



Developing Anodes and Cathodes in a Li-S System

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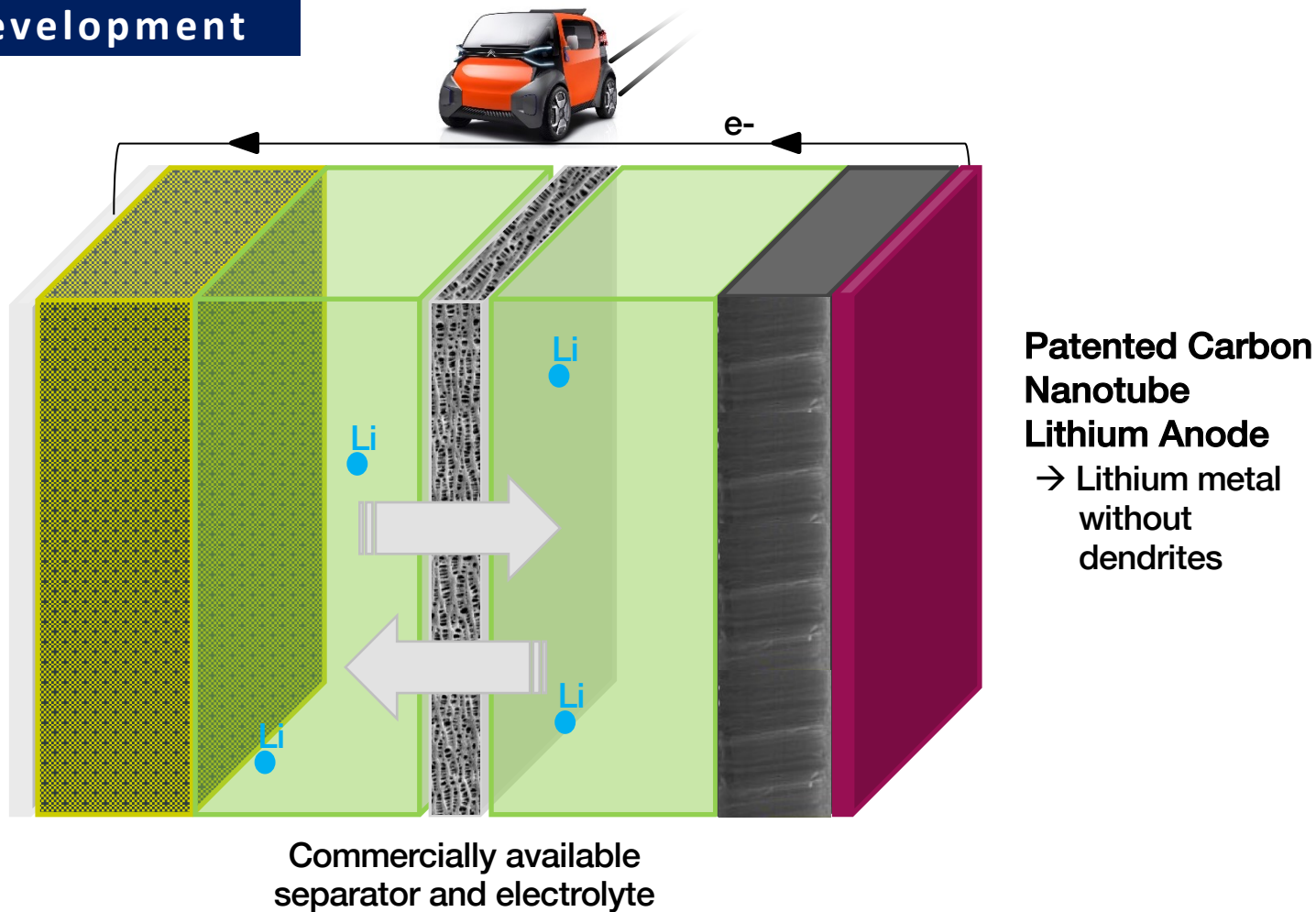
9th Workshop Lithium Sulfur Batteries
Fraunhofer IWS, Nov 28-29, 2022



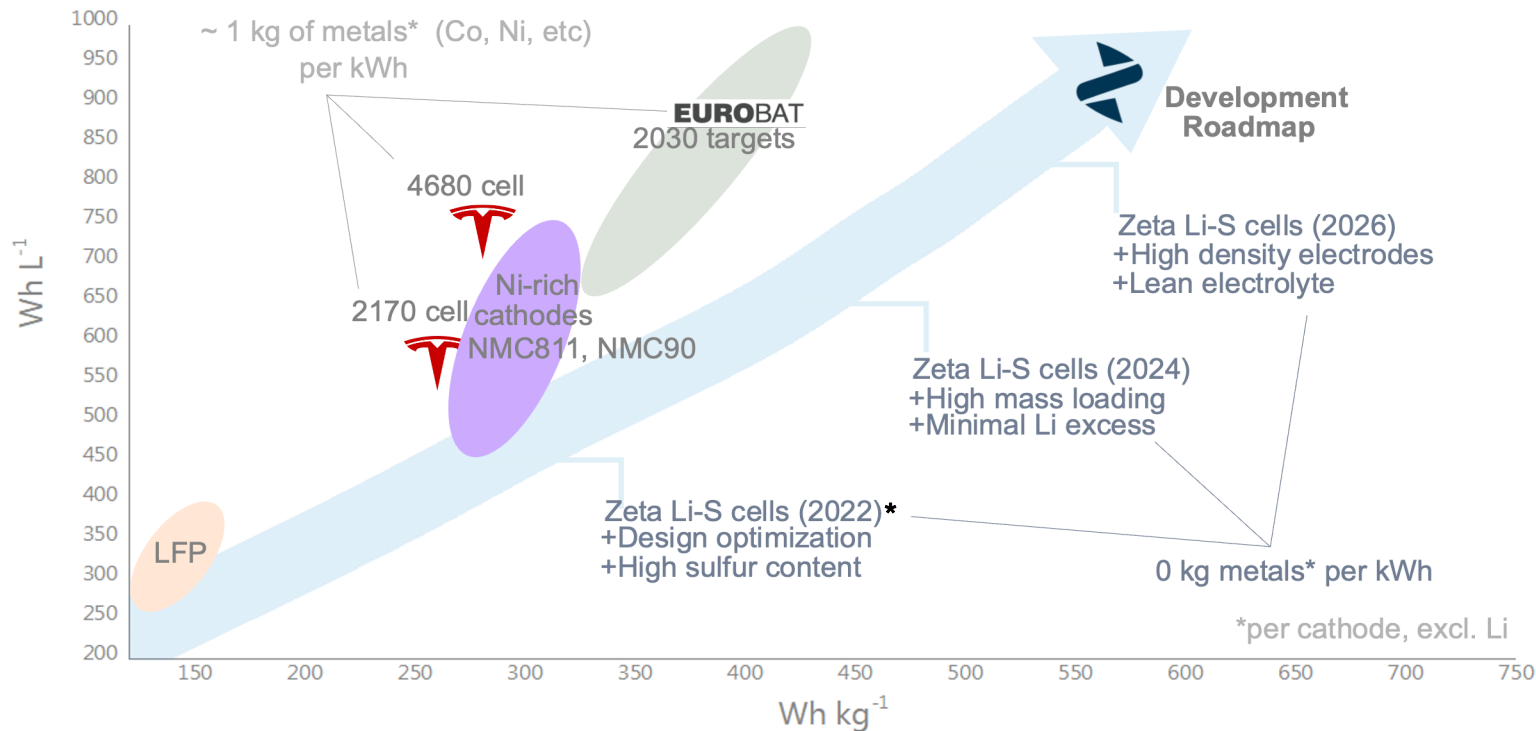
Zeta Technology

- Cathode
- Anode
- Cell

Technology Development

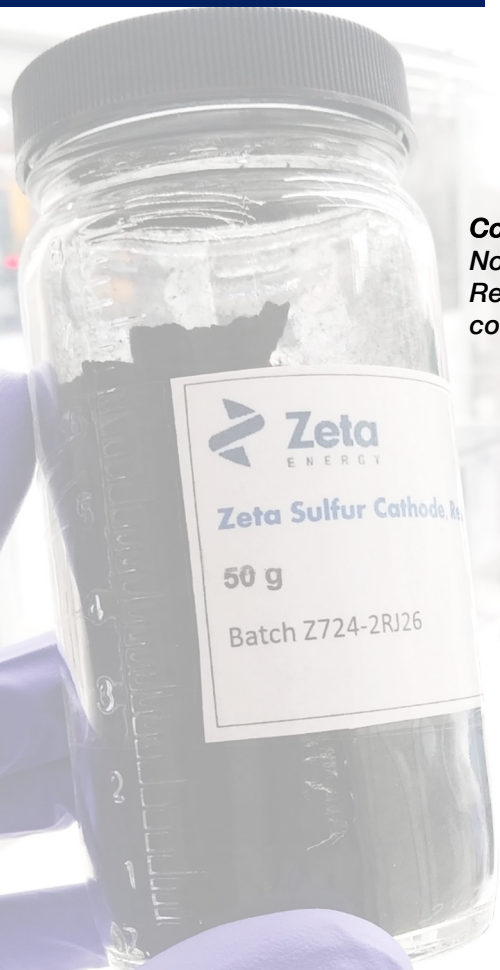


Volumetric/Gravimetric Performance Roadmap



*https://www.eurobat.org/images/members/EUROBAT_Battery_Innovation_Roadmap_2030_White_Paper.pdf (depending on the Li-ion chemistry)

Zeta Battery Technology



Cost
No cobalt or nickel.
Reduced material
cost

Performance
High capacity
cathode and anode
with no dendrites
and with long cycle
life

Sustainability
Cathodes are metal-free and use abundant
precursors (sulfur,
carbon)

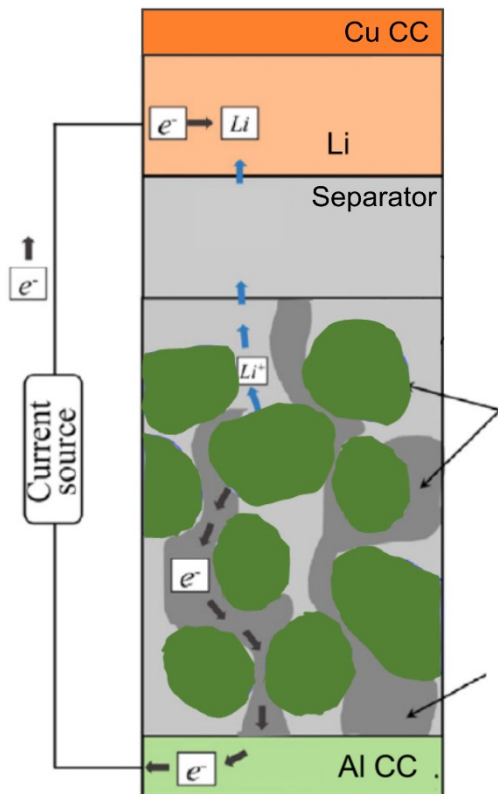
Thermal stability
Cathode decompose
at much higher
temperature than
traditional metal-
based cathodes

Manufacturability
Electrodes can be made using
existing equipment.
Compatible with water-based
processing

Improved shelf-life
Batteries can stay 100%
charged for years*

**when combined with Li metal*

Zeta Sulfurized Carbon Cathode



Electrolyte

- Stable electrolyte
- Gram per Ah ratio

Electrode density

- Determines minimum filling volume for electrolyte
- Volumetric capacity $\geq 500 \text{ mAh cm}^{-3}$

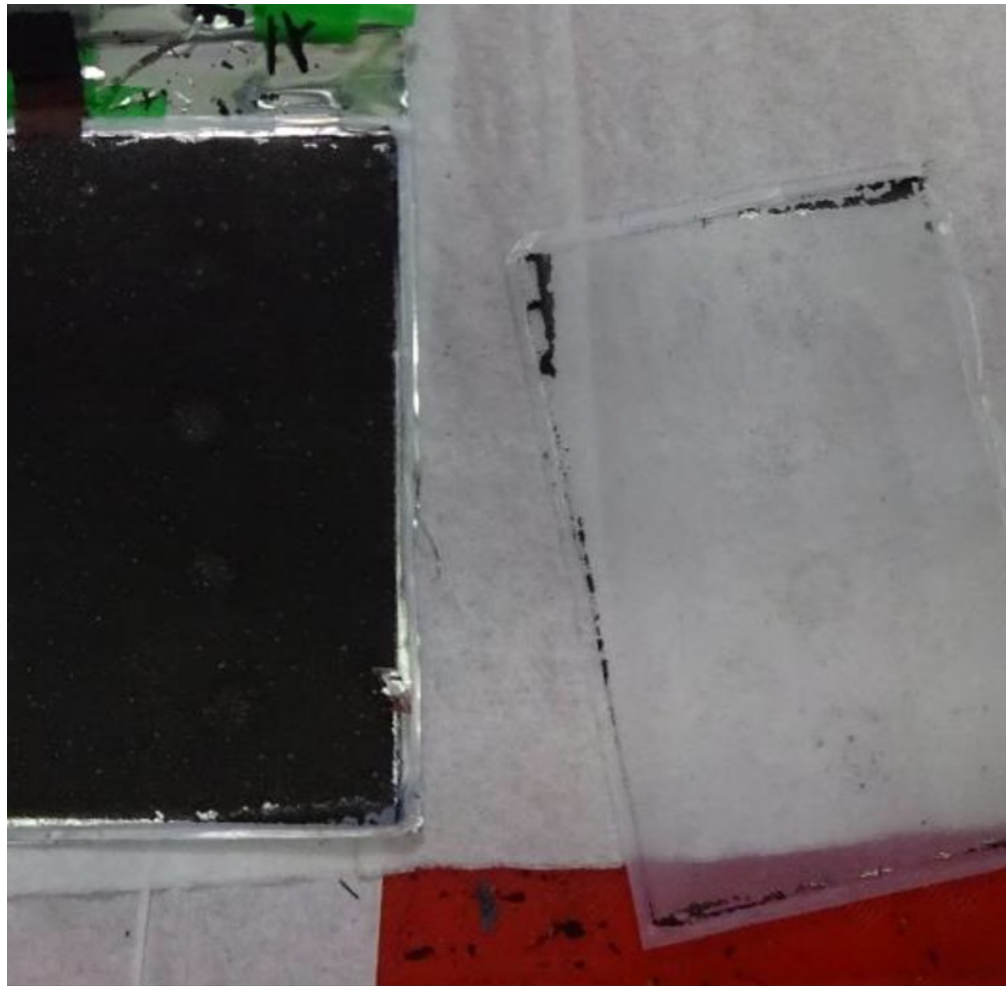
Particle engineering

- Gravimetric capacity
- S utilization
- Particle density

Li metal excess

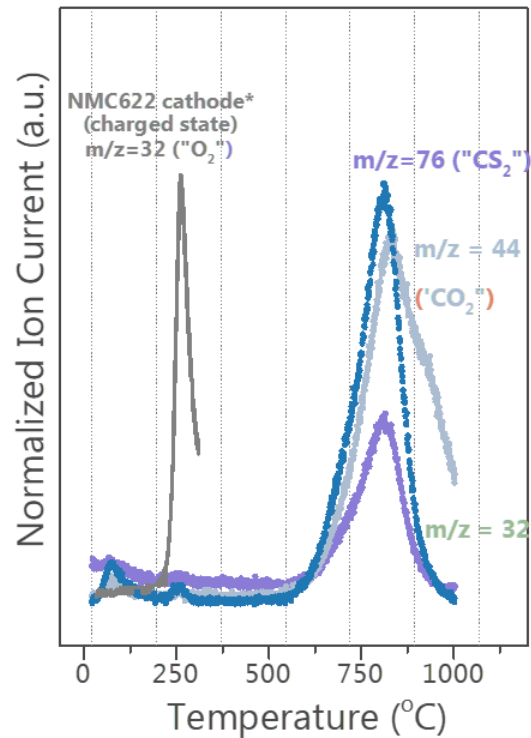
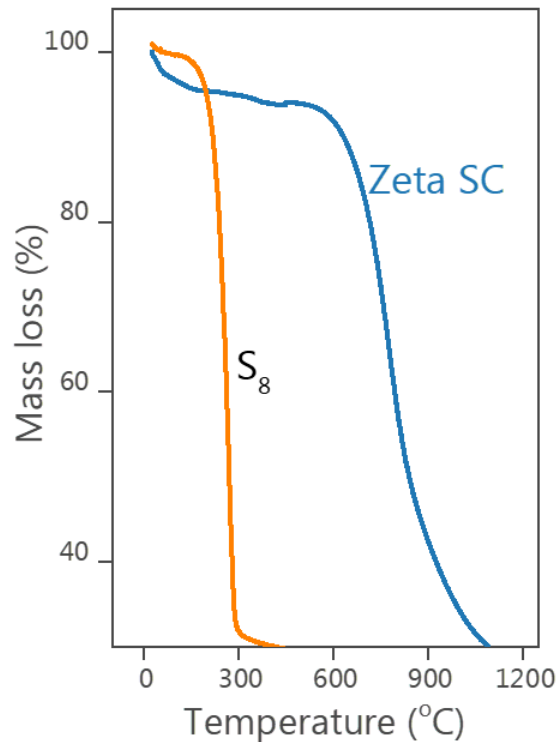
- Minimal Li excess improves volumetric energy density

No Polysulfide Shuttle

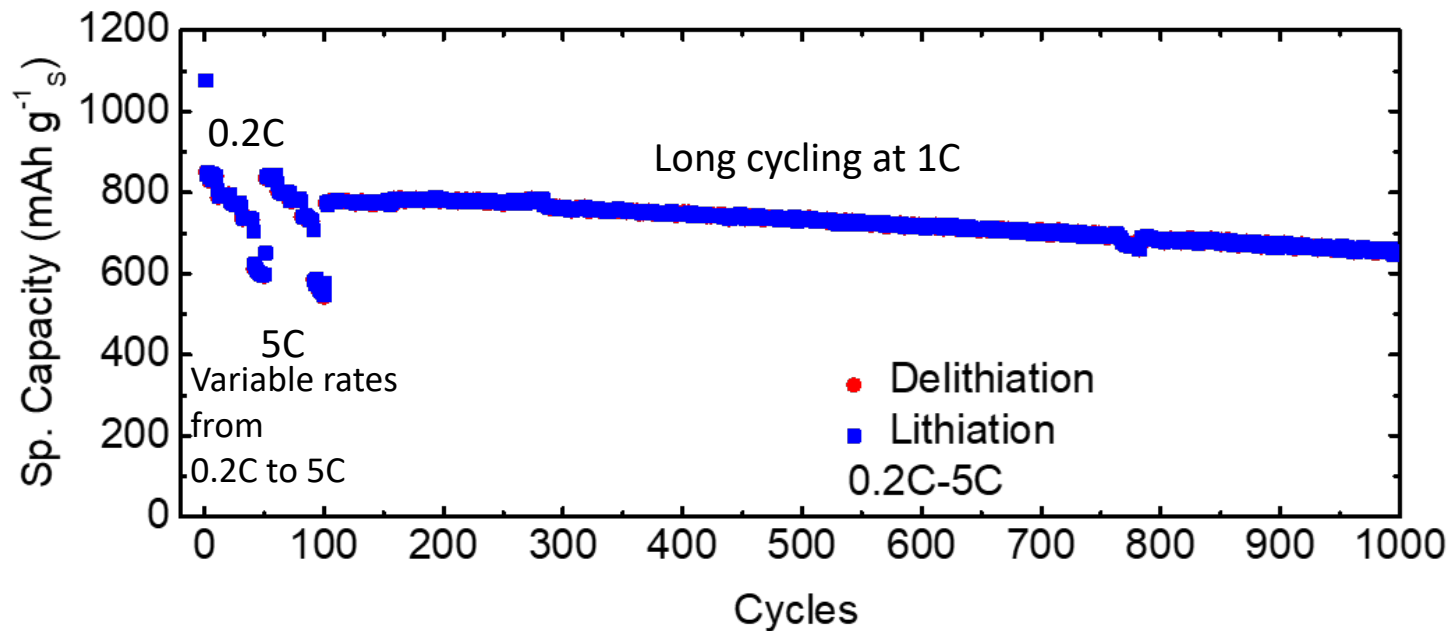


Cathode Thermal Performance

Thermal Stability
Zeta Energy vs.
Traditional
Cathodes



Cathode Cycle Life



Coin cell data – Cathode material for Gen1
>85% capacity retention after 1,000 charge/discharge cycles at 1C
(Note: Provides direction for what is possible with Gen1 cell)

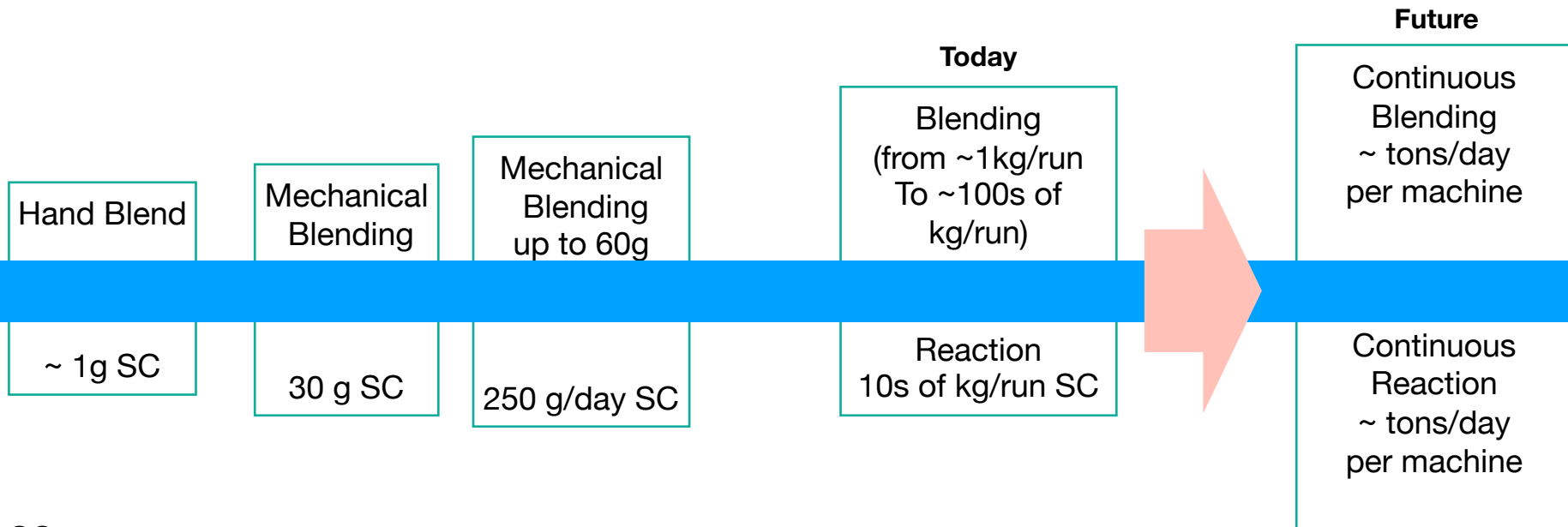
Self Discharge

Cell holds the charge for extended periods of time >5 months → Numerous high margin applications!

Cell	Capacity retention after full charge	
	Cycles/Period / C-rate	Retention (%)
10/9/2019-HCC1 (coin)	~50/ 5 days/ 0.5C	99.9%
10/9/2019-HCC5 (coin)	~50/ 5 days / 0.5C	~100%
10/4/2019-HCC1 (coin)	~50 / 5 days / 0.5C	99.9%
05/29/2018-PC1 (pouch)	~100/ 5 months / 0.2C	99.5%

Cathode Material Scaling

Blending



SC: Sulfurized Carbon

Reaction

Cathode Material Scaling

*Large scale mixing
100s of kg*

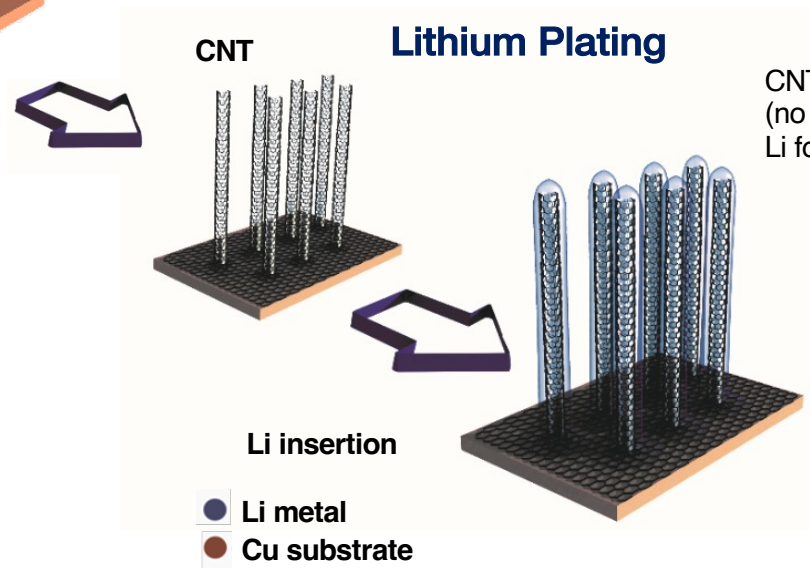
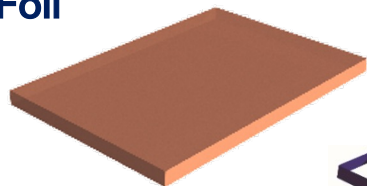


Anode Development

- **Lithium metal anode – Li hosted by Carbon Nanotubes**
- **Vertically Aligned Carbon Nanotubes (VACNT)**
- **Robust seed layer**
- **Continuous CNT growth on foil to specific thickness**
- **Dendrite free (!)**
- **Production process scaling – dry process**
- **From vignettes through sheet to roll2roll process**
- **Utilize equipment from other established industries**

Zeta Anode Development

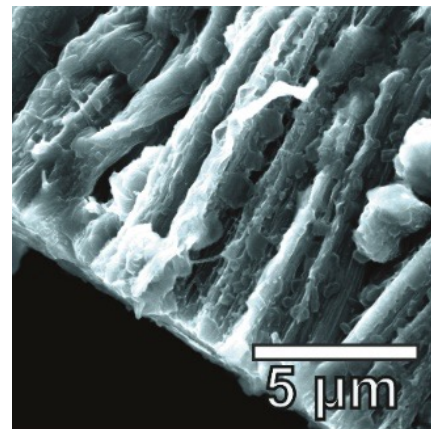
Cu Foil



CNT-Li anode

- High surface area
- High porosity
- High electrical conductivity

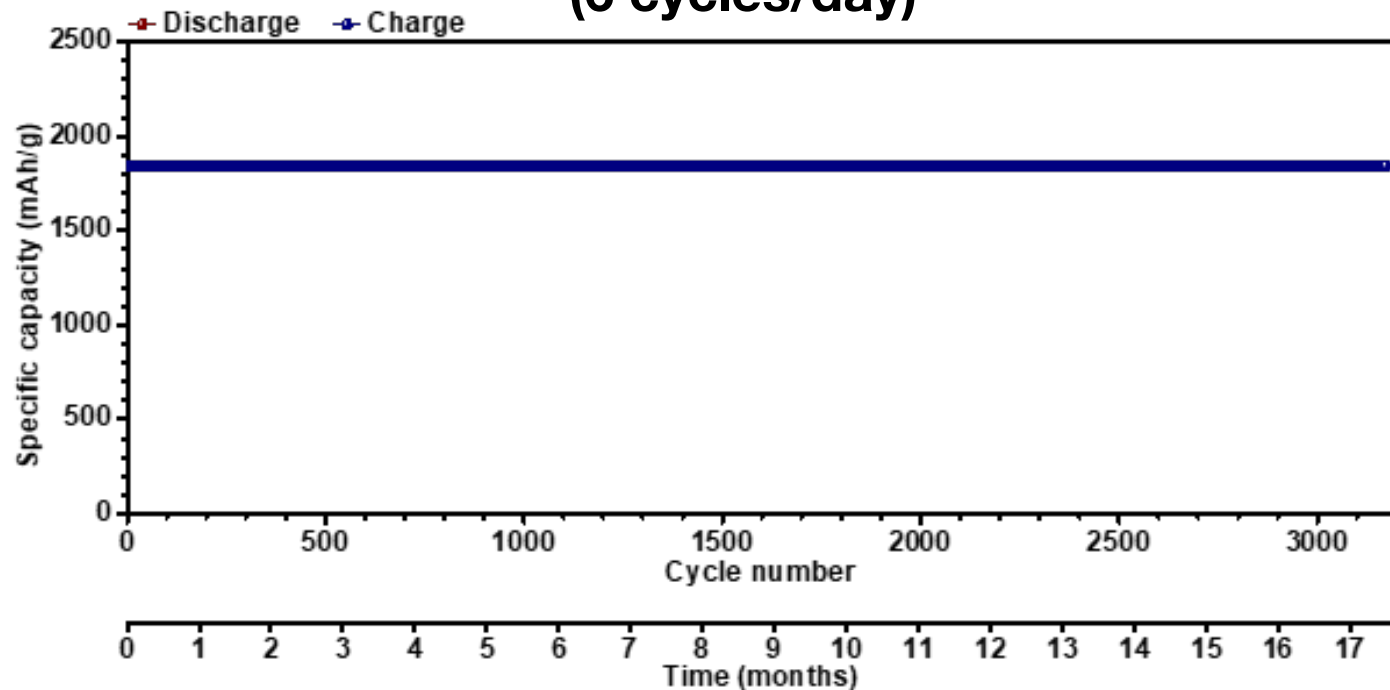
CNT-Li
(no dendritic/mossy
Li formation)



Lithiated CNTs

Anode cycle life

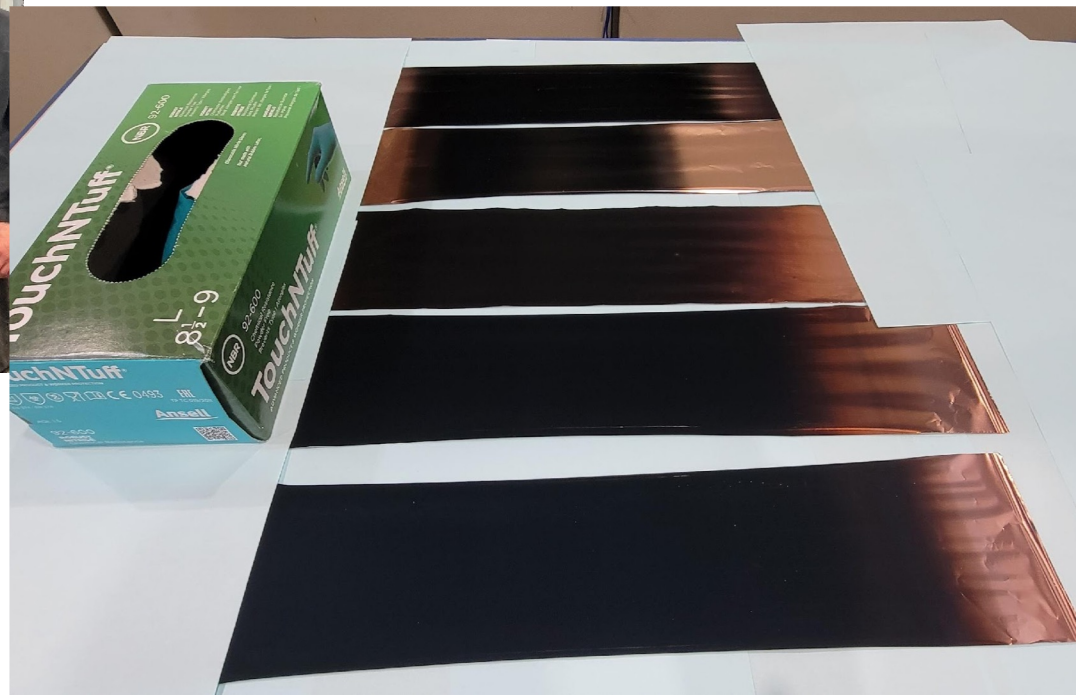
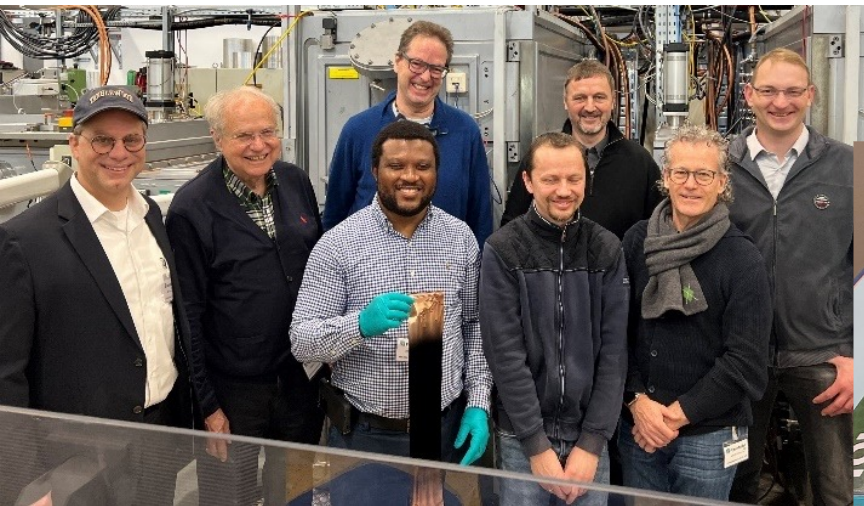
Long cycling at 0.5C
(6 cycles/day)



~100% capacity retention
after 3,000+ charge/discharge cycles at 0.5C (still running!)

*Commercial graphite anode capacity ~350 mAh/g

April '22



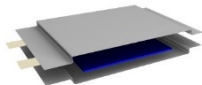
Cell Dev

Zeta Battery Development



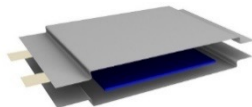
mAh's

2017/18



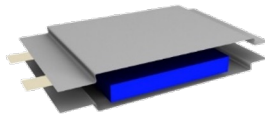
100 mAh

2019



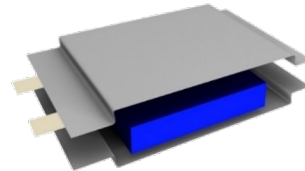
1Ah

2020



3 - 25Ah

2022

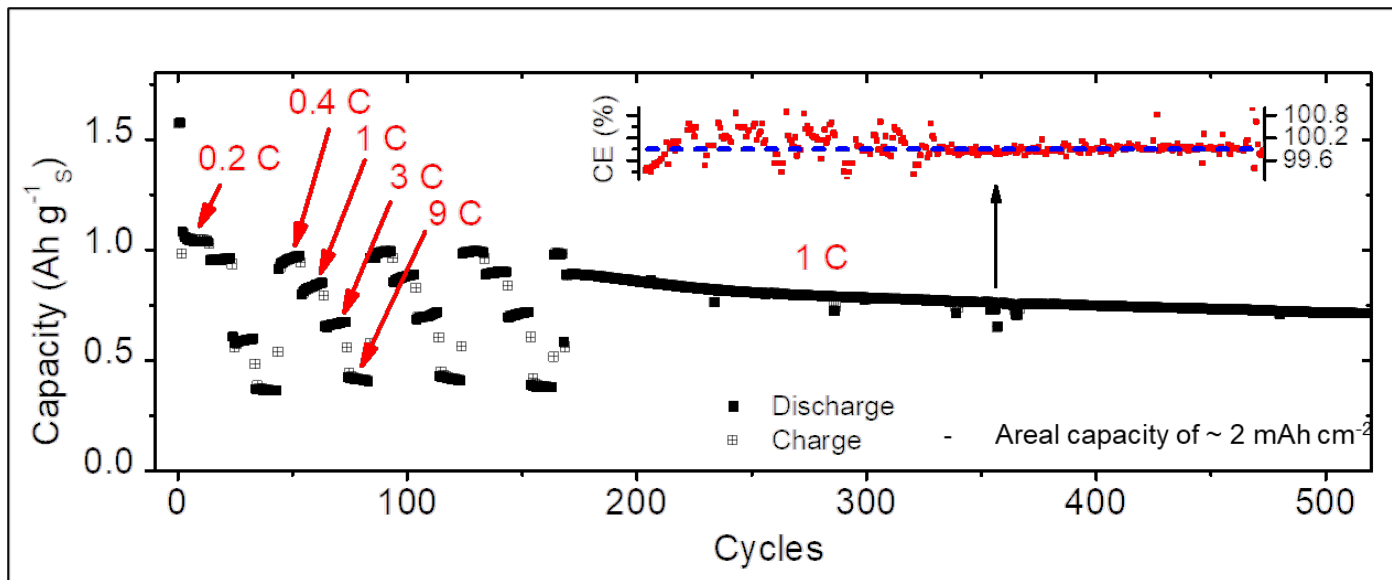


>25Ah

2022/23



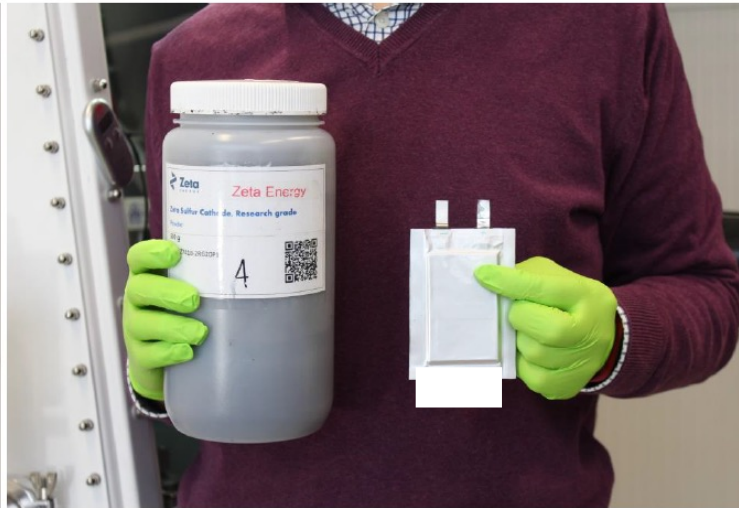
Full Cell



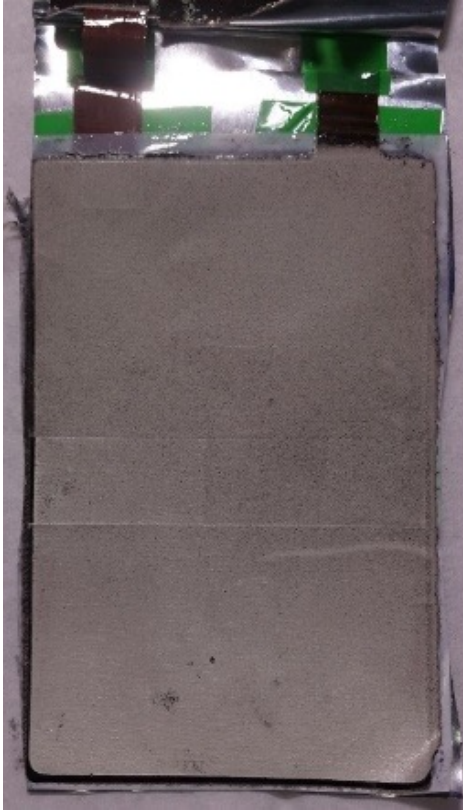
- > 85% capacity retention after 550 cycles
- Pulse discharge stress tested up to 9C with immediate reversion to mean capacity curve
- Near 100% Coulombic Efficiency after 550 cycles

Pouch Cell Milestone

- Pouch cells are used for cell development



Largest Lithiated VACNT Electrode – Ever!!!



- Lithiated VACNT Anode
- VACNTs on copper foil
- Double-sided VACNT growth
- Double sided lithiation

Final Thoughts!

- Successes of some Li-S battery companies help other Li-S battery companies
- Never underestimate material scale up – start early
- Prioritize pouch, prismatic, or cylindrical cell development early



Zeta
ENERGY

Thank You!