Rechargeable batteries for improved low-temperature performance based on alloy anodes

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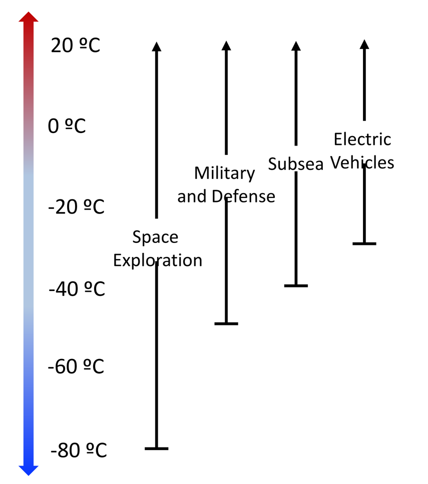
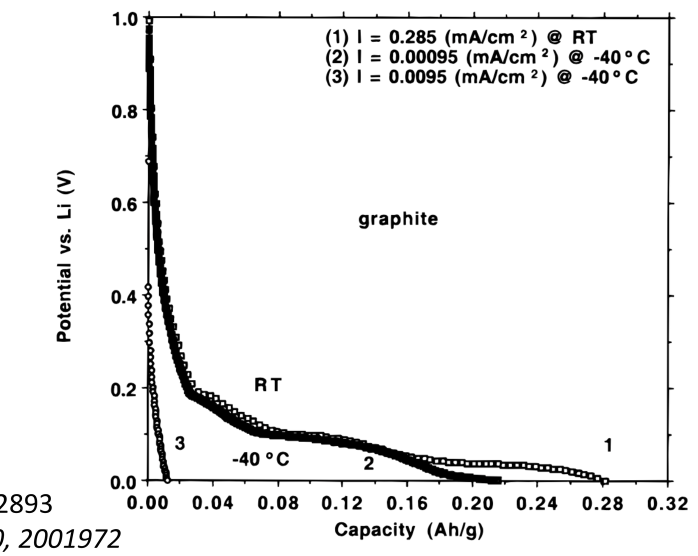
Introduction

Energy storage is necessary in a wide range of temperatures, but commercial graphite anodes fail at low temperatures.





C.K Huang *et al* 2000 *J. Electrochem. Soc.* **147** 2893
Abhay Gupta *et al* Adv. Energy Mater. 2020, 10, 2001972

Materials that electrochemically alloy with lithium offer promising performance for high-energy, low-temperature energy storage

	Specific Energy (Wh/kg)	Reaction Potential (V)	Li^+ Diffusivity (cm^2/s)
Graphite	233	0.125	10^{-11}
Indium	311	0.3	10^{-8}
	Higher energy density reduces weight of payload for same energy need	Slightly higher reaction potential minimizes lithium dendrite formation while maintaining high energy	High diffusivity improves rate performance at low temperature

Takeaway

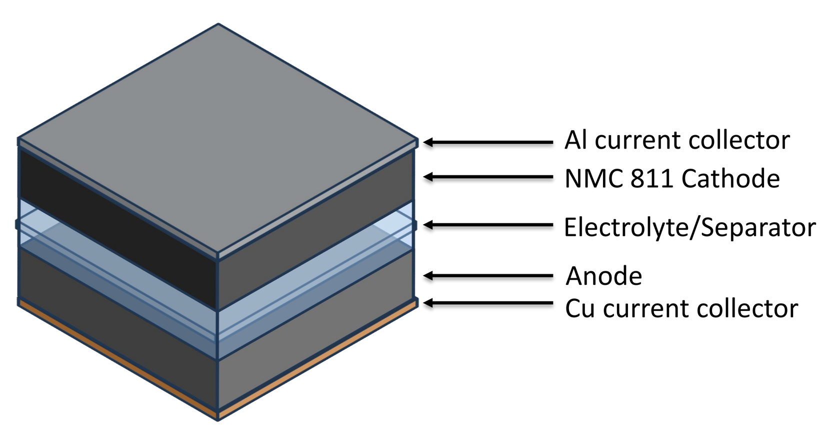
Lithium alloys are a promising alternative battery electrode to enable high energy, low-temperature batteries with high scalability for Lunar and other applications

- Early-scale optimization enabled battery operation down to -60 ºC, with energy density of over 100 Wh/kg at -40 ºC
- Anode fabrication mirrors processes already carried out on a global scale and prioritizes ease of integration with existing battery manufacturing technique
- Future work will further optimize system for long lifetime and maximum capacity utilization

Modeling reveals high energy batteries enabled by lithium alloys

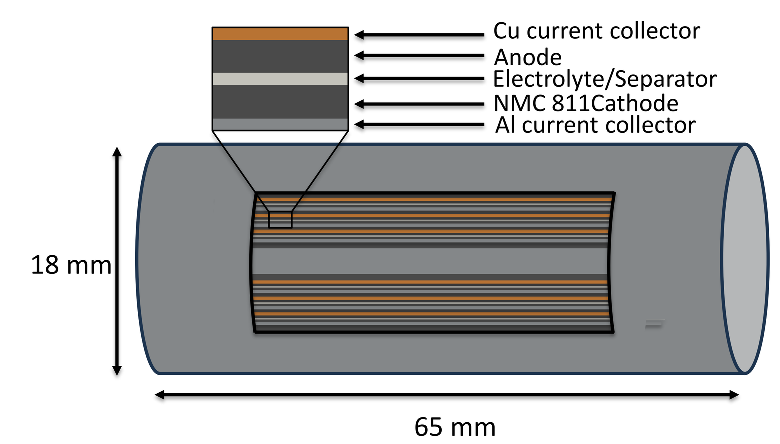
Stack Level

- Does not account for packaging weight
- Includes inactive components of battery stack



Cell Level

- Accounts for entire weight of battery cell



$$Specific\ energy = \frac{V_{avg} * Cap}{Weight}$$

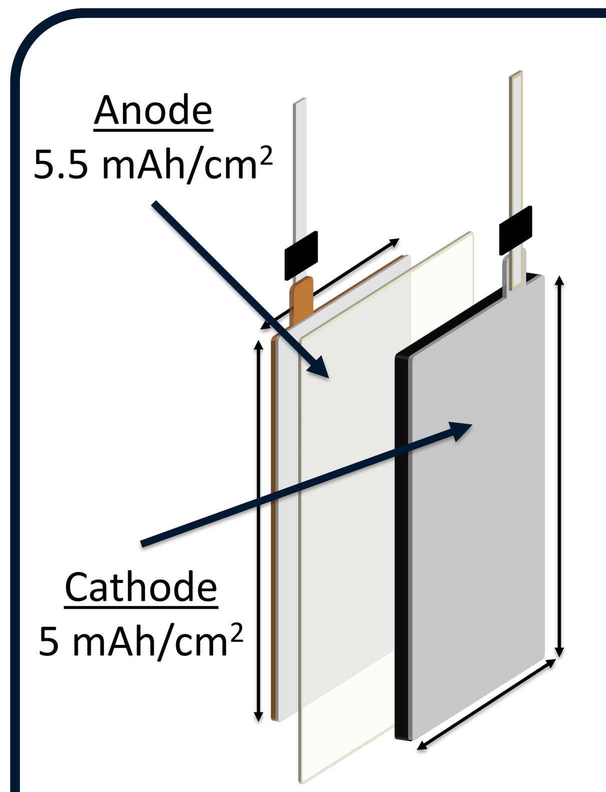
$$Energy\ density = \frac{V_{avg} * Cap}{Volume}$$

		Stack		18650		
Anode	Areal Capacity (mAh/cm^2)	Specific Energy (Wh/kg)	Energy Density (Wh/L)	Specific Energy (Wh/kg)	Energy Density (Wh/L)	Total Capacity (Ah)
Graphite	3	246	701	217	645	2.9
Graphite	5	281	779	233	709	3.2
Indium	5	345	1185	311	1088	5.1

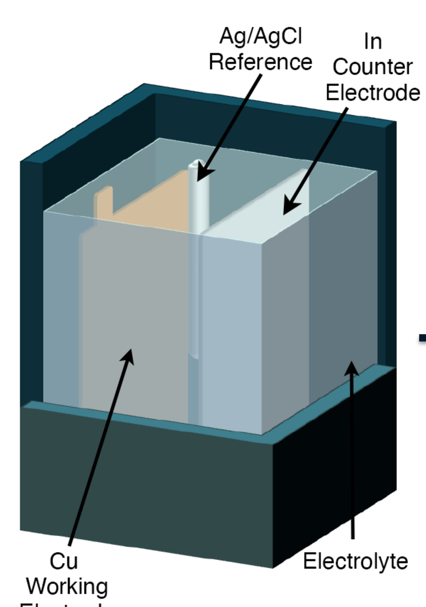
Even at high loading, graphite cannot achieve 300 Wh/kg. Thicker electrodes would result in poor performance at low temperature due to diffusional limitations.

Novel materials meet energy metrics for next generation applications with thin electrodes.

Novel anode fabrication was required to achieve energy metrics



Anode must be ~7 µm thick to achieve energy metrics

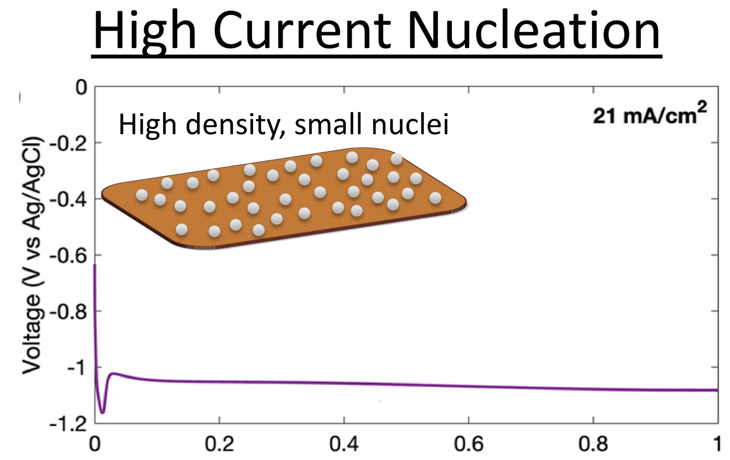


Deposition

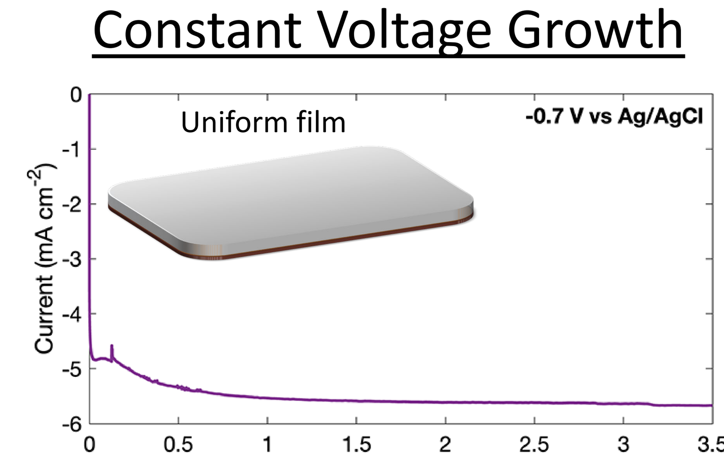
Two-step electro-deposition results in uniform, large area electrodes with controllable thickness.

Indium demonstrates air and moisture stability, simplifying manufacturing compared to other next-gen materials

High Current Nucleation

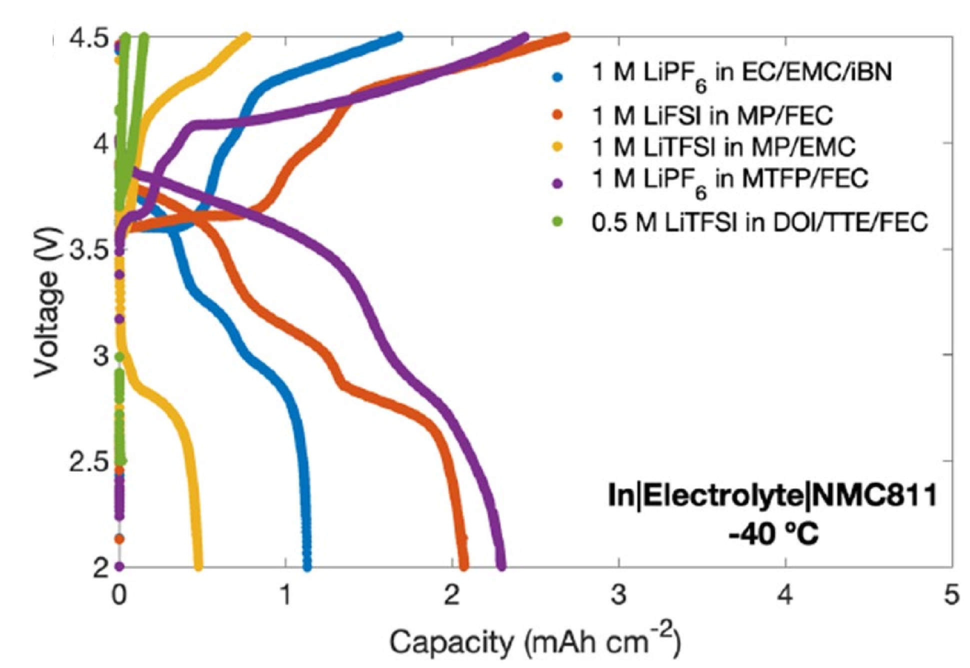


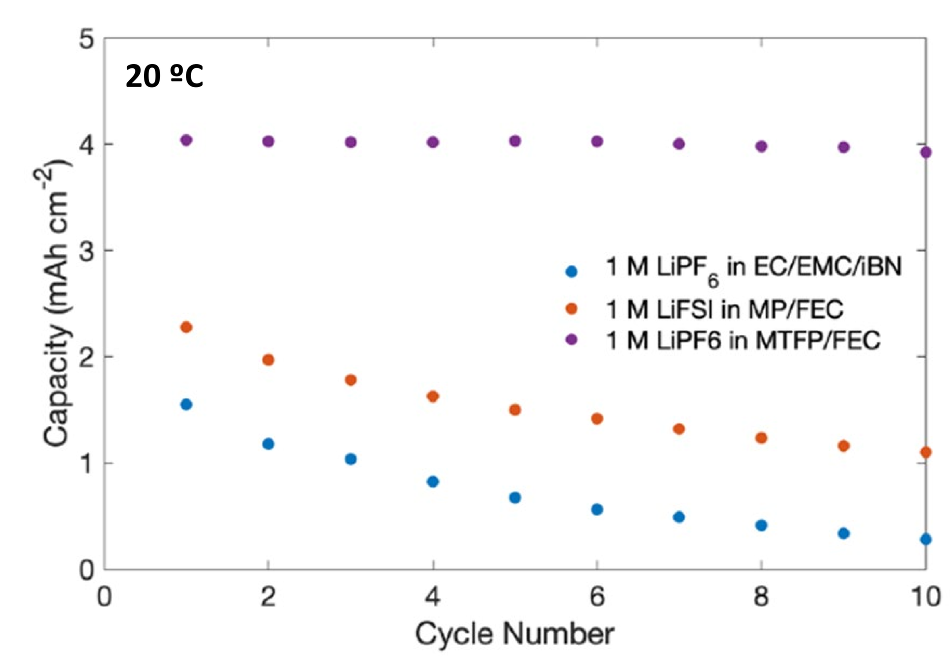
Constant Voltage Growth



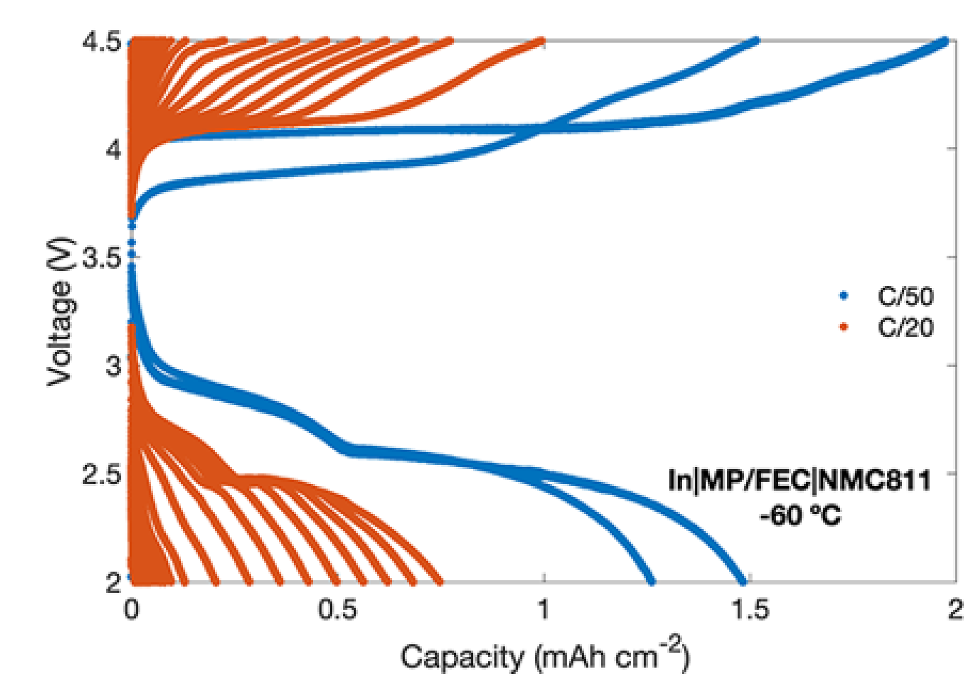
Electrolyte development enables low-temperature operation

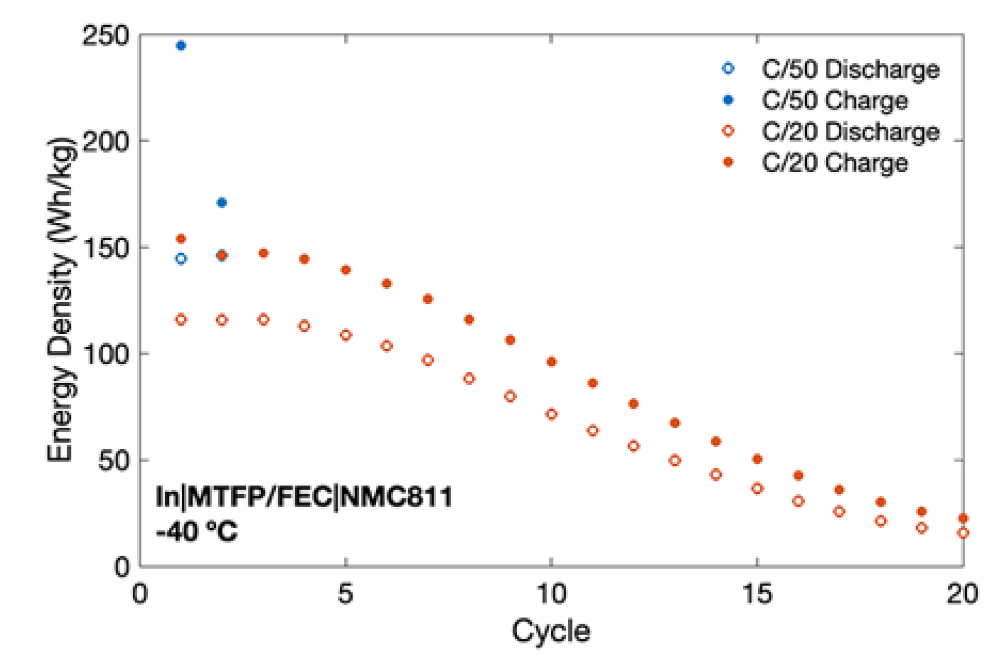
Electrolyte composition drastically alters performance



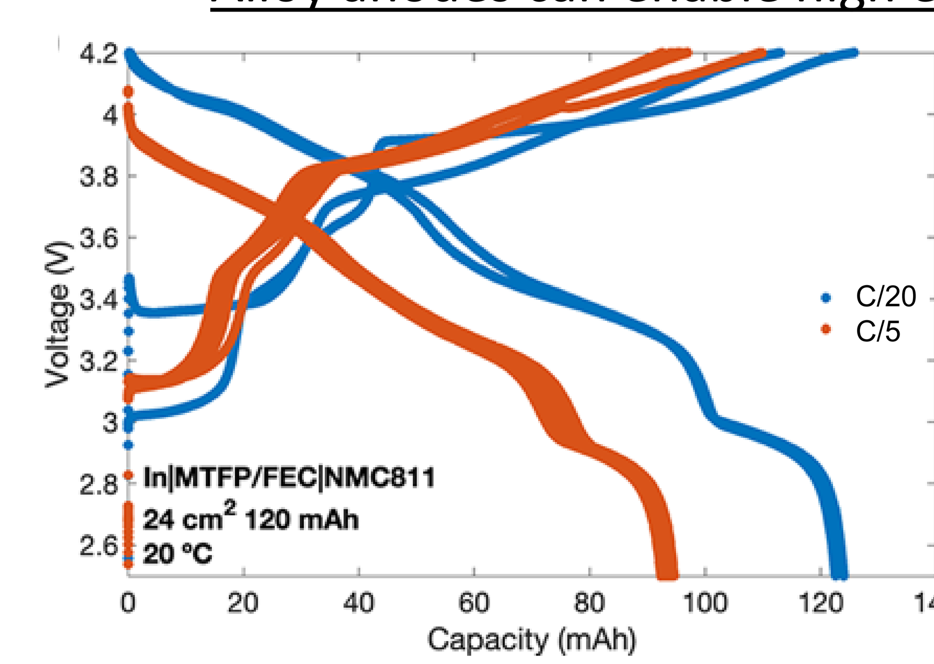


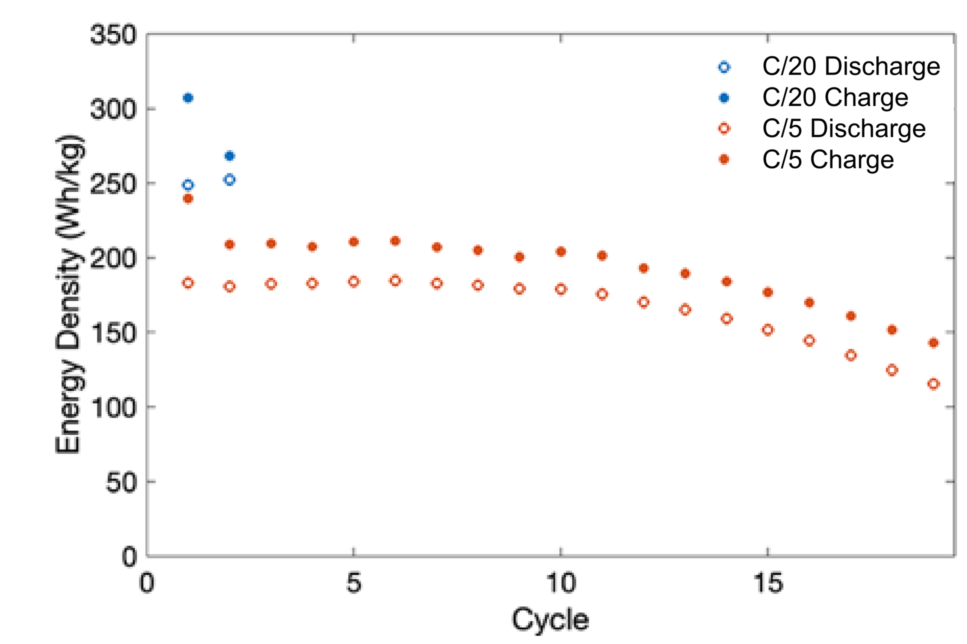
Certain electrolytes allow for high-energy cycling at low temperature





Alloy anodes can enable high energy cycling at room temperature





Acknowledgments

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