Development of Fast-Charging and Wide Temperature Li-ion Batteries

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Overview

- **Problem –** Group 1 Unmanned Aerial System (G1 UAS) endurance & Intelligence, Surveillance, and Reconnaissance (ISR) ISR persistence
- **Solution –** Fast-charge and wider-operating temperature energy storage technologies
- **Maturation Strategy**
- **Current Status**
- **Next Steps Moving Forward**
- **Conclusion**

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Target Applications – Mobile Energy

Provide portable, autonomous, distributed, and networked, persistent Intelligence, Surveillance, and Reconnaissance (ISR) and ISR-Targeting capability to the warfighter enabled through G1 UAS

Emerging Energy Storage & Distribution Systems

PURDUE UNIVERSITY

BIC

BATTERY STREAK® CHARGE LIGHTNING FAST

AMERICAN LITHIUM ENERGY

HAYLON TECHNOLOGIES

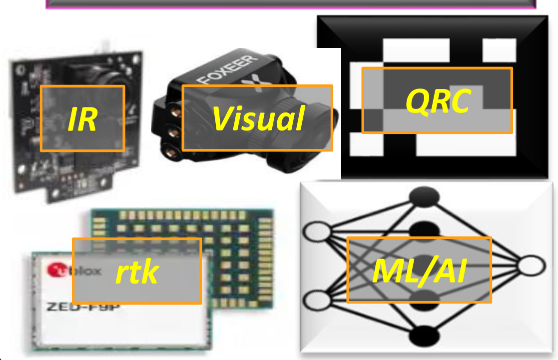
UPGRADE ENERGY

UMKC

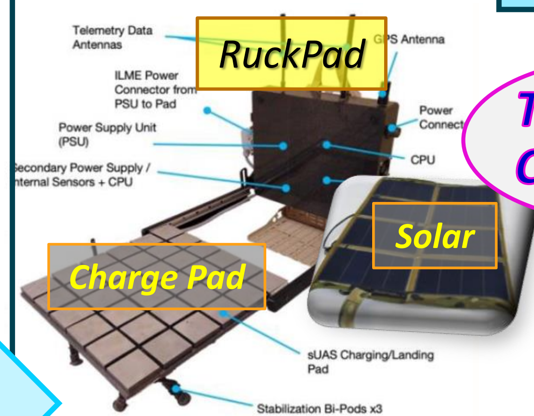
MIDE

IOWA STATE UNIVERSITY

Autonomous Operations



Expeditionary Mobile Energy for G1 UAS



FORCYTE

Mission Model

Transition Capability

Expeditionary Partners

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Approach

How are you solving the problem?

- ✓ Established informal agreement between Forcyte, NSIN, SOCOM AT&L & Crane (FY23).
- ✓ Received National Security Innovation Network (NSIN) Maker (Forcyte) & FY24 NISE 219 (Crane) Funding to achieve project objective
- ❑ Build and grow Industry & Academia Partnerships, and NSWC Crane skillsets in Battery & Power Management Systems
  - ❑ Leverage Cooperative Research and Development Agreements (CRADAs) and internships
- ✓ Hand-off of RuckPad technology to NSWC Crane team
- ✓ Team member is Certified Pilot for UAS's
- ❑ Establish S&T Innovation P&E laboratory
- ❑ Evaluate & Assess RuckPad V2.0 to Provide recommendations for version 3.0
- ❑ Re-engage with SOCOM AT&L POC's, NSWC Panama City, and Expeditionary partners for feedback and opportunity
- ❑ Leverage NSIN & National Security Innovation Capital (NSIC) project funding

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Power & Energy S&T Innovation Lab

- **Li-Ion Batteries**
  - ✓ Approved for COTS Li-Polymer (LiPo) UL approved batteries
  - – *Custom battery packs with COTS cells*
- **Lab SOP**
  - – Equipment, instruments, software
  - – Operating instructions
  - – Hazard Analysis and Risk Assessments
- **Major Equipment, Instruments & Components**
  - ✓ Laboratory & soldering workbenches (3), project tables (2), carts (2), shelves
  - ✓ Test Equipment
    - Keithley Instruments: DAQ6510 (2), 2636 SMU, 2260B Power Supplies (2), Electronic Loads (2), USB data logger
  - ✓ TestEquity Thermal Chamber (-70°C to +150°C), Flammable cabinets (3)
  - ✓ Solder station with microscope, ionizer, ESD and T&H sensor
  - ✓ BMS, Power Management Unit,& Energy Harvesting development boards

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G1 UAS P&E Roadmap

- **Evaluate Forcyte RuckPad v2 (FY24 NISE)**
- **Advance Fast-Charge & Wide Temperature Battery Systems**
  - **Niobium based Li-ion cell/battery**
    - Purdue & Battery Streak - American Lithium Energy 18650 Cells
    - NSIN Capstone & Maker, and External funding
  - **High Power/Energy batteries (Haylon Technologies)**
    - NSIN Maker & SBIR Phase II's
  - **Upgrade Energy COTS batteries**
    - NSIN Maker & Collaborating with NSWC Panama City
  - **Battery Management System**
    - Purdue, Upgrade Energy & NSWC Crane
    - NSIN Capstone & Maker, and external funding
- **Power Management Unit**
  - **Power distribution and control**
  - **NSWC Crane**
    - Iowa State & UMKC for thermal management

1. **NSWC Crane conducts independent T&E**
2. **Develop Technical Manual based on actual flight profiles**
3. **Workforce Development**

   SSEP Student Aaron Davis

   NREIP & SMART Student Austin Choi

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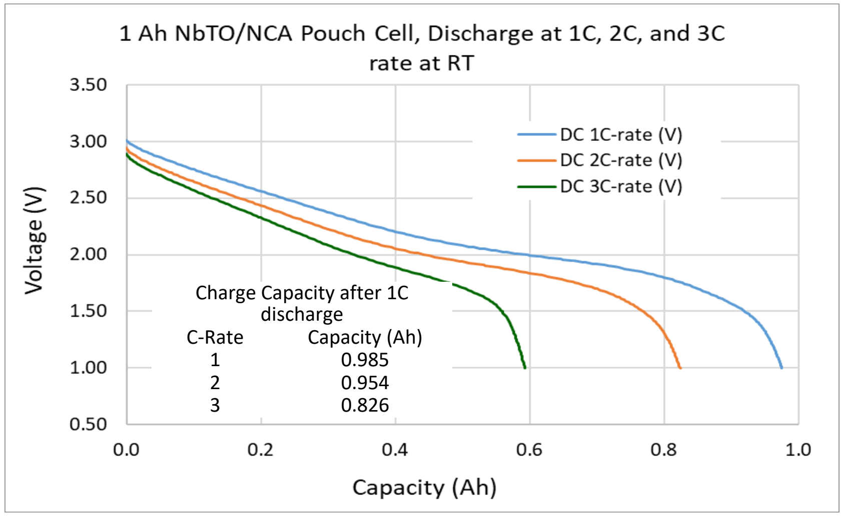
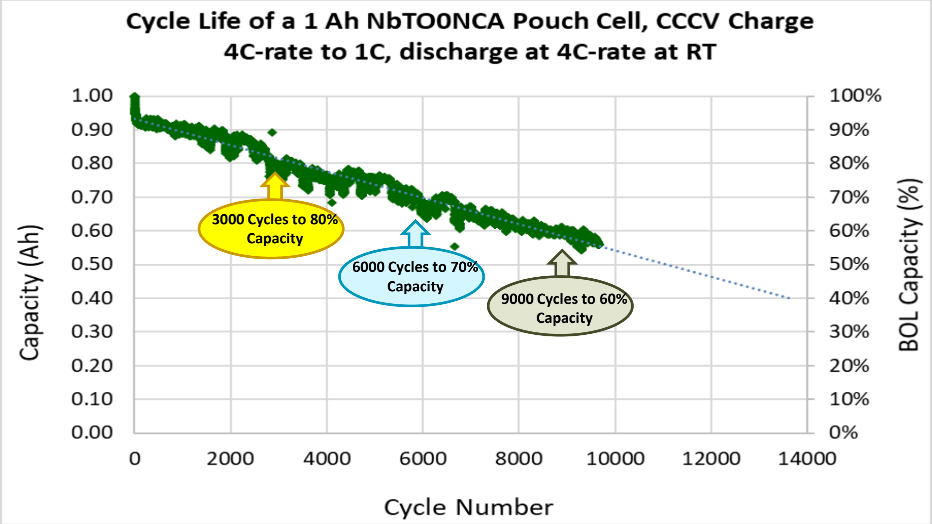
Battery Streak Nb Battery Technology

- **1.0 Ah Pouch Cell, NbTO / NCA**
  - NbTO Anode, NCA Cathode
  - CBMM provides niobium
  - Replacing NCA Cathode with LVPF → Cobalt Free!
  - Niobium improves capacity retention & high charge rate capabilities
  - Lower internal impedance → lower cell temperature
  - American Lithium Energy to produce 18650 cells



- **Cycle Life Evaluation at RT and 0°C**
  - 100% Depth of Discharge (1.0V – 3.2V)
  - Charge and Discharge at 4C-rate
  - At RT, 80% Capacity after 3000 cycles
    - 70% after 6000 cycles, 60% after 9000 cycles
  - At 0°C, 5% Capacity loss after 500 cycles
- **Self-discharge at 100% SoC**
  - 2.1 mV/day at RT → 1.0V in 2.6 years
  - 14.3 mV/day at 50°C



Purdue NbWO Cell Configurations

- **NbWO can be used as either the anode or cathode**
  - When paired with lithium metal, achieves high energy density but have to combat lithium metal shortcomings (dendrites, safety)
  - When paired with graphite/hard carbon, need to pre-lithiate one of the electrodes
    - Can pre-lithiate graphite/hard carbon or NbWO, NbWO preferred as it is the cathode
  - When paired with LFP, can achieve a larger cell voltage and good safety

Anode	Cathode	Notes
Lithium metal	NbWO	High energy density from lithium metal. 1.2 – 2.5 V
(Li)-Graphite/ (Li)-Hard Carbon	(Li)-NbWO	One electrode requires pre-lithiation. 1.2 – 2.5 V
NbWO	LFP	High safety, good rate capability. 1.0 – 3.2 V

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Electrolytes for NbWO Electrodes

Lithium salt + Solvent + Additive

- **No commercially available electrolyte for low temperature operation**
- **Variety of ether-based solvents (CPME, THF, DPE)**
  - Need to use LiFSI salt as LiPF6 has low solubility in ethers
  - LiFSI salt corrodes stainless steel at high potentials, need to mitigate with inert materials
- **FFN electrolyte employs NONA additive that decreases freezing point**
  - Has been tested at low temperatures, not high temperatures

Solvent	Salt	Conductivity	Temperature Range
Commercial electrolyte: Ethylene carbonate (EC) / Diethyl carbonate (DEC)	1M $LiPF_6$	High	EC freeze: 35 °C EC boil: 243 °C
Cyclopentyl methyl ether (CPME)	1M LiFSI	Low	Freeze: -140 °C Boil: 106 °C
Tetrahydrofuran (THF)	1M LiFSI	Moderate	Freeze: -105 °C Boil: 66 °C
Dipropyl ether (DPE)	1.8M LiFSI	Moderate	Freeze: -122 °C Boil: 90 °C
FFN → F: Fluoroethylene carbonate (FEC) F: Methyl (2,2,2-trifluoroethyl) carbonate (FEMC) N: Nonafluorobutyl methyl ether (NONA)	1M LiFSI	Low	Electrolyte mixture performs at -50 °C

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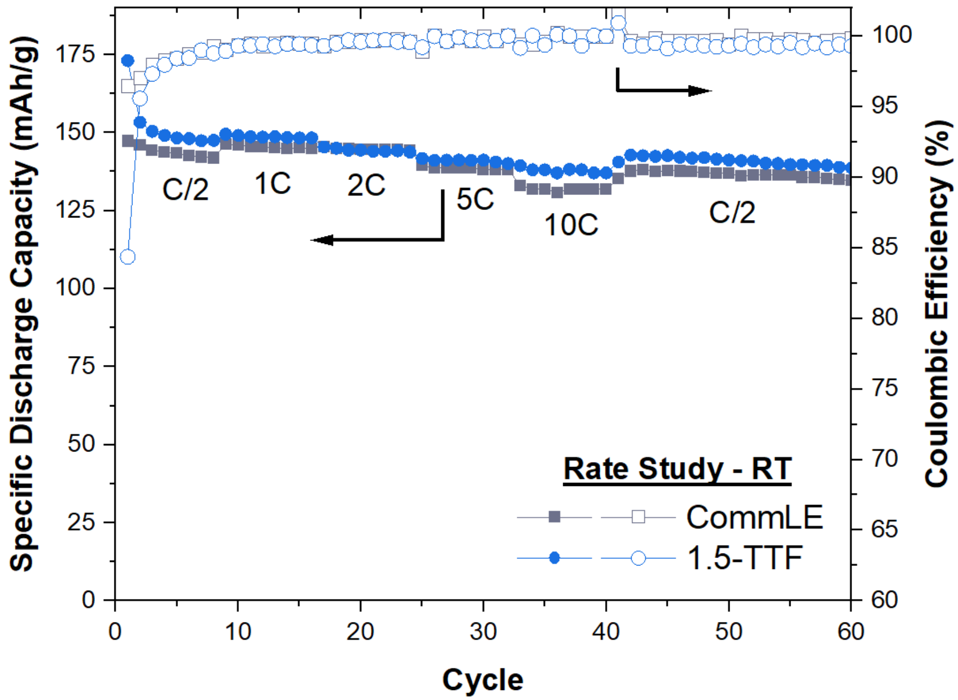
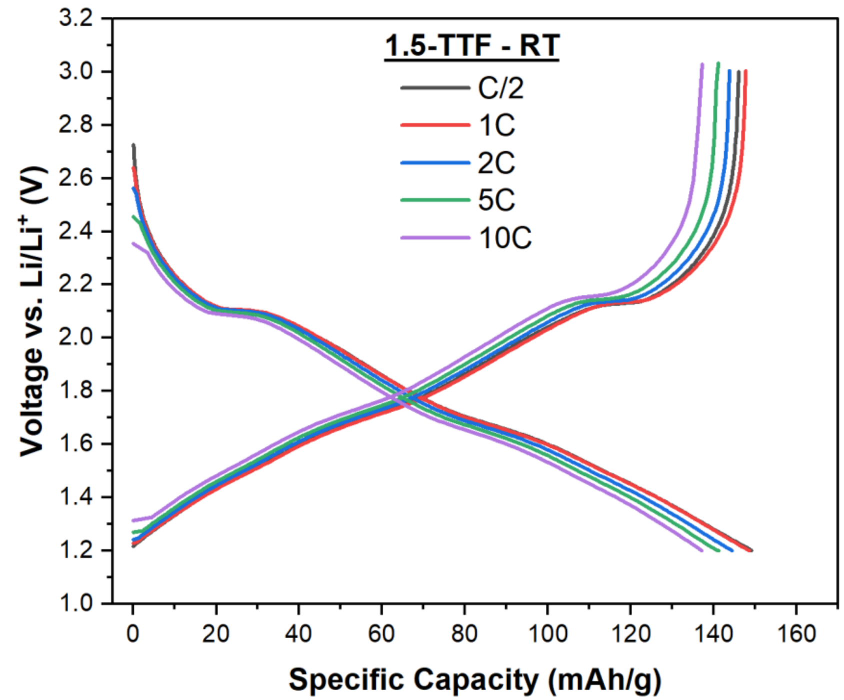
Cycle Rate Study at RT





- 1.5-TTF – 1.5M LiFSI in THF/TTE/FEC 3:6:1 v/v
- CommLE – Commercial 1M LiPF6 in EC/DEC 1:1 v/v
- 1C – 149.3 mA/g
- Very good rate capability: ~93% capacity retention from 0.5C to 10C
- Even at higher rates, overpotentials remain low

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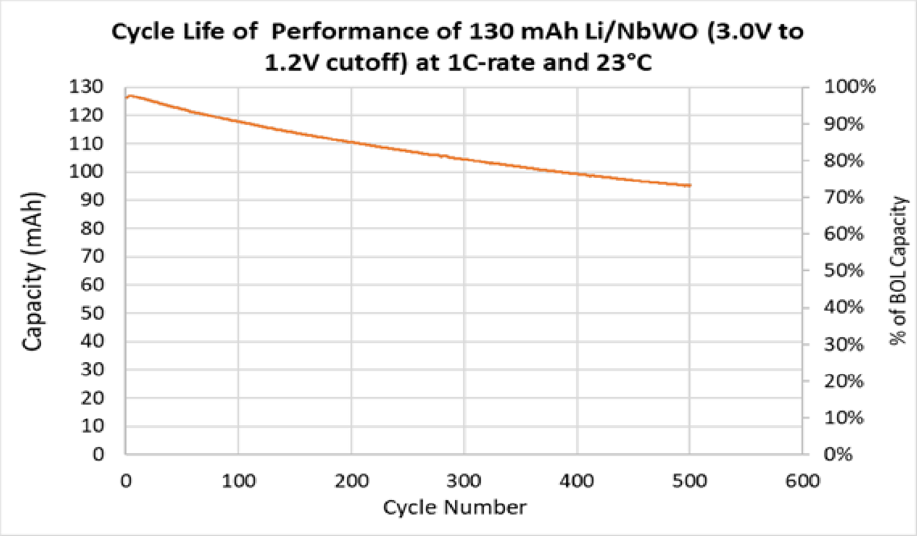
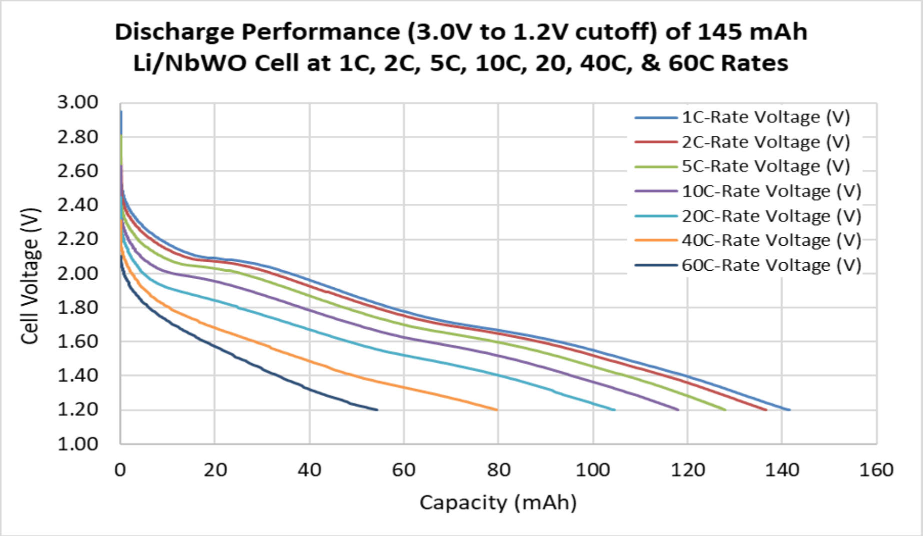
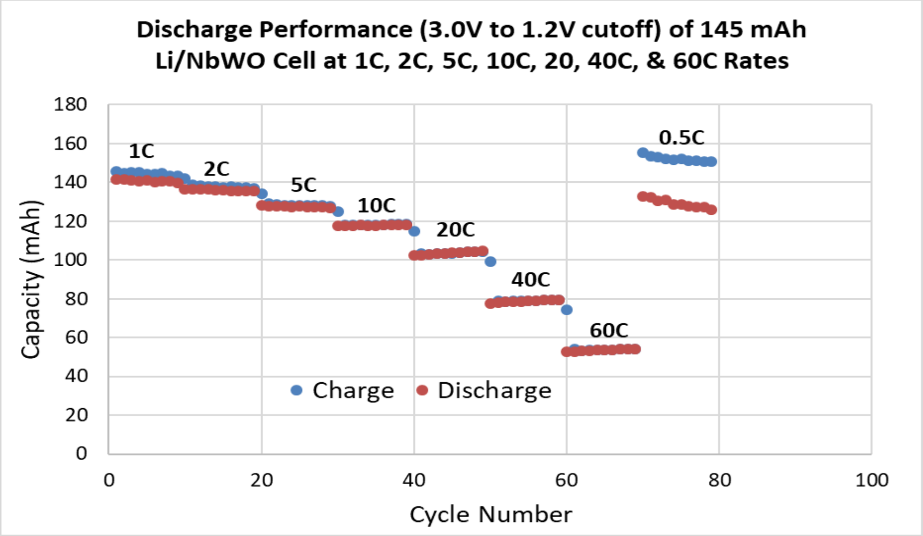
NbWO Li-ion Cell High-Rate Discharge

- **NbWO Cathode, Li metal Anode, 1.5M TTF electrolyte**
- **Cycle Life Evaluation at RT**
  - 100% Depth of Discharge (3.0V – 1.2V)
  - Charge and Discharge at 2C-rate
  - 80% Capacity after 200 cycles







- **High-Rate Charge/Discharge**
  - 5C rate loses 7% capacity
  - 60C rate loses 60% capacity
- **Fabricating 1.0 Ahr pouch cells with hard-graphite/Li anode**

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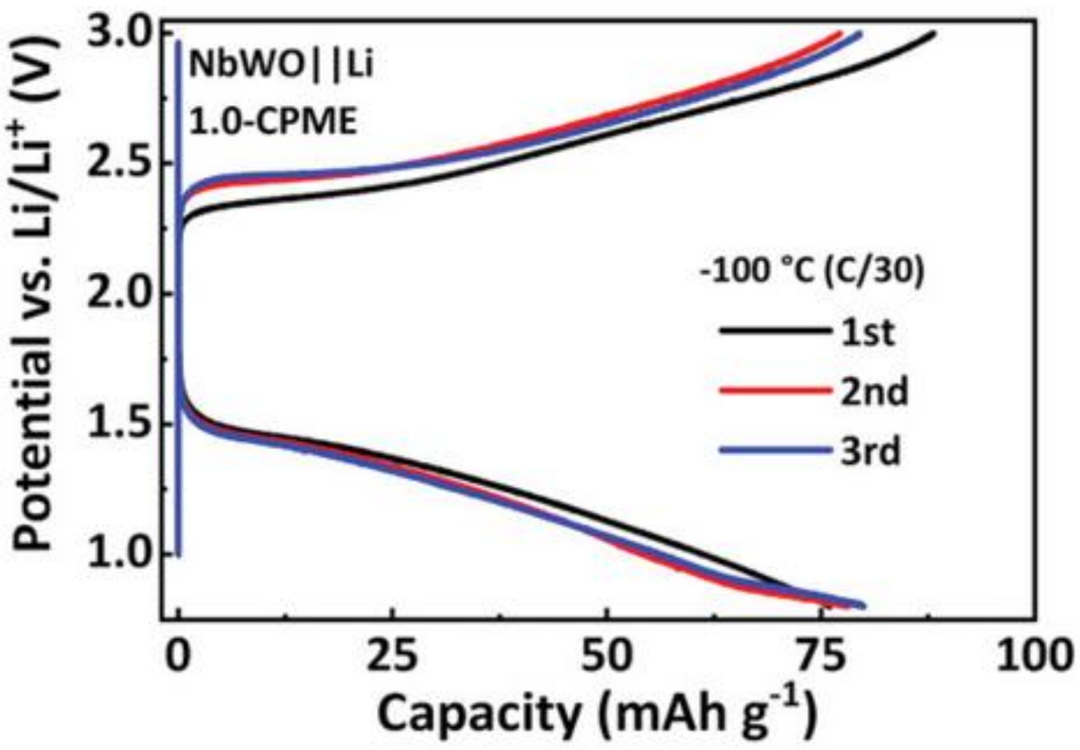
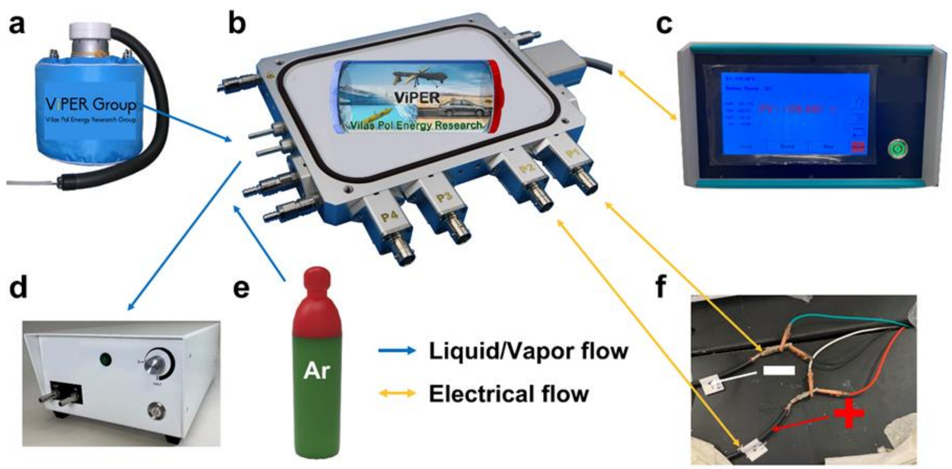
CPME-Based Electrolyte at -100 °C

- **Cyclopentyl methyl ether (CPME)**
  - Melting/Boiling point: -140 °C / 106 °C
- **50% capacity retention at -100 °C**
- **Can CPME be used to enable wide-temperature range battery operation with NbWO cathodes**
  - Low temperature studied
  - Elevated temperatures?
  - Safety aspects?





Purdue's ViPER group sets GUINNESS WORLD RECORDS™ title for the lowest temperature, -100 degrees Celsius, to charge a lithium-ion battery in Dec 2021

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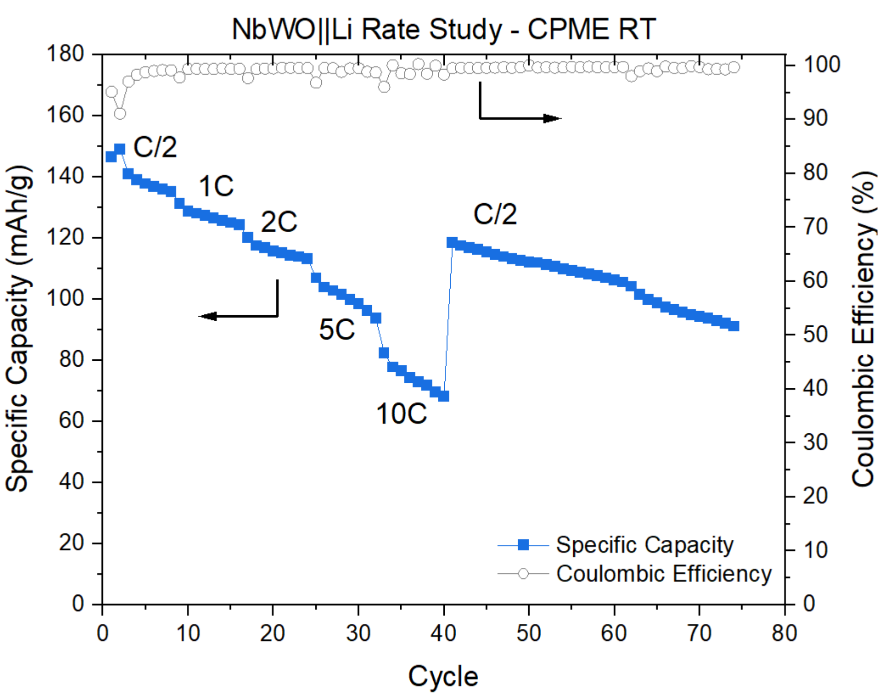
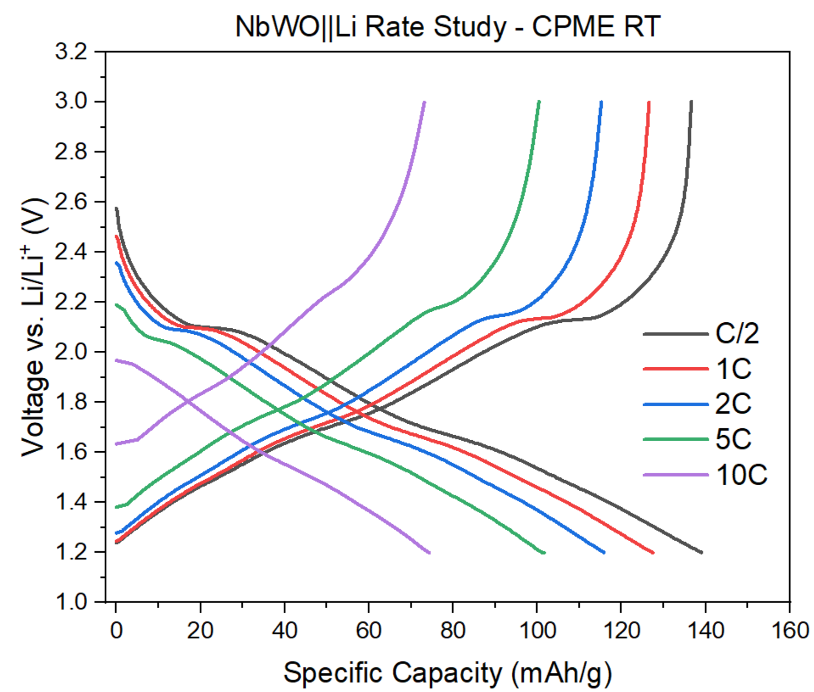
NbWO||Li CPME Cells – Room Temp

- **Rate capability with CPME seems diminished at RT as compared to commercial electrolytes**
- **Discovered Sulfur (S) contamination in electrolyte → Redo with new electrolyte**





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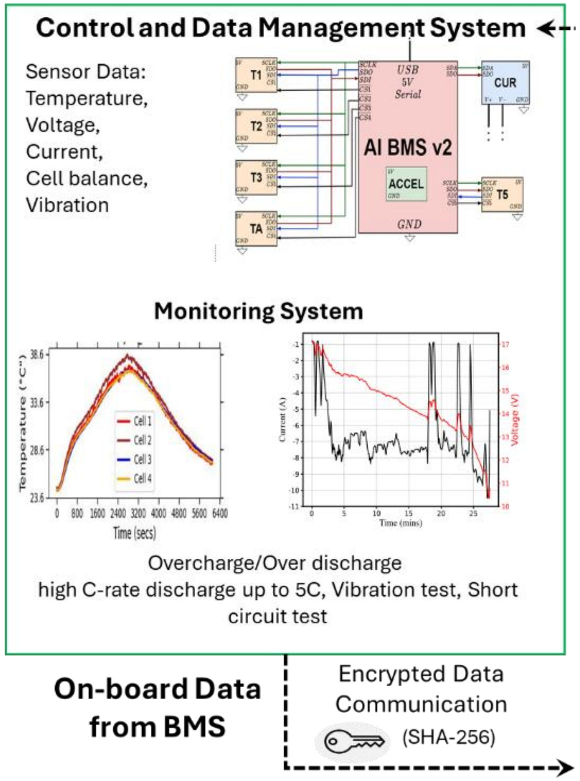
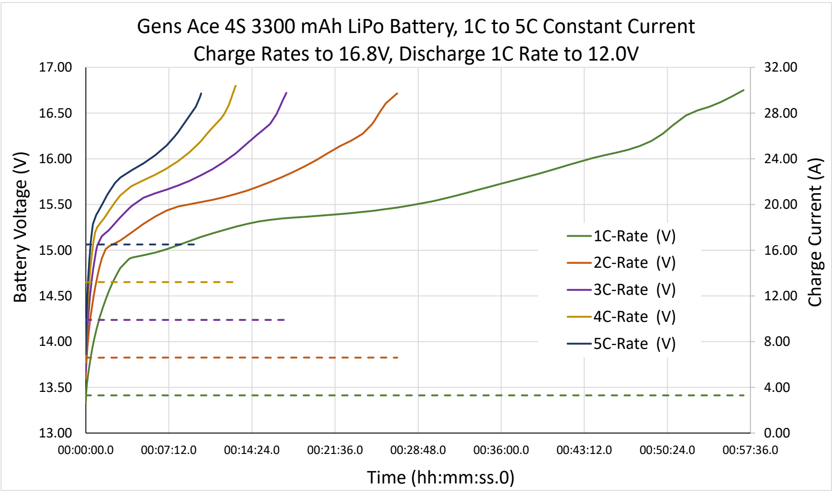
Purdue BMS Project

- Developed fast charging (>5C) control
- Detect cell imbalance, overheating, T&V rate of change
- Design PCB to collect cell parameters → fault using ML & AI
- Validate with failure testing



[Current, Voltage, Temperature, Vibration]

Li-Po 4S 3300 mAh Gens Ace Battery



Charge Rate CC to 16.8V CV to 30 mA	Charge Time (min.)	CC Charge C (Ahr)	CC Charge C (%)
1C (3.30A)	57.0	3.14	93.1%
2C (6.60A)	27.0	2.97	88.0%
3C (9.90A)	17.4	2.87	85.0%
4C (13.20A)	13.0	2.852	84.5%
5C (16.50A)	9.5	2.750	81.4%

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Next Steps Moving Forward

- **Develop roadmaps for Nb battery technologies**
  - Detailed Capability Evolution Plan
  - Go / NoGo waypoints & milestones
  - Scale-up Coin to Pouch
  - Risk Assessment with mitigations
  - Identify funding sources
- **Assess the performance & safety worthiness of Haylon and Upgrade Energy battery technologies**
  - FY25 NISE (in-house research) with NSWC Panama City
  - NSIN Maker projects
  - Army SBIR Phase II T&E
- **Develop roadmap for BMS and PMU technologies**
  - Potential to combine BMS & PMU
  - Locate Smart BMS in RuckPad Charger → reduce weight burden
- **Workforce Development**
  - Talent pipeline from academia to build competent team
    - Leverage presence at Purdue University and others
  - Prepare for attrition

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Conclusions

- Fast charging batteries are possible with NbWO electrodes
- Building US based niobium cell technologies and manufacturing, though existing niobium cell manufactures exist (Nyobolt and Niobium Tech)
- ALE, Battery Streak, and Purdue are working together to improve electrolyte/electrode performance
- Cooperative R&D Agreements (CRADAs) and NDAs in place
- NSWC Crane driving and managing technology development while providing T&E services
- Results from FY24 assessment & evaluation of RuckPad V2 system will feed into an improved version 3
- Additional development needed for PMU and BMS to handle high current rates and prepare for burst energy control for power beaming