RECHARGEABLE BATTERIES WITH IMPROVED DISCHARGE CAPACITY AT -40 ^{o}C TO -60 ^{o}C FOR SURVIVING THE LUNAR NIGHT

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Low-Temperature Lithium Batteries

Image credit: NASA

NASA SBIR Phase II Project (starting soon)

“Solid-State Rechargeable Batteries for Extreme Lunar Surface Environments”

Future science (& ISRU) missions to the lunar surface require hardware, electronics and energy storage systems that can tolerate the extreme low temperatures of the lunar night.

- Continuous or intermittent operation throughout the night. (-180 ^{0}C at night)
- Tolerate the night and wake up and operate at the Lunar dawn. (+120 ^{0}C middle of day)

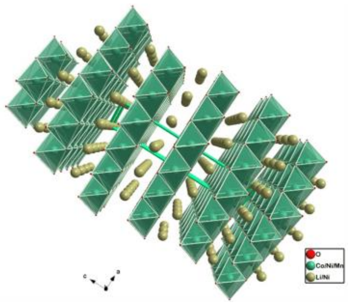
The low temperature performance of lithium batteries is limited by several factors:

- Conductivity of the liquid electrolyte below -20 ^{0}C.
- Resistance of the solid electrolyte interface (SEI) or the cathode electrolyte interface (CEI).
- Charge transfer resistance of the SEI and/or CEI (moving lithium ions into and out of the solid electrodes).

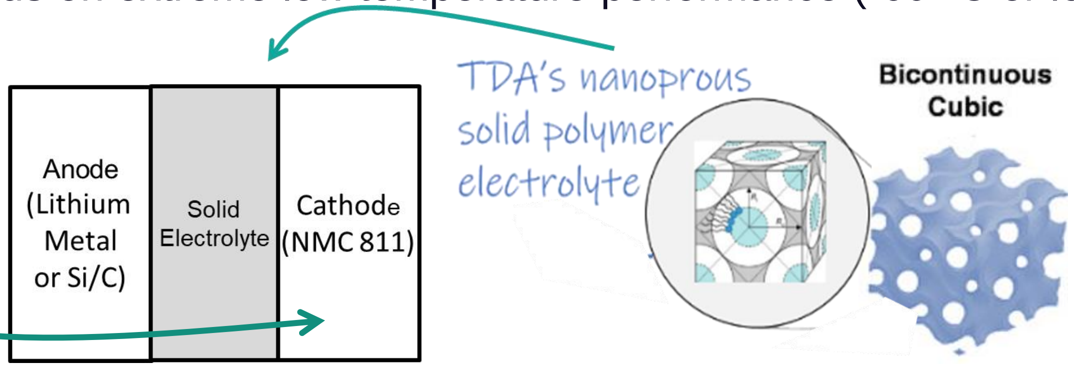
Existing lithium batteries must be housed in temperature regulated chambers kept between 0 ^{0}C and +40 ^{0}C.

NASA – Solid State Battery (SBIR focus) – survive the lunar night

- **The long-term goal is to develop a solid-state battery**
  - No liquid electrolyte.
  - Nanoporous solid polymer electrolyte.
  - Extreme low and high temperature tolerance.
  - Push the boundaries of what is possible now.
  - Focus on extreme low temperature performance (-60 °C or lower).



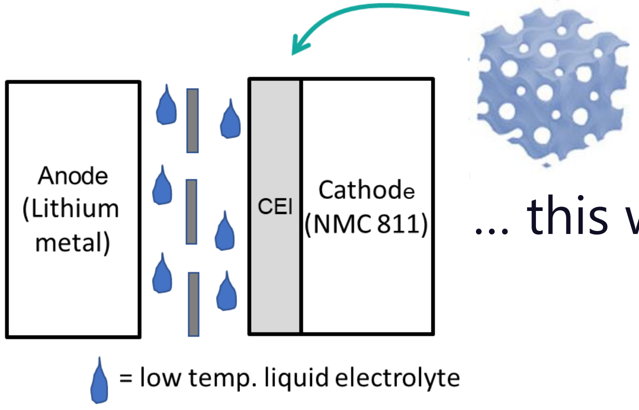
NMC811



Long-term

Short-term / Now

However, …

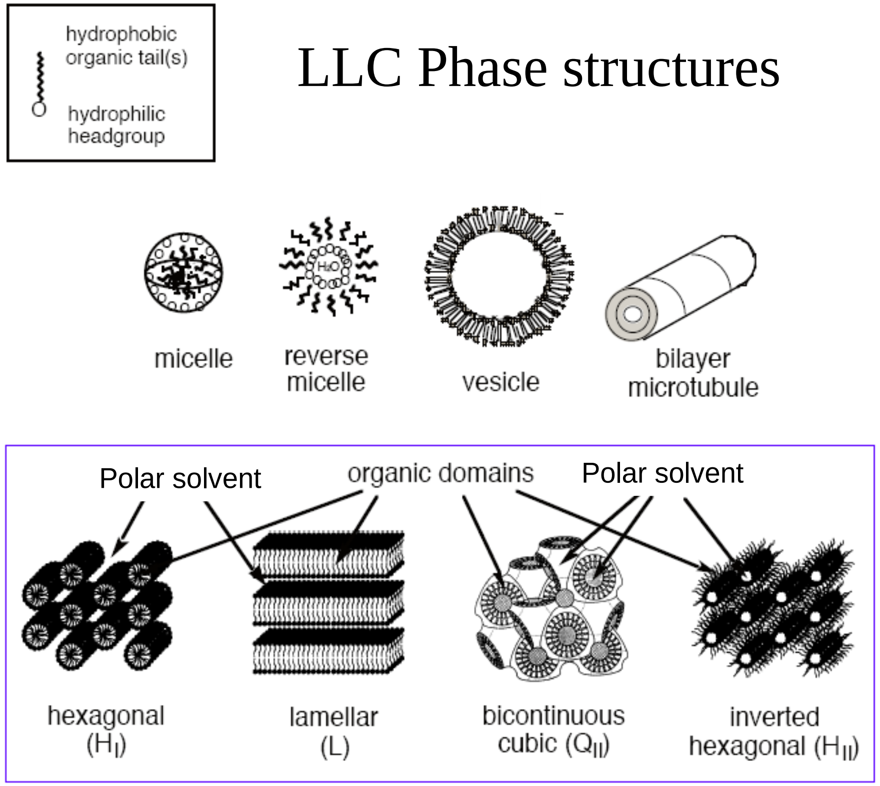


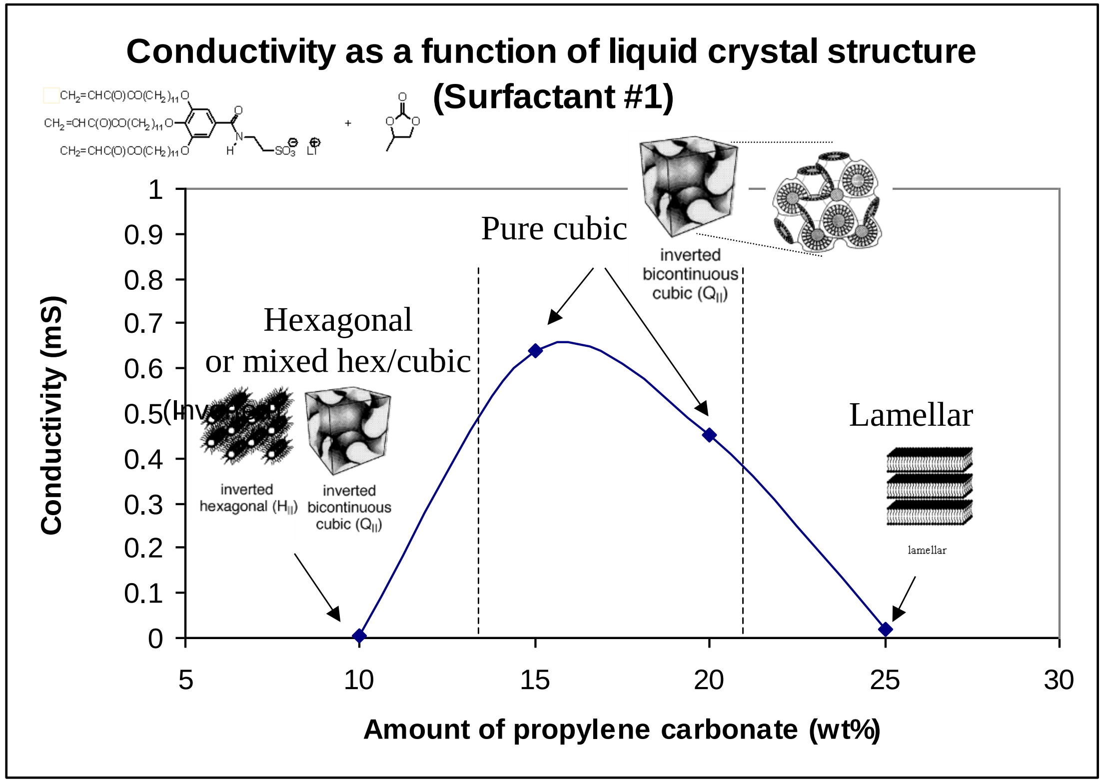
… this works now (for -40 to -60 ^{0}C)

NMC 811 image credit: Molecules. 26. 3188. (2021)

Polymerizable Liquid Crystals with Li^+ Conductivity

- Contain one or more hydrophobic organic tails and a charged headgroup.
- self-organize into liquid crystal structures.
- The tails can be cross-linked to their nearest neighbors *in situ* to form robust polymer networks that retain the original structure.
- Designed to be (electro)chemically stable.
- The bi-continuous cubic phase has a 3-dimensional interconnected pore structure that conducts lithium ions (high conductivity).





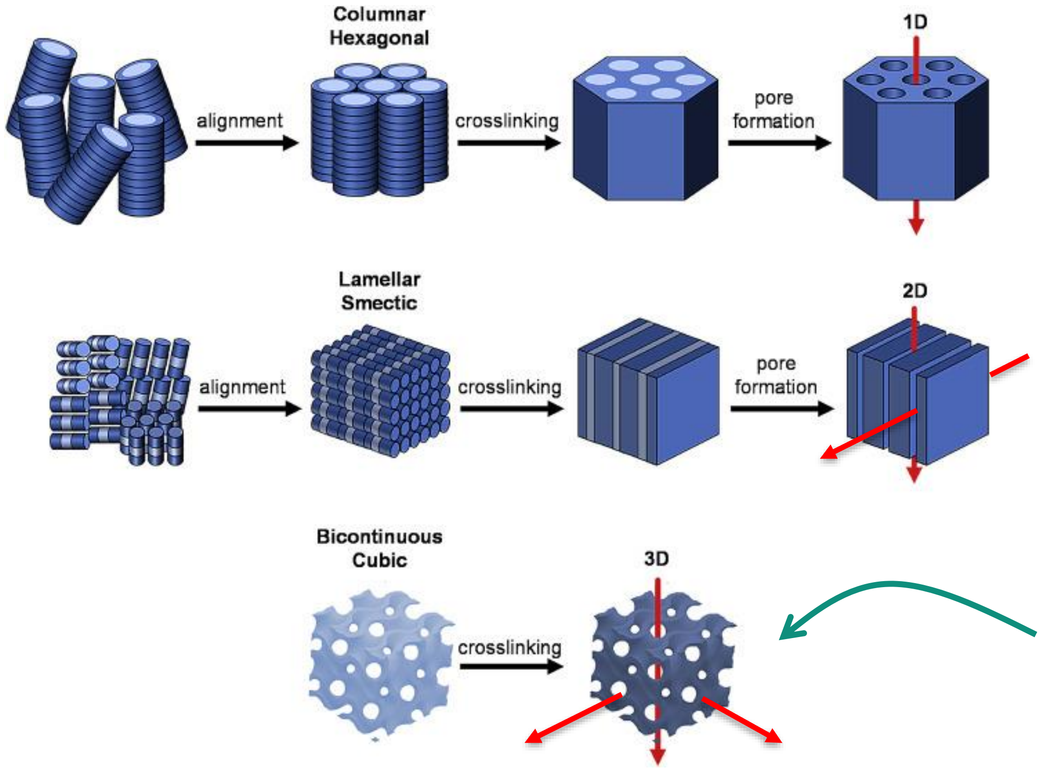
Patented and Patents Pending

Self-assembling liquid crystals for nanoporous polymers

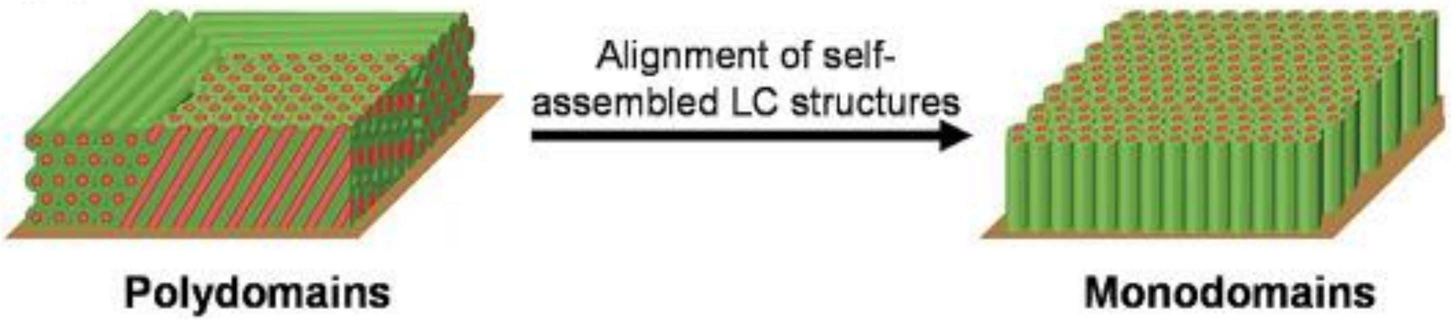
OK

Better

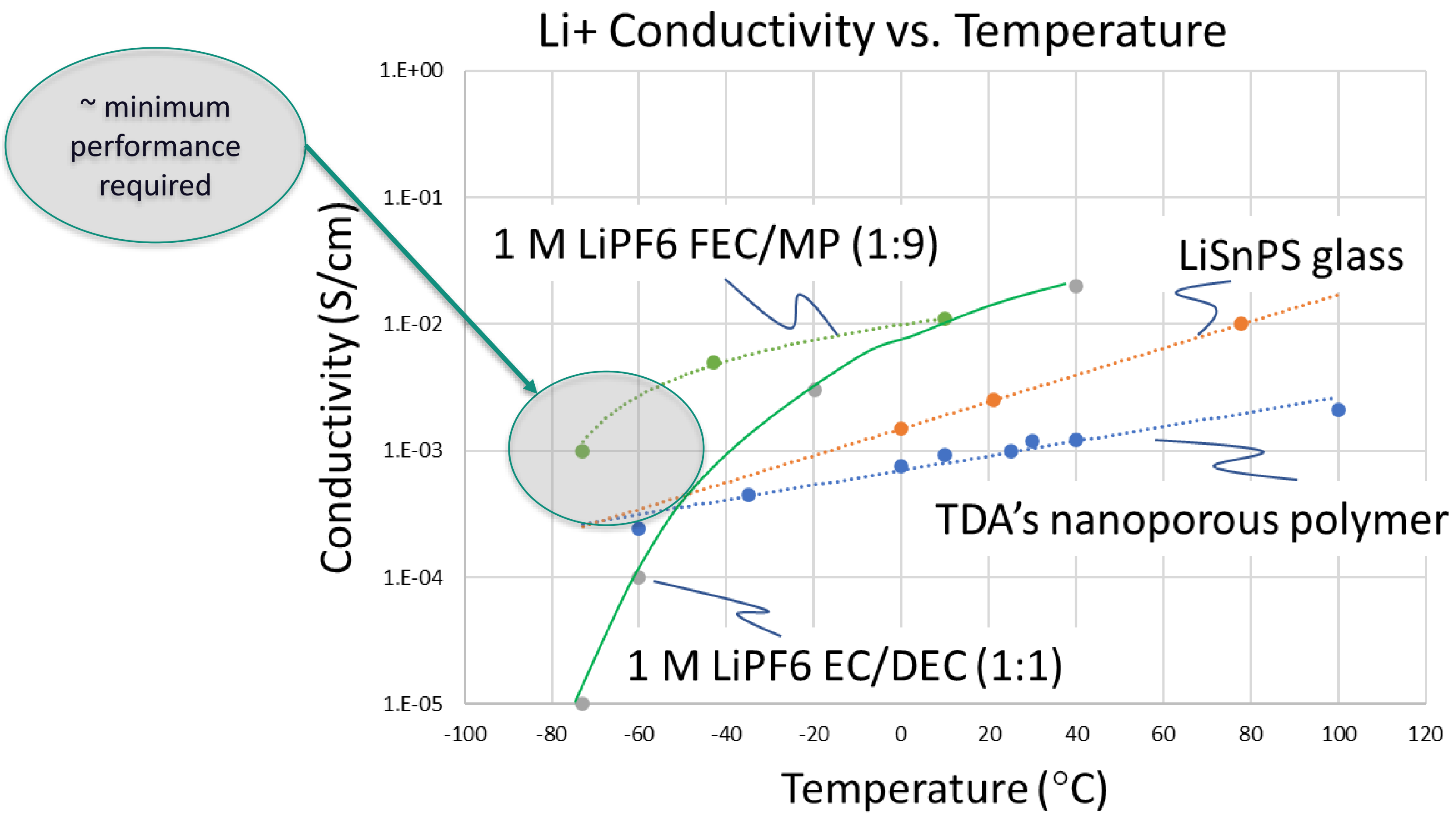
Best



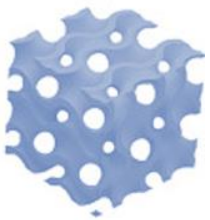
No need to align



Li$^+$ Conductivity of Glass, TDA's Polymer and Liquids



Bicontinuous Cubic



Conductivity is not the entire story: charge transfer resistance is also important

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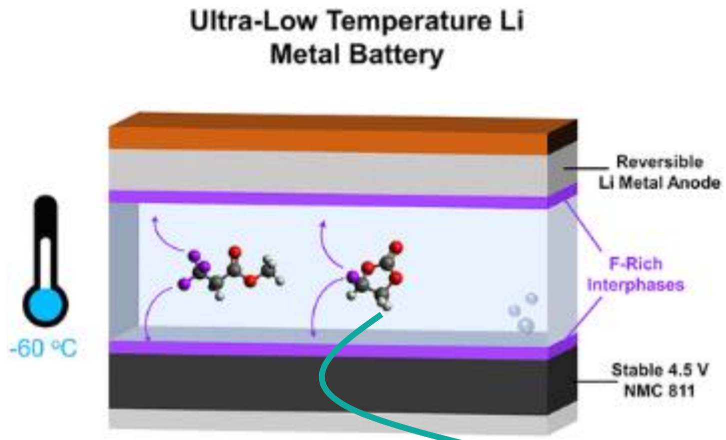
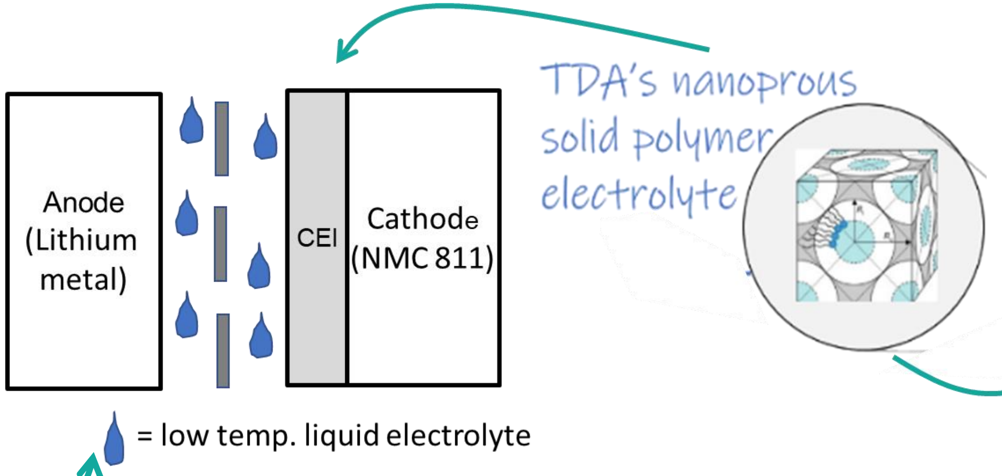
Low temperature liquid electrolytes w/artificial CEI

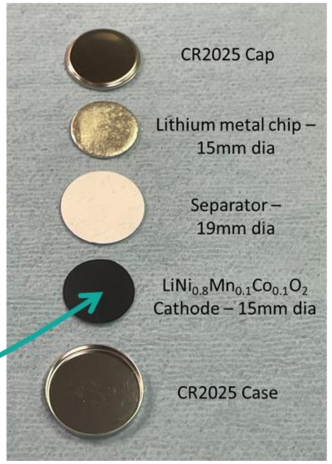
NASA-funded work at UCSD

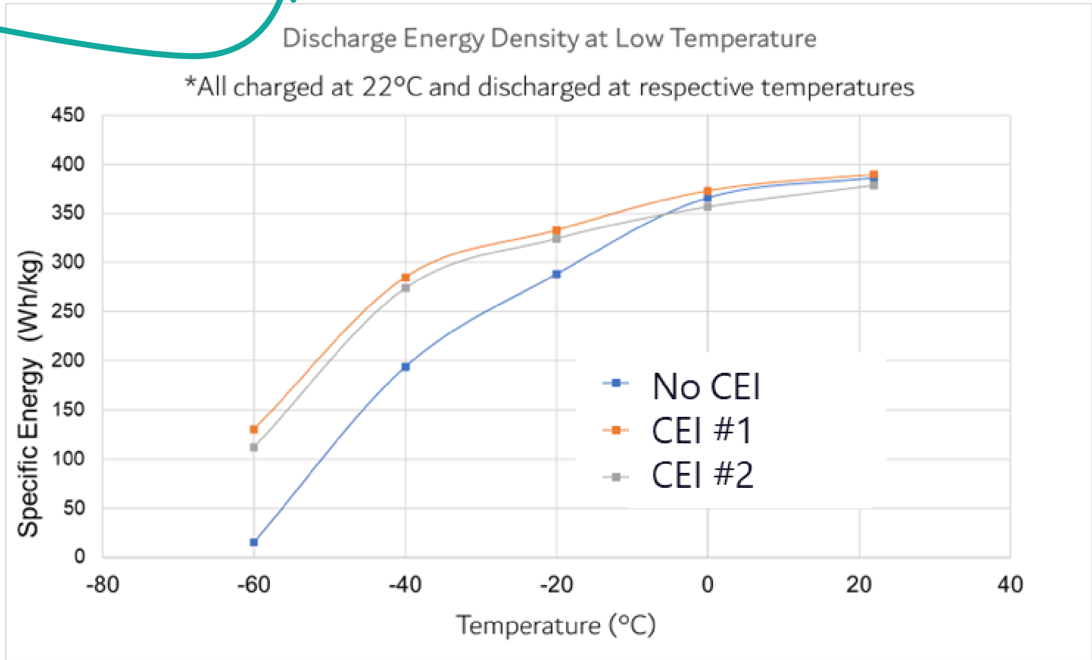


partial reproduction

Low temp liquid electrolyte plus our artificial CEI





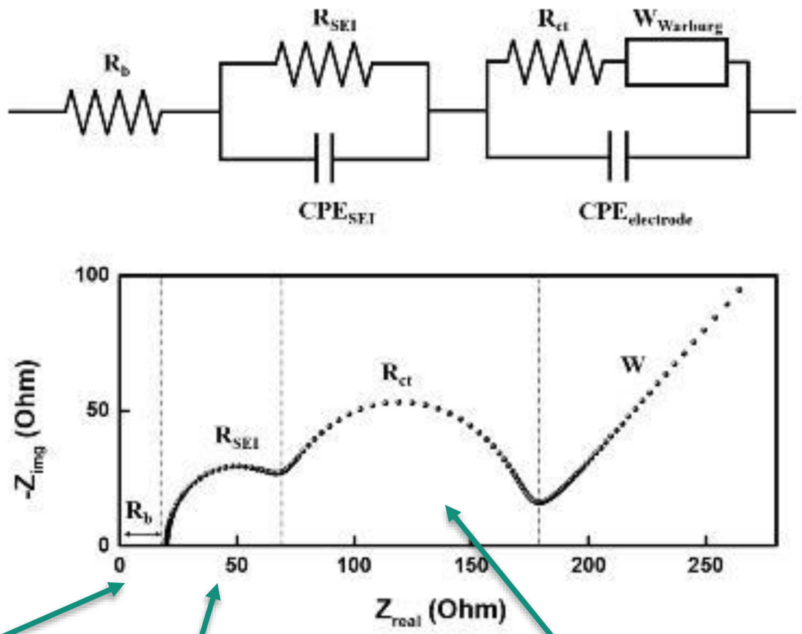


Partial reproduction: Holoubek, *et. al ACS Energy Lett.* 2020, 5, 5, 1438–1447

Patented and Patents Pending

EIS of coin cells

working electrode at cathode / reference at lithium anode

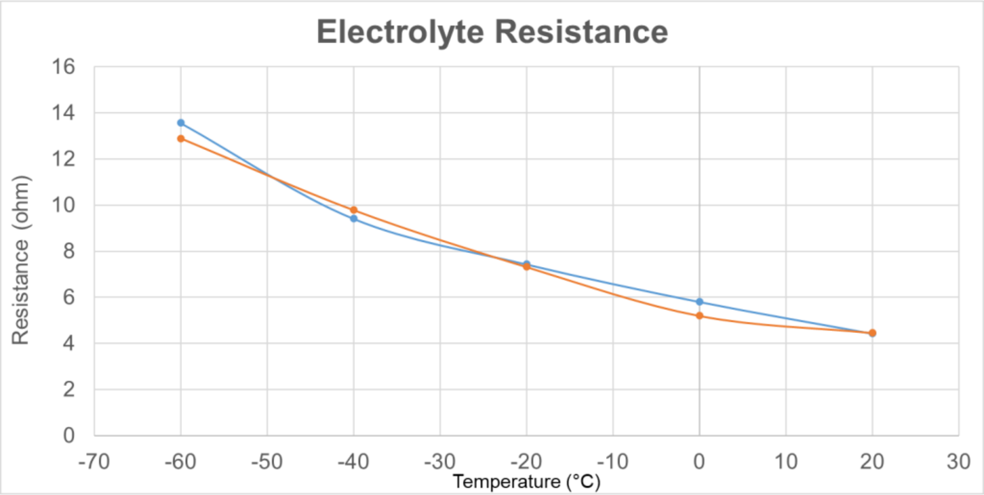


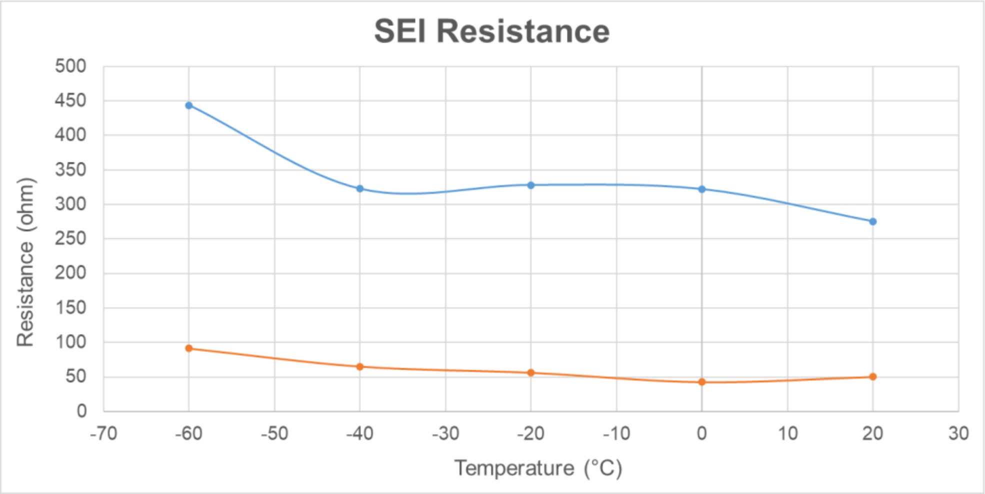
Electrolyte resistance function of viscosity

SEI (or CEI) resistance ~linear function of temperature

Charge transfer VERY strong function of temperature

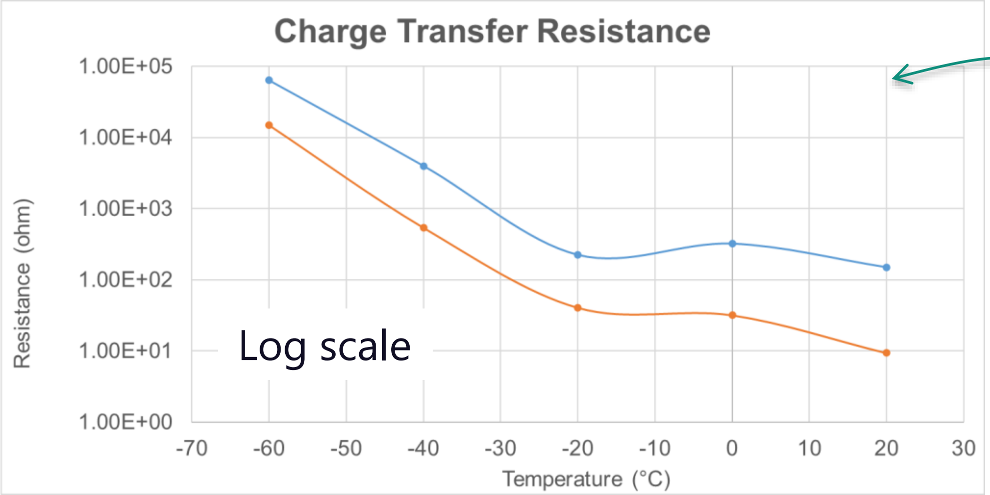
Resistance: Electrolyte, CEI(SEI) and Charge Transfer

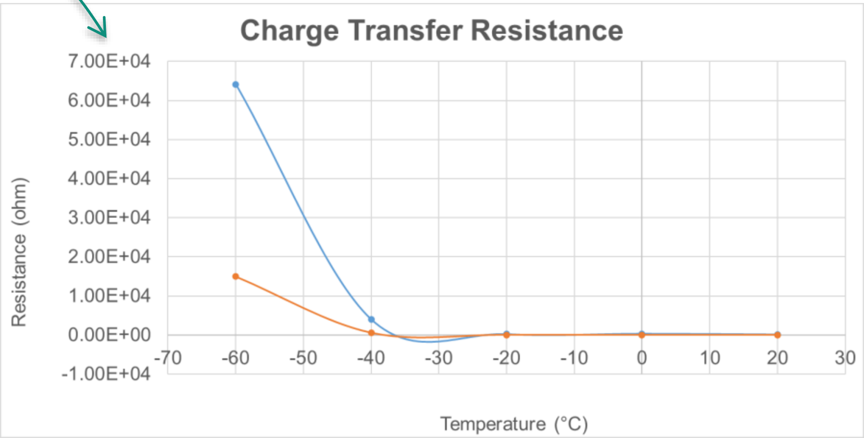




NMC 811 Uncoated

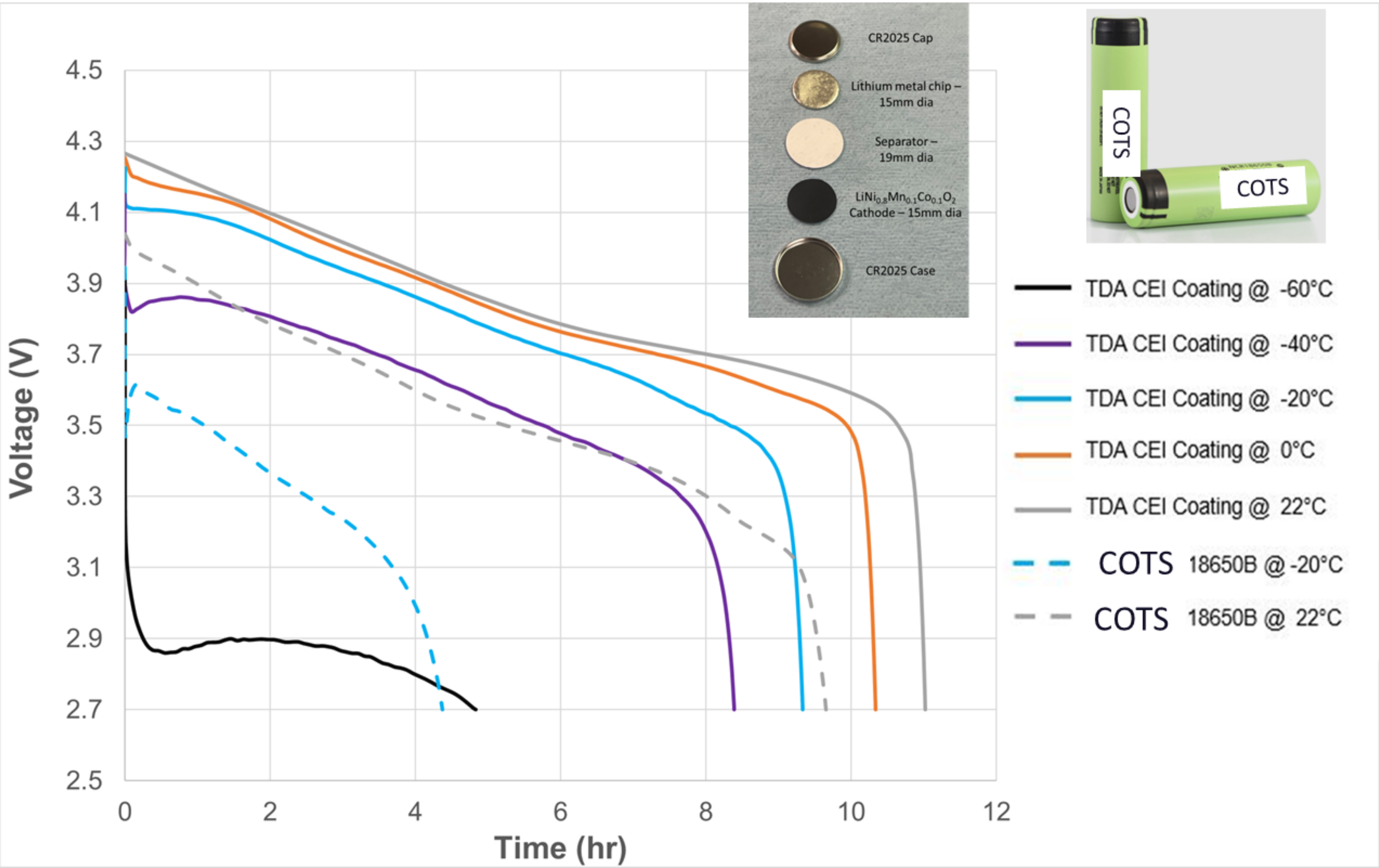
NMC 811 coated





Discharge Profiles vs. Temperature

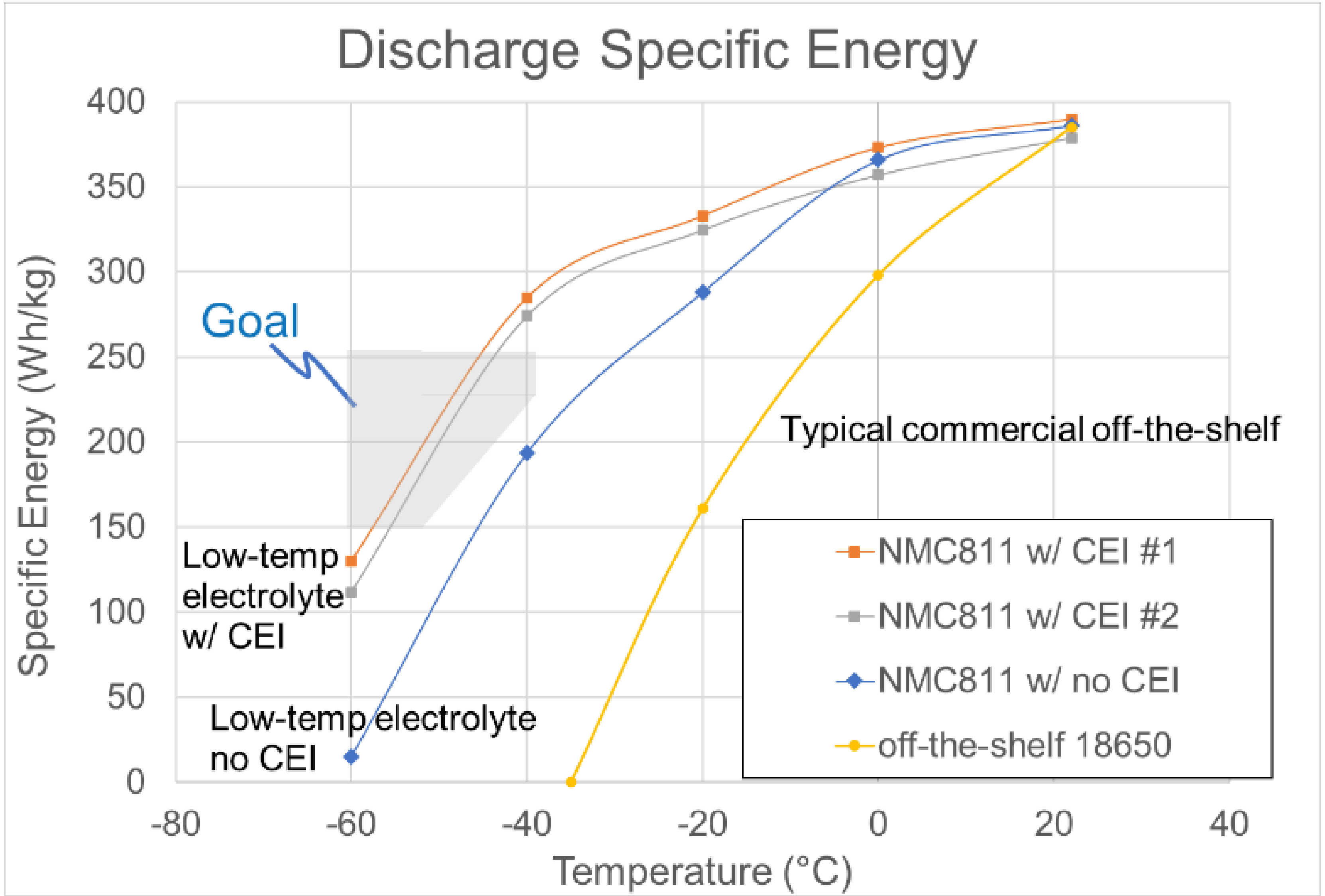
TDA vs. Commercial-of-the-Shelf



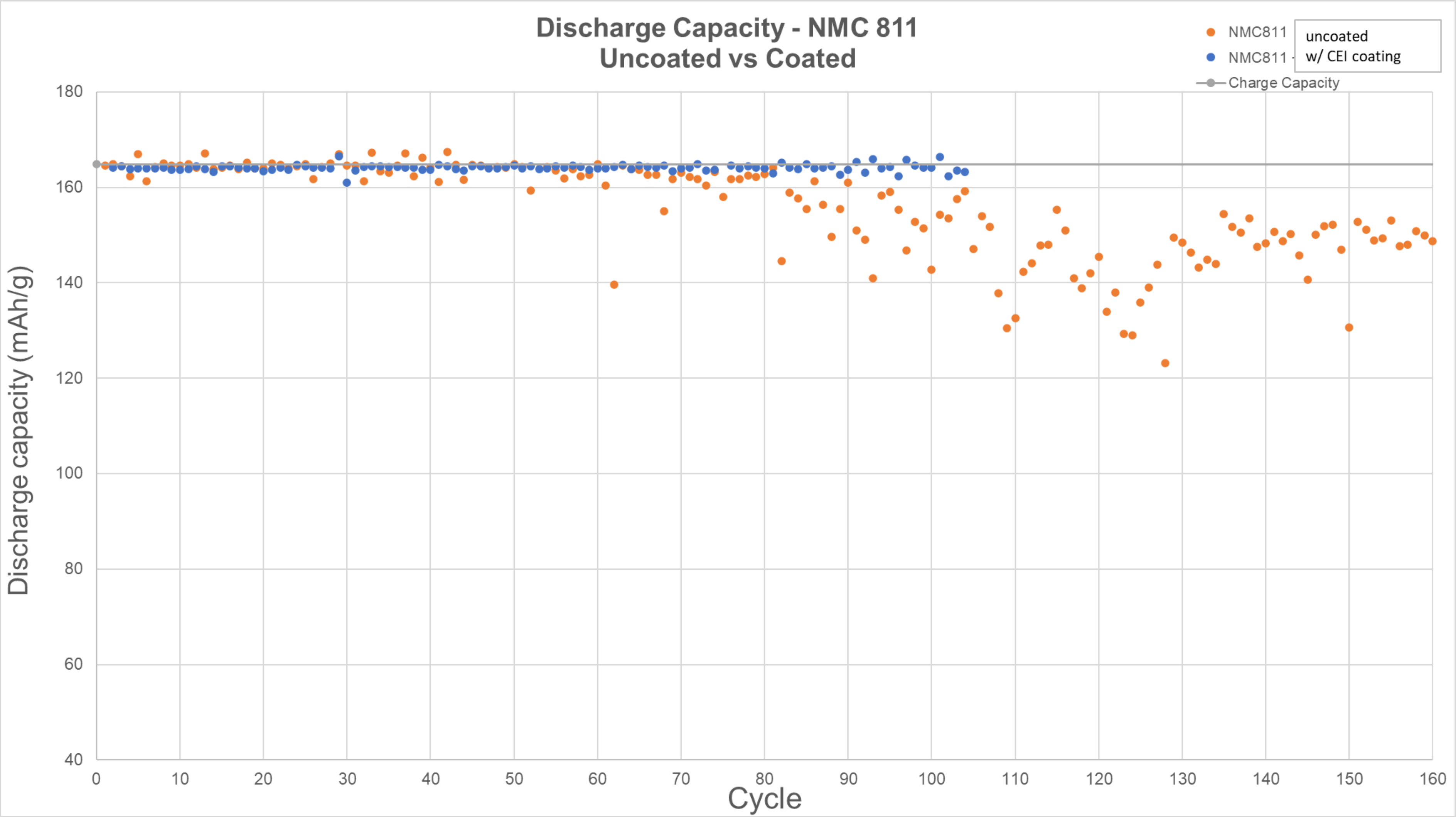
C/10 charge and discharge rate

Patented and Patents Pending

Prototype Low Temperature batteries vs. off-the-shelf battery



Stability: coated cathode vs. no coating



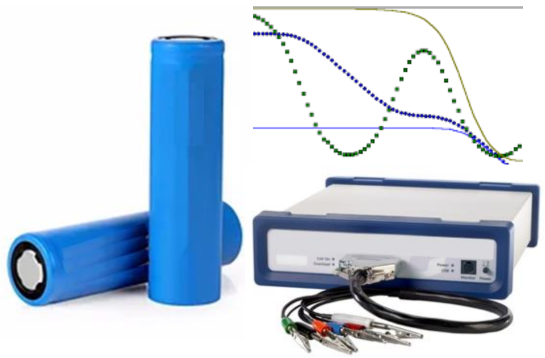
Conclusions & Future Work

- When charged at 22 ^{o}C, vastly improved discharge capacity, voltage and energy when next discharged at -40 ^{o}C or -60 ^{o}C.

- > 250 Wh/kg at the cell level at -45 ^{o}C (automotive electronics rated -40 ^{o}C).
- > 150 Wh/kg at -55 ^{o}C (military electronic rated -55 ^{o}C).
- **ADVANTAGEOUS** to house batteries and electronics in **chamber** designed to maintain **-55/-40 ^{o}C to +40 ^{o}C.**
- **Reduced thermal management mass & volume.**
- **Higher specific energy at low temp – reduce battery mass.**

- Primary application target: small landers, rovers, lunar surface instruments, robots (ISRU).

- Other applications: high-altitude balloons, electric powered aircraft, EVs in cold climates
- Future work:
  - Demonstration of prototype cells at cryogenic temperatures / relevant environments.
  - Partnering with battery producers for full battery cell production.
  - Tech demo: high-altitude balloon / then lunar demo?



We are Interested in Feedback from the SRR community

- What performance improvements in rechargeable batteries are most important for your cislunar application?

- Please reach out if you wish to collaborate on:
  - Low-temperature battery testing / 3rd party validation
  - Suborbital battery technology demonstrations
  - Shared payload for orbital / lunar technology demos
  - Potential integration of flight certified batteries into future missions or mission planning

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Questions?

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