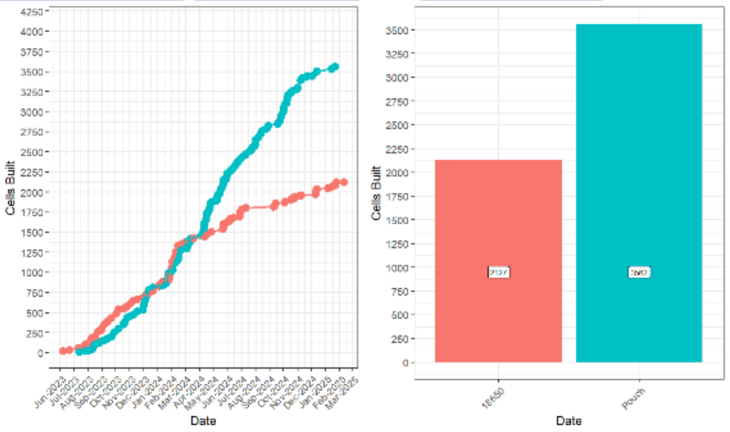


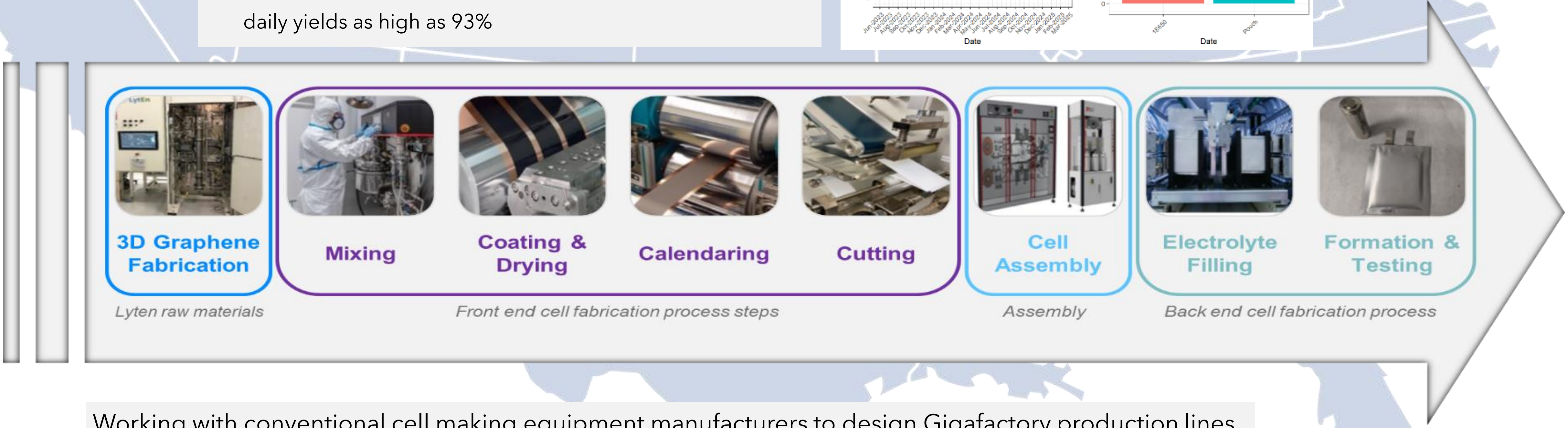
Anode Development



Lyten Uses Standard Production Equipment

- Semi-automated cell pilot line in dry-room (2MW capable)
- No custom cell assembly equipment
- Water based cathode slurry (no NMP)
- Demonstrated production rate of 100 cells / 8-hr shift
- More Than 5,500 Cells Produced to date
- Average yield throughout life of the battery pilot line is 80%; daily yields as high as 93%





Working with conventional cell making equipment manufacturers to design Gigafactory production lines

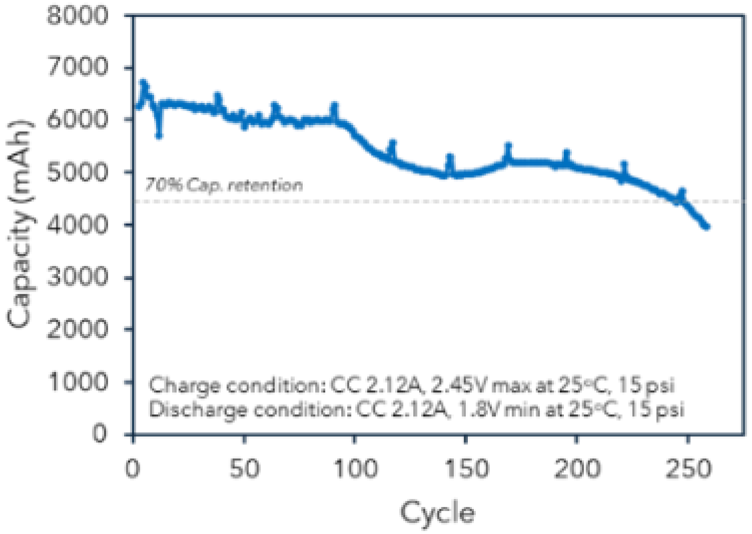
L0009-P1 Specification – May 2024

Specifications

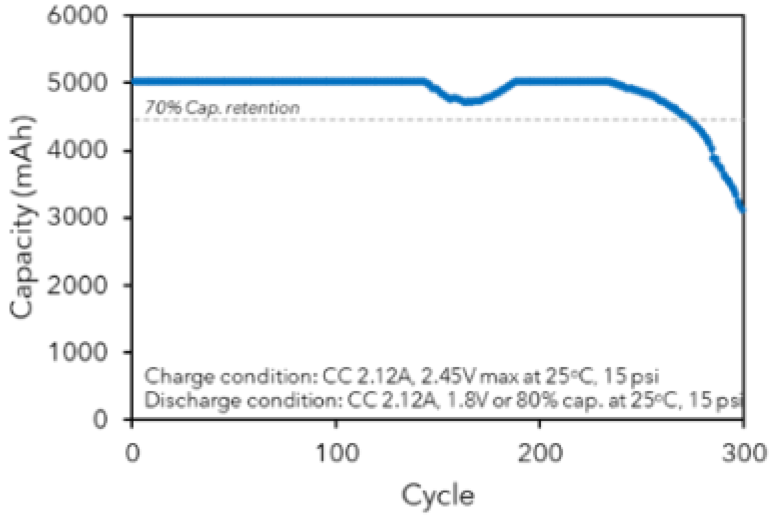
Capacity	6.34 Ah (typ.) 6.13 Ah (min.)
Energy	13.4 Wh (typ.) 12.7 Wh (min.)
Specific Energy	248 Wh/kg (typ.)
Energy Density	291 Wh/L (typ.)
Nominal Discharge Voltage	2.1 V
Charge Cut-Off Voltage Discharge Cut-Off Voltage	2.45 V 1.8 V
Mass	54.01 g (typ.)
Cycle Life (100% DOD)	238 min. @ 70% Capacity
Max Continuous Discharge Max Continuous Charge	6 A 2.12 A
Max Pulse Charge / Discharge,10s	24 A (0 – 100% SOC)
DCIR @ 100% SOC, 1C, 10s	10 mΩ (typ.)
Operating Temperature	Charge: 10°C to 45°C Discharge: -35°C to 45°C Storage: -35°C to 45°C
Cell Breathing	3 – 5% (typ.)

*All values are typical and determined at 25°C, C/D @ C/3 (2.12A), 15 psi

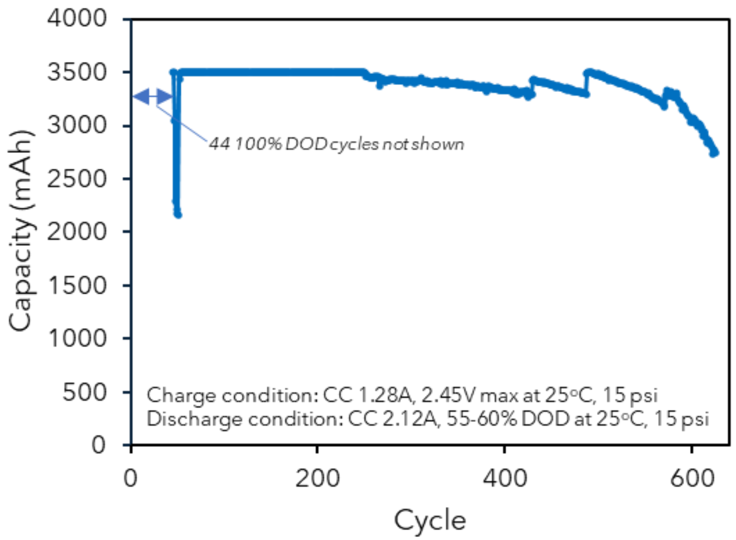
100% DOD Cycle Life Characteristics



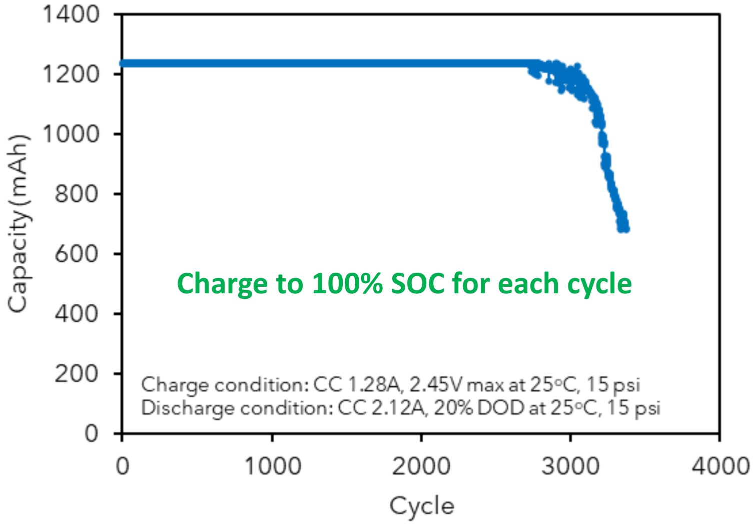
80% DOD Cycle Life Characteristics



55-60% DOD Cycle Life Characteristics



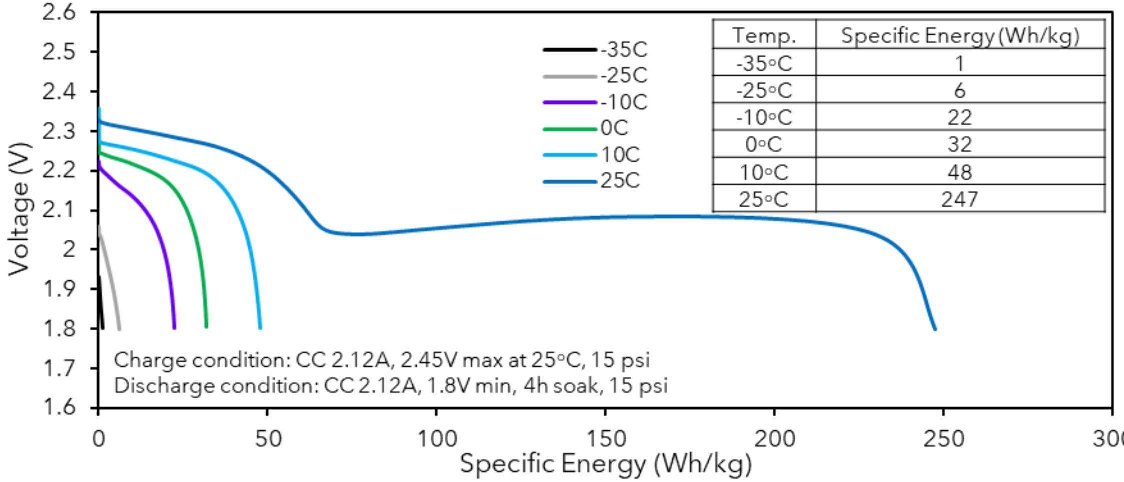
20% DOD Cycle Life Characteristics



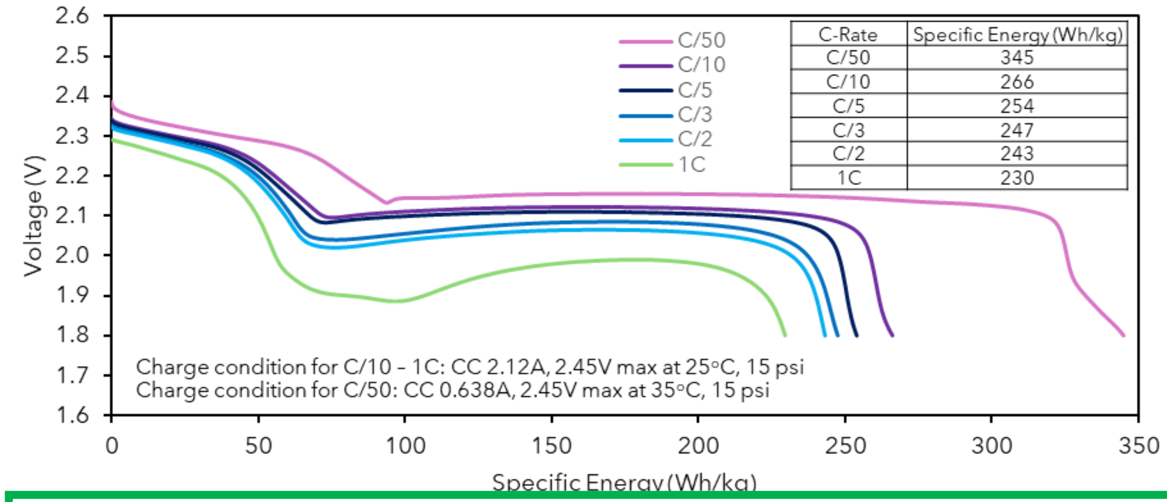
- **Higher specific energy (≥325 Wh/kg) and 200 cycles have been demonstrated in recent cells**

L0009-P1 Discharge Characteristics – May 2024

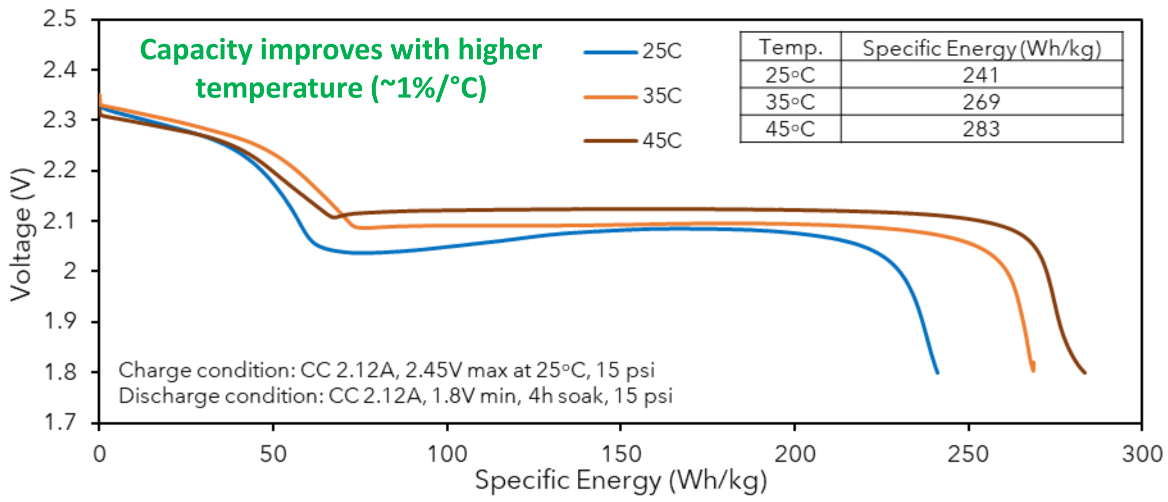
Discharge Cold Temp. C-Rate Characteristics



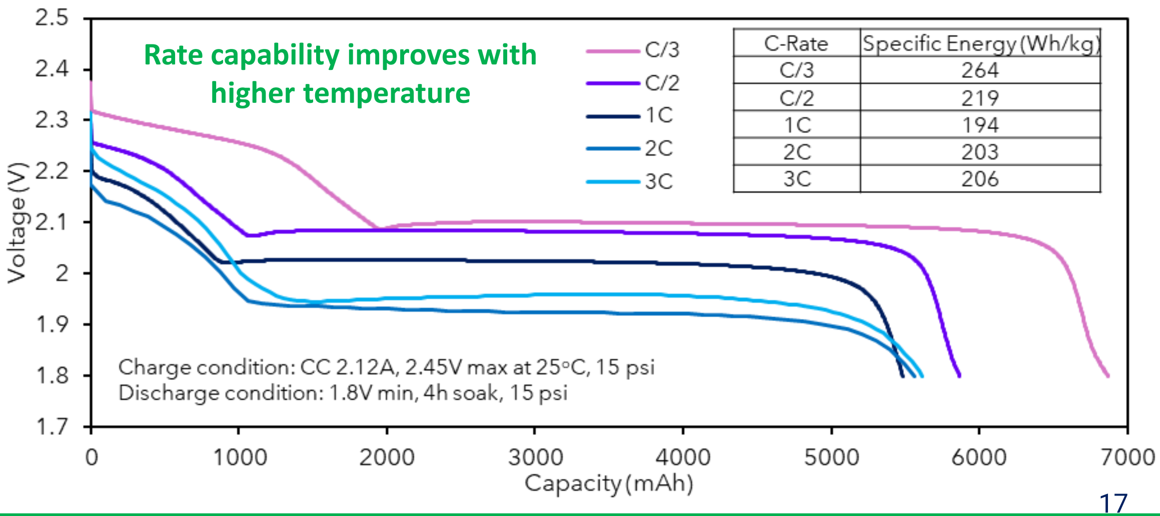
Discharge C-Rate Characteristics (25°C)



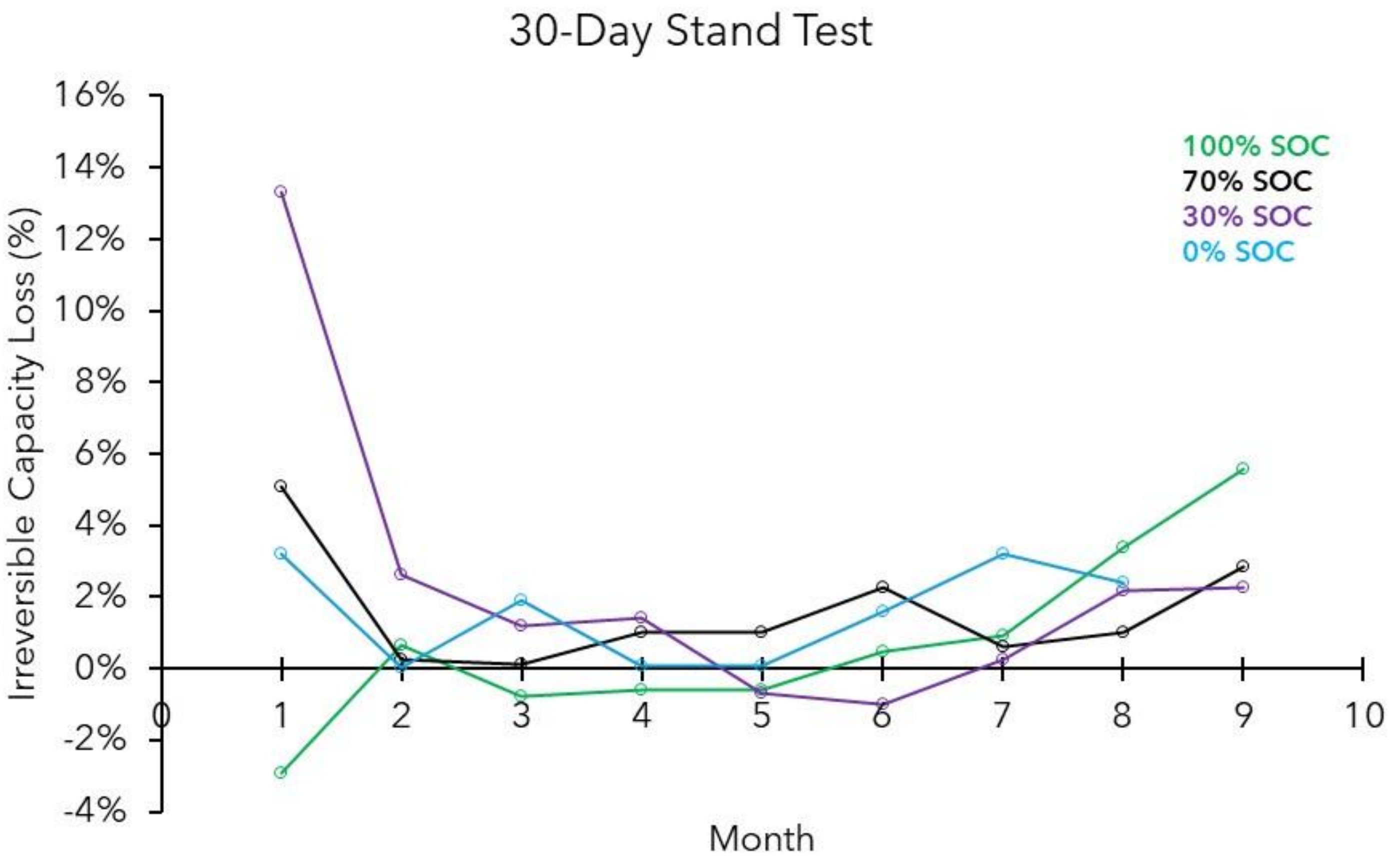
Discharge High Temp. C-Rate Characteristics



Discharge C-Rate Characteristics (45°C)

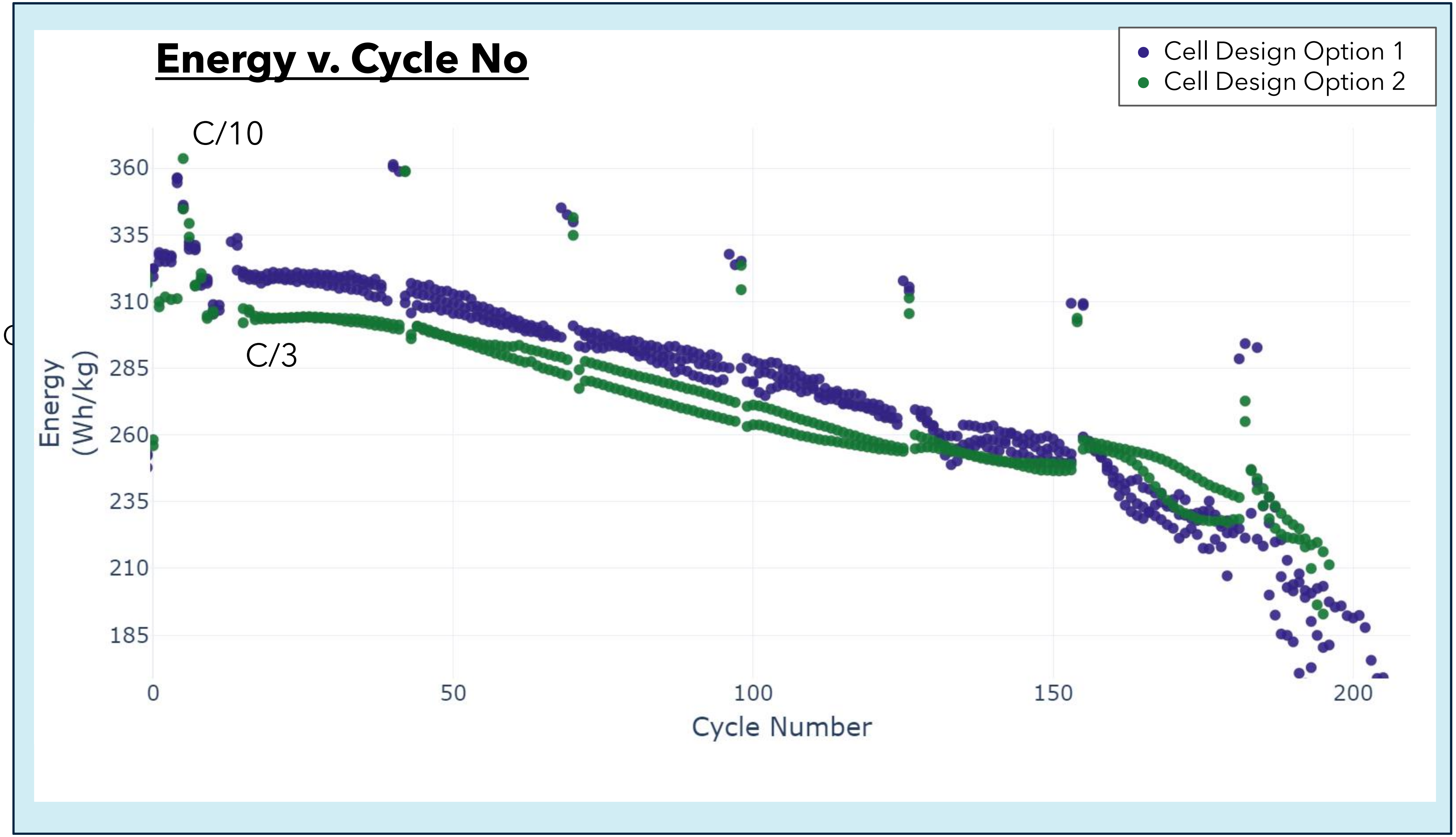


L0009-P1 Calendar Aging – May 2024



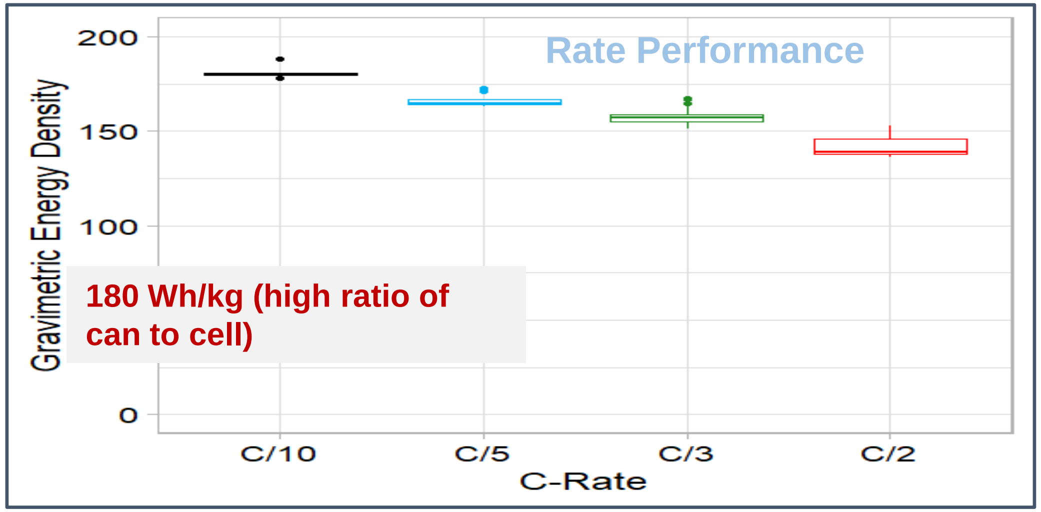
- After first 30-day stand period, cells typically experience 0 – 2% irreversible loss depending on the SOC for first 6 months
- **Storage at 100% SOC shows comparable or better performance to storage at low DOD**
  - 5x 100% DOD cycles are performed every 30 days.
  - At 0% SOC, cells experience *negative* reversible capacity loss of ~5%, and as little as 0% irreversible loss.
  - After 6 months and 35 full DOD cycles, irreversible loss increases.

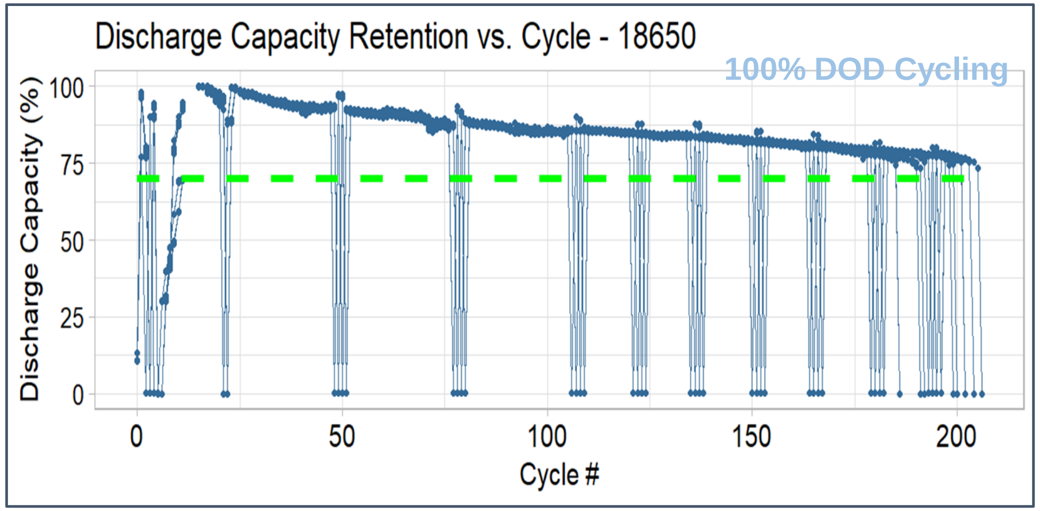
RECENT HIGH ENRGY (350 Wh/Kg) CELLS (LOW E/S)

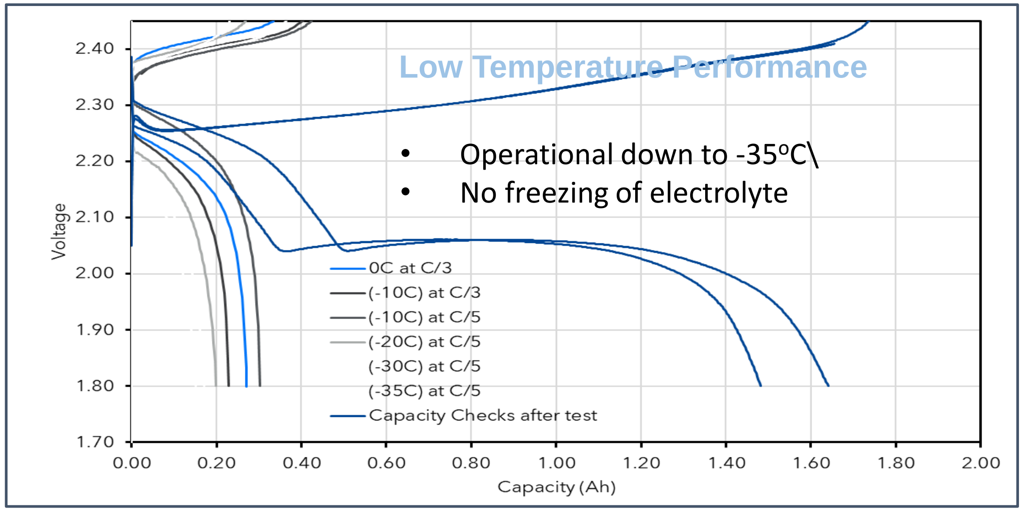


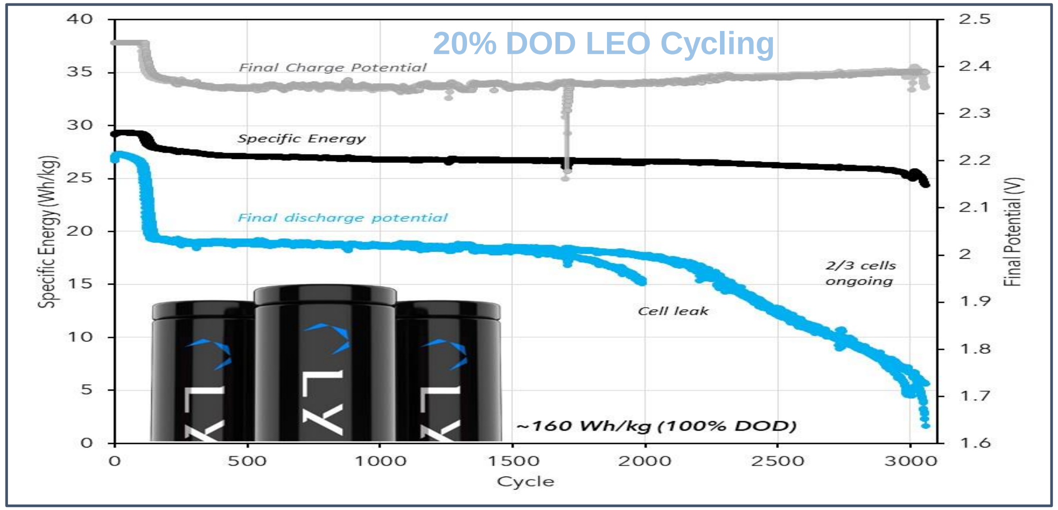
Li-S CYLINDRICAL CELLS

18650 CELLS







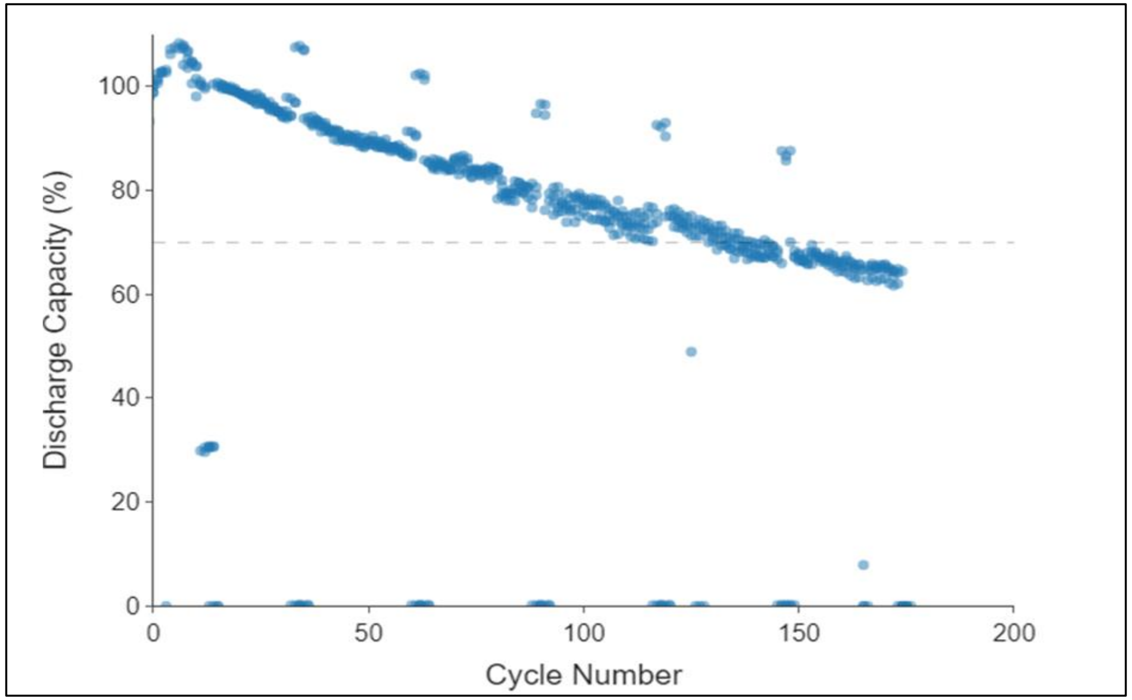


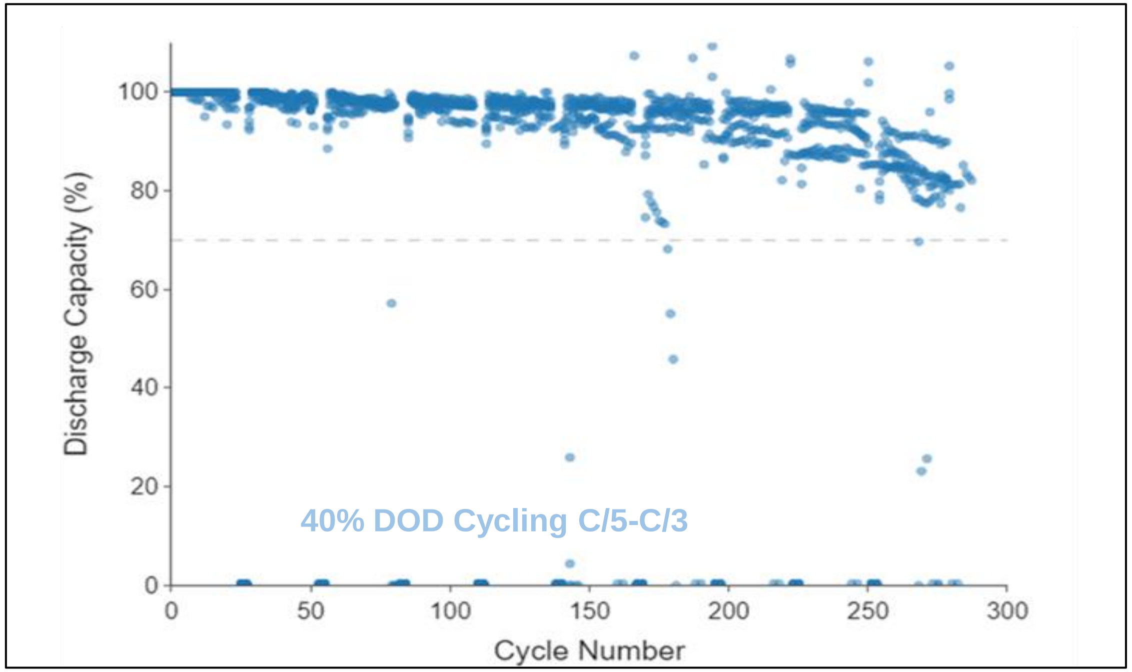
- No freezing of electrolyte even at -35C. Low capacity due to the second plateau missing.

- >3000 cycles expected with the new electrolyte.

Li-S CYLINDRICAL CELLS

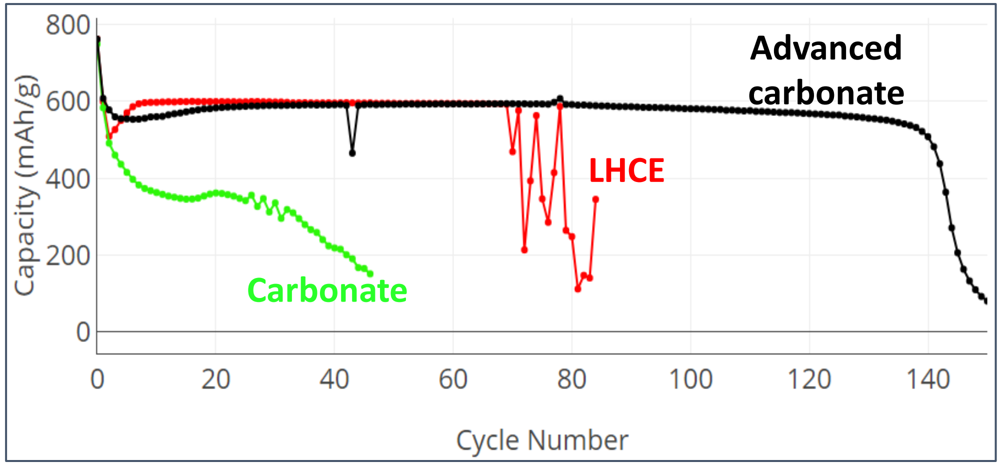
21700 CELLS

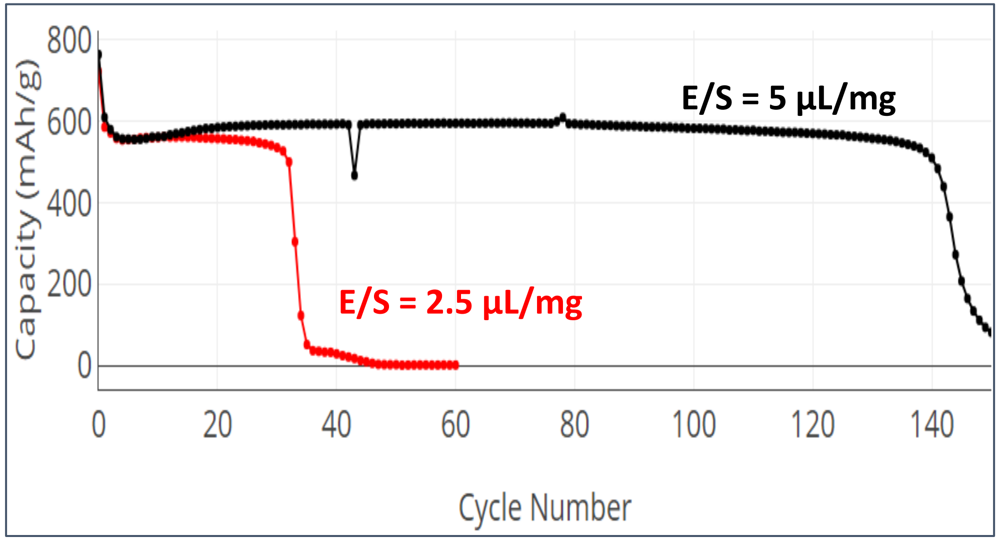


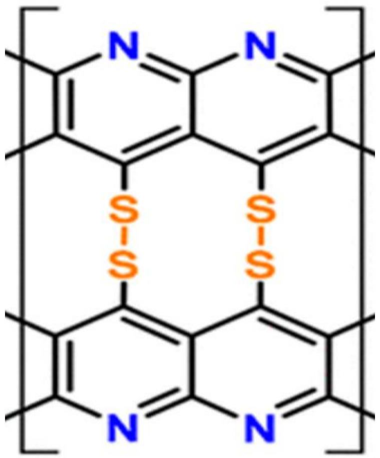


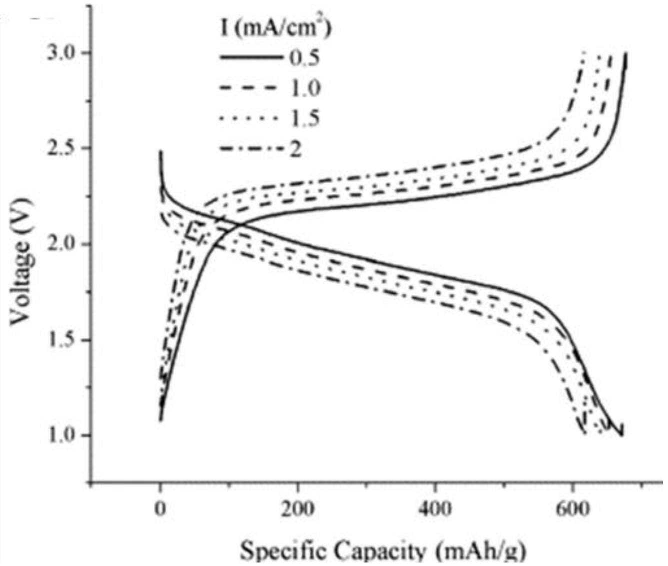
- Achieved 210 Wh/kg in the recent build;
- Expected to increase to 240 Wh/g with a reduction in inactive materials.

SPAN (Sulfurized Poly-acrylonitrile) CATHODES









No intermediates, no polysulfides?

- Electrolyte design has a huge impact on the capacity and cyclability of SPAN cathode
- The decoupling of the reaction from the electrolyte should allow for low E/S operation
- SPAN does not show a significant drop in capacity as we go from E/S of 5 to 2.5 µL/mg
- Lithium stripping/plating quality strongly influences cycle life

3rd Party Abuse Testing

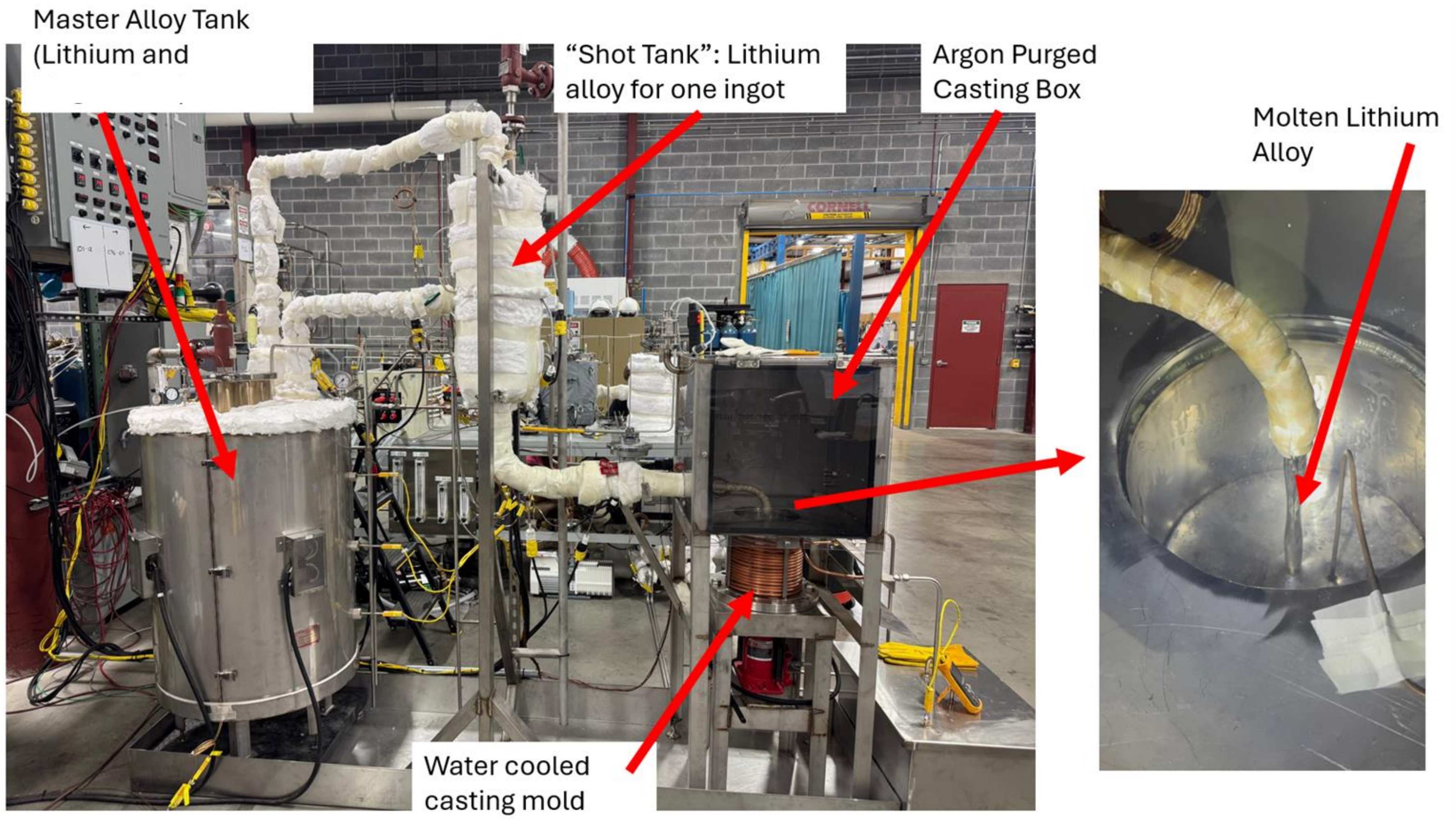
LYTEN

MOBILE POWER SOLUTIONS
Battery Technology Center

- Pouch cells passed all abuse testing at 3rd party site at 100% SOC, 2.8 Ah in late 2023; 18650s only failed impact.
- Pilot pouch cells pass overcharge testing to at least 1500% SOC and overdischarge to <934% DOD at 1C.
- Thermal runaway suppression testing on 18650s revealed CO_2 and H_2O allow for faster cooling and lower peak temperatures.
- Thermal runaway point in heat-wait-seek testing driven by melting point of anode.

Test	Format	Cell ID	Result
Nail Penetration	Pouch (2.8 Ah)	PP000207	PASS
		PP000249	PASS
	18650 (1.6 Ah)	PC000513	PASS
		PC000511	PASS
Crush / Impact	Pouch (2.8 Ah)	PP000205	PASS
		PP000202	PASS
	18650 (1.6 Ah)	PC000508	PASS
		PC000517	Thermal Runaway
Overdischarge (150%)	Pouch (2.8 Ah)	PP000201	PASS
		PP000208	PASS
	18650 (1.6 Ah)	PC000505	PASS
		PC000506	PASS
Overcharge	Pouch (2.8 Ah)	PP000204	PASS
		PP000224	PASS
	18650 (1.6 Ah)	PC000503	PASS
		PC000504	PASS
Short-circuit	Pouch (2.8 Ah)	PP000203	PASS
		PP000210	PASS
	18650 (1.6 Ah)	PC000509	PASS
		PC000510	PASS

Casting Our Own Alloy Ingot



Li Alloy Ingot

Li-S Battery Powered Drone Flight Demo

- Titan Dynamic Black Bird was integrated Lyten Li-S battery (assembled by Upgrade Energy) on 03/31/2025
- Successfully demonstrated Li-S powered UAV flight on 04/03/2025
- Total flight duration of 1 hour and 45 minutes completed; total capacity of 8 Ah was consumed
- Li-S battery was configured to 10S2P (2 packs of 5S2P) and estimated capacity of 11.6 Ah to 12.0 Ah

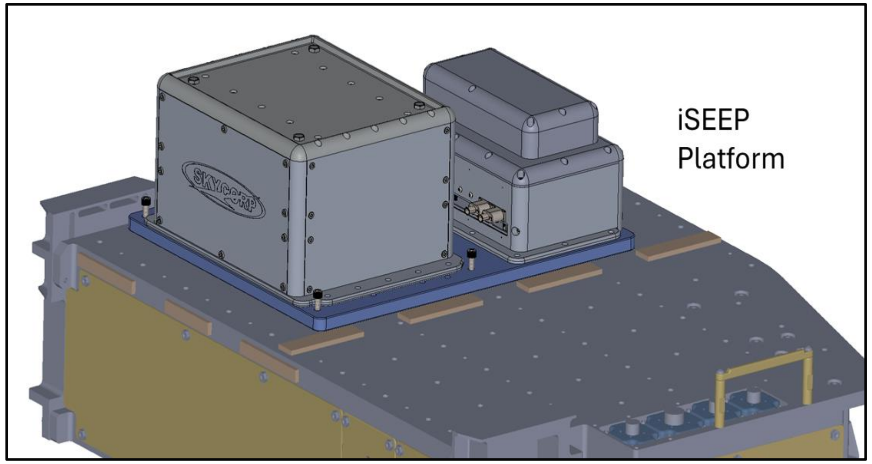
TD Black Bird

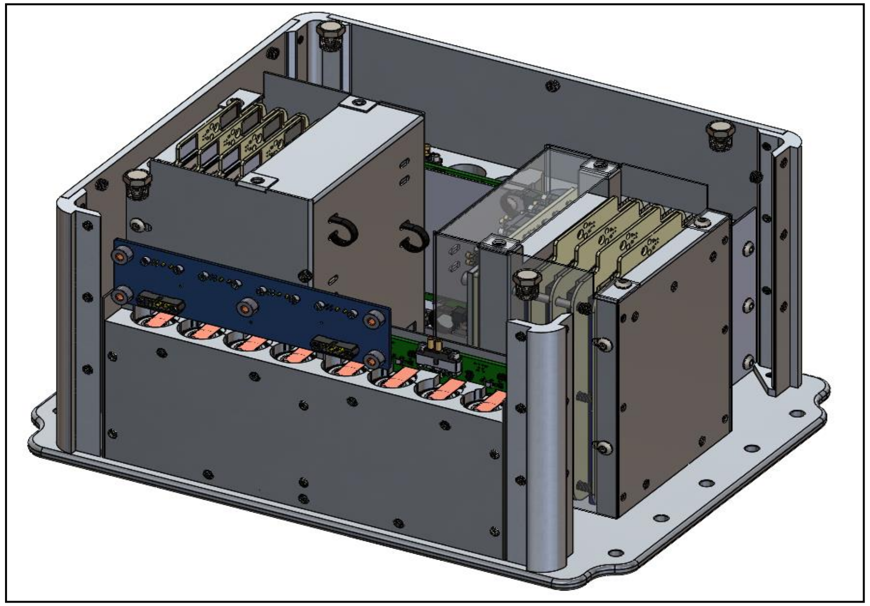
Specification	Value
Takeoff	Conventional
Max Voltage	25.2 V
Motor Peak Power	2 kW
Wingspan	2.6 m
Fuselage Length	1.4 m
Aircraft Weight (w/o battery)	2.88 kg

Lyten Li-S Cells To be Flight- Tested on ISS

SOLSTISE (Simulated Operation of Lithium-Sulfur Technology in Space Environment)

- The goal of the project is to flight-qualify three space-relevant cell formats (18650, 21700 and pouch cells) of Lyten Li-S cells to TRL-7 and to understand the microgravity 9and radiation) effects on the performance of Li-S cells with a sulfur cathode (solid-liquid-solid reaction) and Li metal anode (Li dendrites).
    - Flight-test 24 cells (2-4 Ah), i.e., 8 each of 18650, 21700 and pouch cells.
    - Each cell will be independently controlled by commanded scripts and will be cycled in different regimes relevant to distinct NASA applications.
        - LEO Satellites (20% and 30% Depth of discharge)
        - Planetary Landers/Rovers (C/5 cycling with high power pulses) (C/8 cycling to 80% DOD)
        - Extra Vehicular Activities (EVA) and Astronauts tools (e.g., Space Gloves) (Cycling at C/8)
- Twenty-four tests will be carried out to establish operational and cycle lifetimes for 6-12 months on-orbit on the JAXA Kibo external Exposed Facility.
    - A total of 72 channels of telemetry data will be collected recording each cell's voltage, current, temperature and the cumulative radiation levels.
- Compared against ground simulation test data under similar conditions
- Flight-tested cells will be retrieved from the ISS for detailed tear-down analyses to understand microgravity effects on individual cell components.
- Integration Partner: Spacebilt (and Space BD)
- Anticipated launch: January 2026





Scaling Plan

LYTEN

Pilot Line: SOP 2023

- Cylindrical 18650 / 21700 (1 MWh → 50 MWh in 2026)
- Pouch < 10 Ahr (1 MWh)
- Customers:
  - Remotely operated vehicles (drones, submersibles, rovers)
  - Portable Power
  - Satellites
  - Micromobility
  - A-Samples for all industries

2 MWh

Pilot – San Jose

100 MWh Production Line: SOP 2026

- Pouch small & large format

100 MWh

Mega – San Leandro

- Customers:
  - Fast-to-deploy stationary
  - Remotely operated vehicles (drones, submersibles, rovers)
  - Portable power
  - EVTOL
  - B-Samples for all industries

6-10 GWh

Giga - Reno

Gigafactory: SOP 2028

- 6 GWh – 10 GWh
- Cylindrical 18650 / 21700 / 46xx
- Pouch small & large format
- Customers:
  - Portable power and fast-to-deploy stationary
  - Micromobility
  - Last mile delivery vehicles
  - Heavy equipment
  - Limited production automotive
  - C-Samples for all industries

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