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SUPERCAPACITOR CHARACTERIZATION

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DOE OE Energy Storage Peer Review & Annual Meeting, 2026

U.S. DEPARTMENT of ENERGY NNSA

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PROJECT OVERVIEW

- Goal: Provide demonstration support to **non-Lithium** energy storage startups to develop a **robust system integration** platform for **multi-hour** grid services, & **de-risk Li supply chain**.
- Current Practice: Grid-scale BESS are predominantly Li-based, which are susceptible to thermal runaway and cannot support multi-hour operations. Non-Li technologies retrofit BoS components built for Li, which leads to sub-optimal performance & unsafe operation.
- Why SNL: Our team specializes in energy storage system integration that requires expertise in power electronics, controls, communication protocols, and firmware/software development.
- Innovation: Self-healing supercapacitors that can support multi-hour grid services .
- Duration: FY25-FY26, characterize and report different supercapacitor technologies.
- Impact: Characterization of new technologies & demonstration support will considerably reduce their integration cost and enable safe grid interface. This will accelerate deployment and thereby help both the manufacturers and utilities.
- Vertical/Investment Area: Grid Integration and Field Validation
- Alignment/Supports strategic pathway: Grow grid capacity

CHARACTERISTICS OF SUPERCAPACITORS

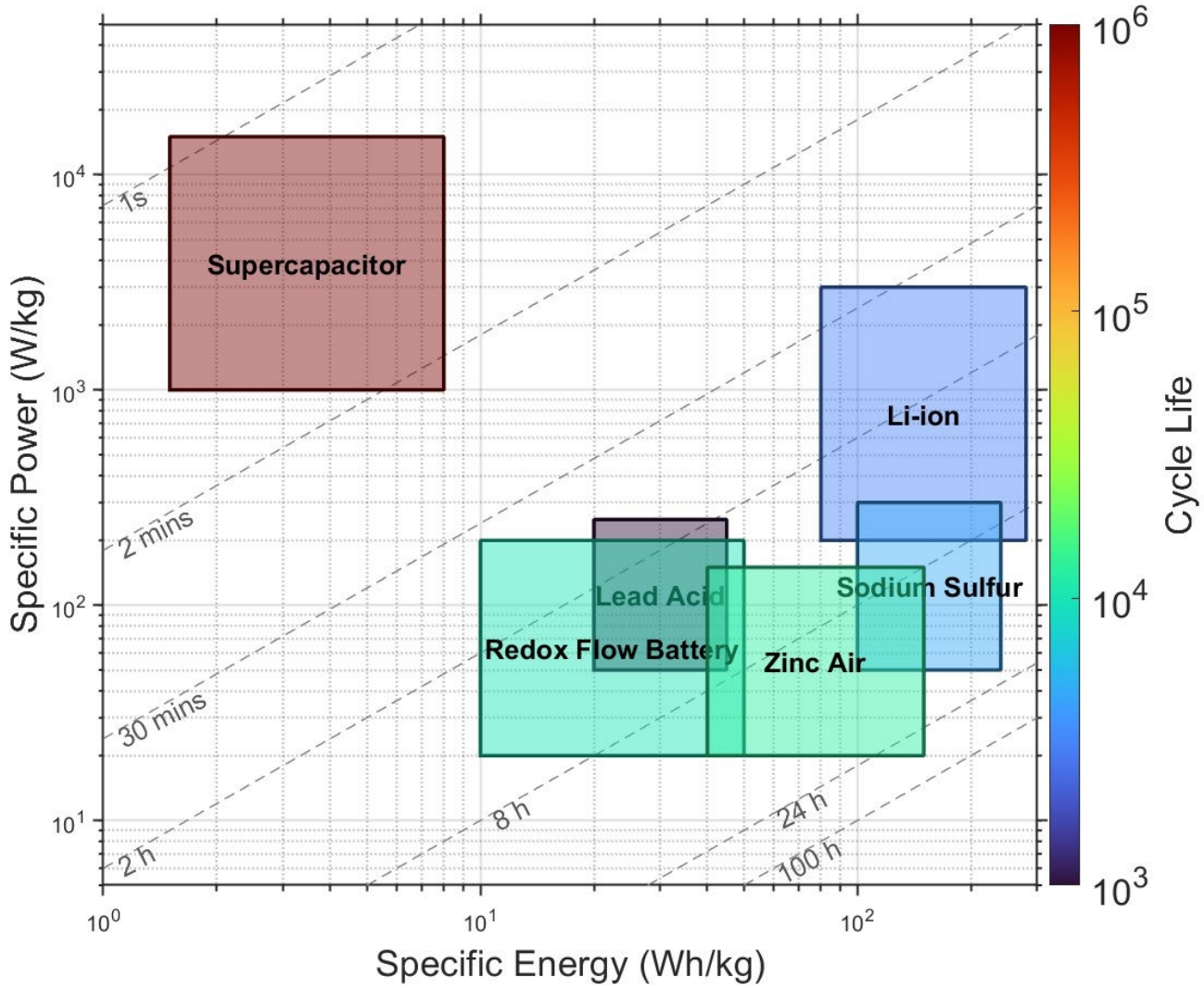


Fig. 1. Ragone Plot of Energy Storage Technologies

- Power Density: 1.1 MW/liter
- Energy Density: 10 – 30 Wh/liter
- Response Time: Milliseconds
- Number of Cycles: 10000
- Technology Maturity: Medium
- Self-discharge: 5 – 40%

SUPERCAPACITORS FOR GRID APPLICATIONS

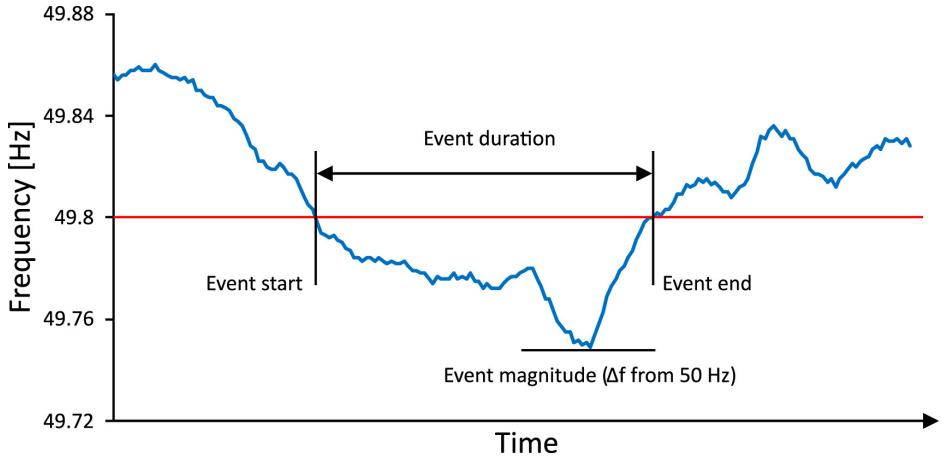


Fig. 2. Frequency event which requires **primary response in < 10s and lasts for 30s***

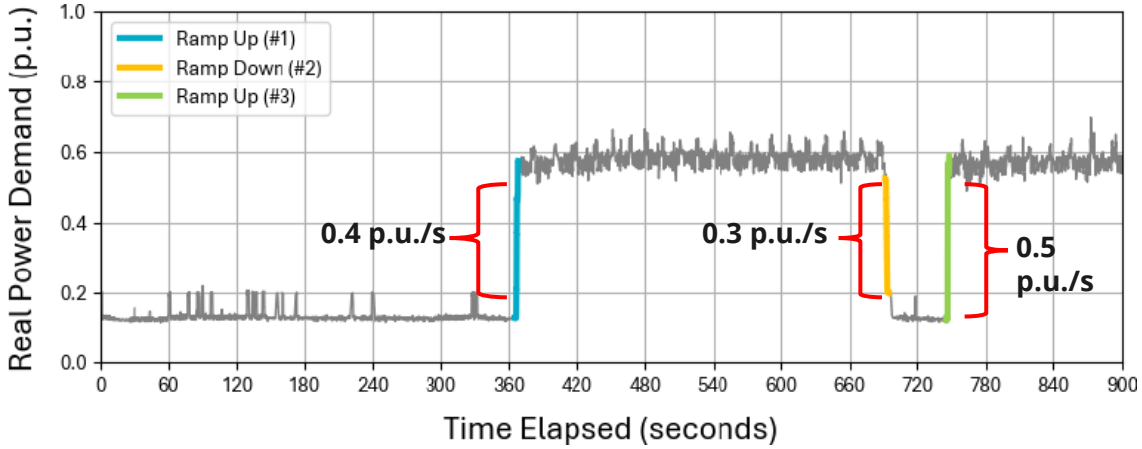
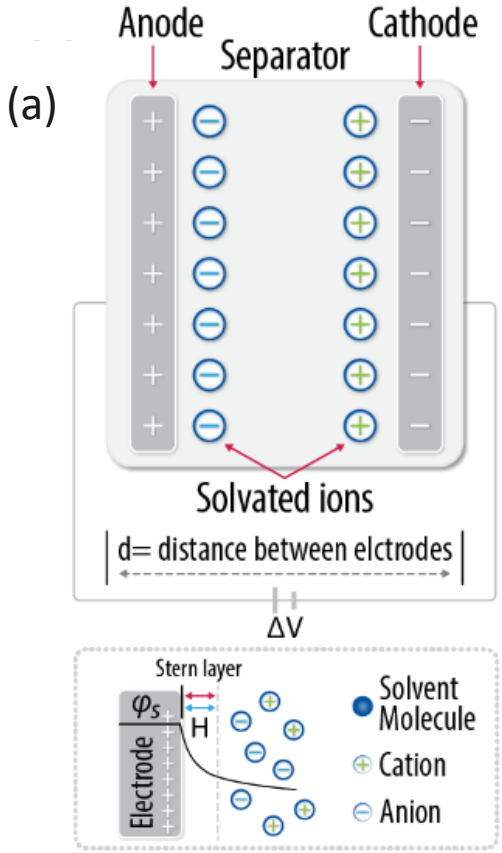


Fig. 3. Data Center (**50 MW**) load profile for an AI training run**

- Ancillary services: primary frequency response, voltage regulation, and black start require fast response
- Hybridization with modular BESS
- Loads that demand very high power discharge in a short duration

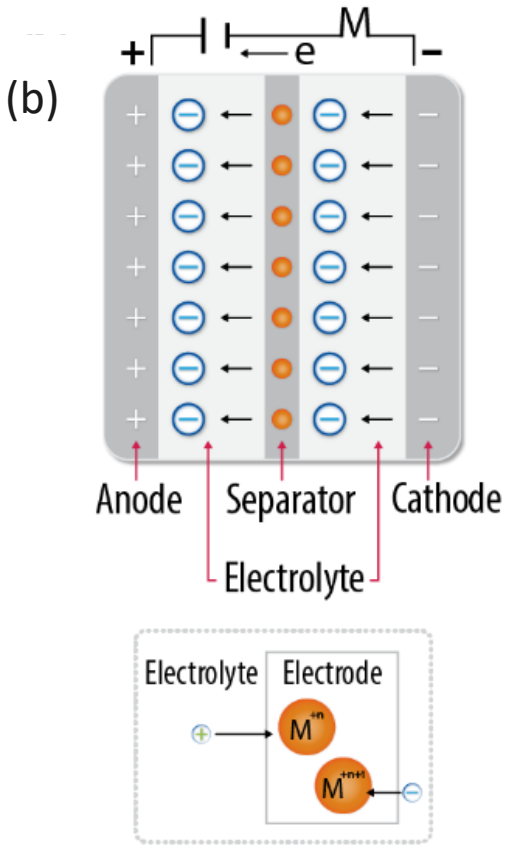
* Homan, Samuel, and Solomon Brown. "An analysis of frequency events in Great Britain." *Energy Reports* 6 (2020): 63-69.
** Force, N.L.L.T., 2025. Characteristics and risks of emerging large loads. *NERC, White Paper*.

TYPES OF SUPERCAPACITORS



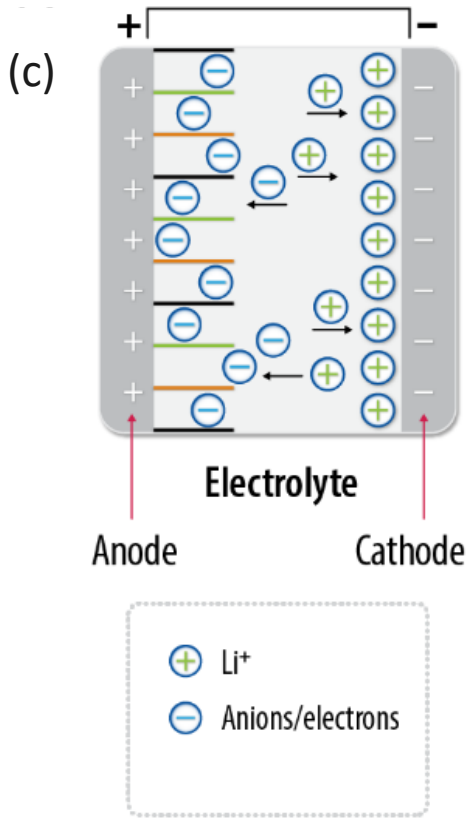
Electrochemical double-layer capacitor (EDLC)

- Activated Carbons
- Graphene
- Carbon Fibers



Pseudocapacitor

- Metal Oxides
- Conducting polymers
- Noble Metals



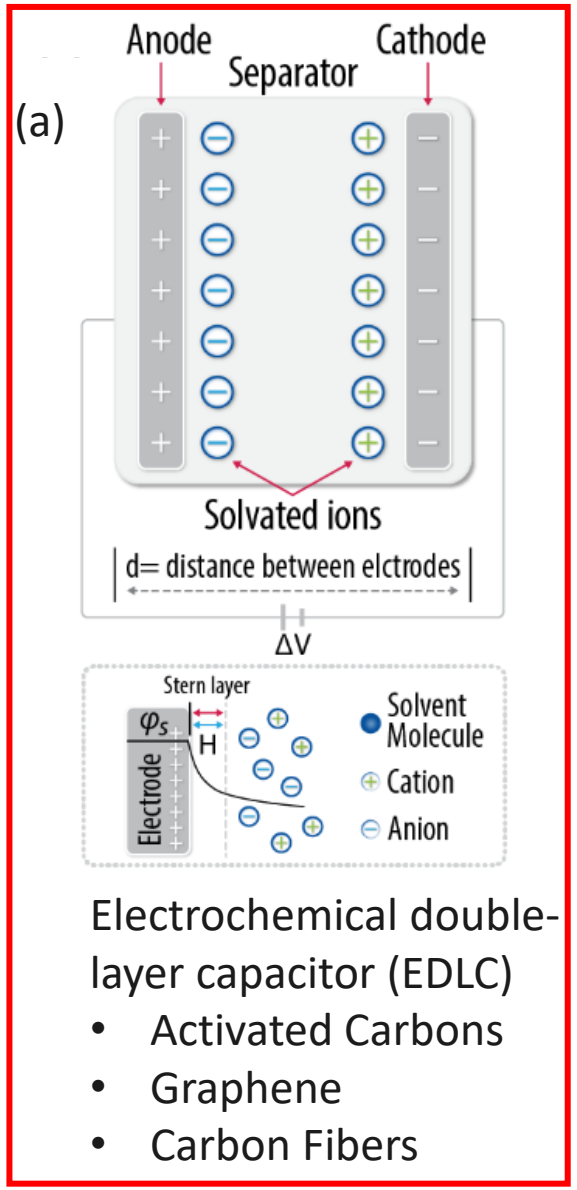
Hybrid Electrochemical Capacitors

- ASCs
- HSCs

Syeda Wishal Bokhari, et al, Advances in graphene-based supercapacitor electrodes, *Energy Reports*, 2020.

TYPES OF SUPERCAPACITORS

- Advanced material development
- Minimizing self-discharge
- Module development & testing



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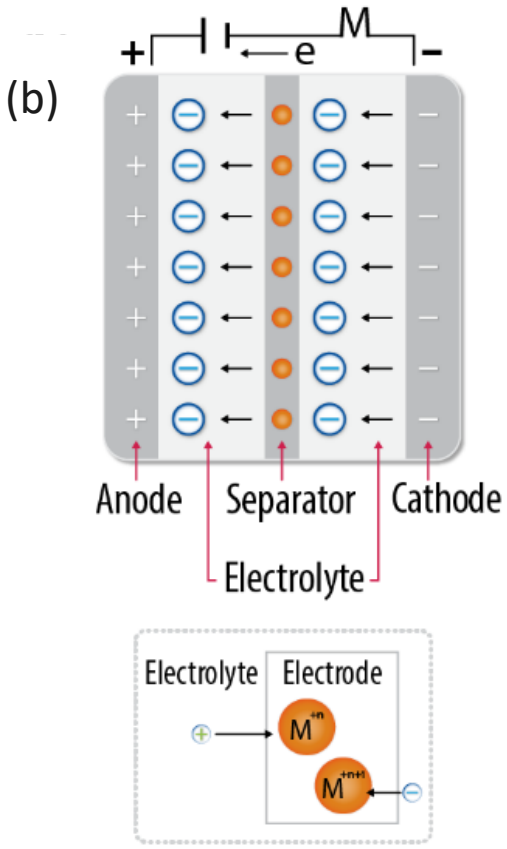

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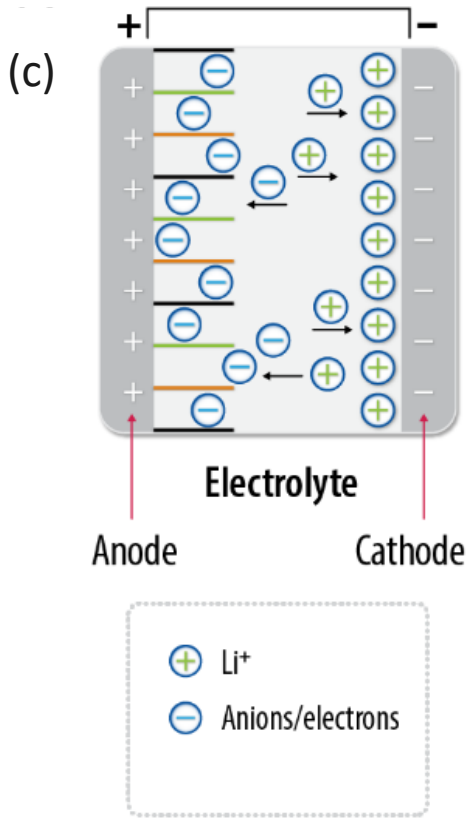

Hybrid Electrochemical Capacitors

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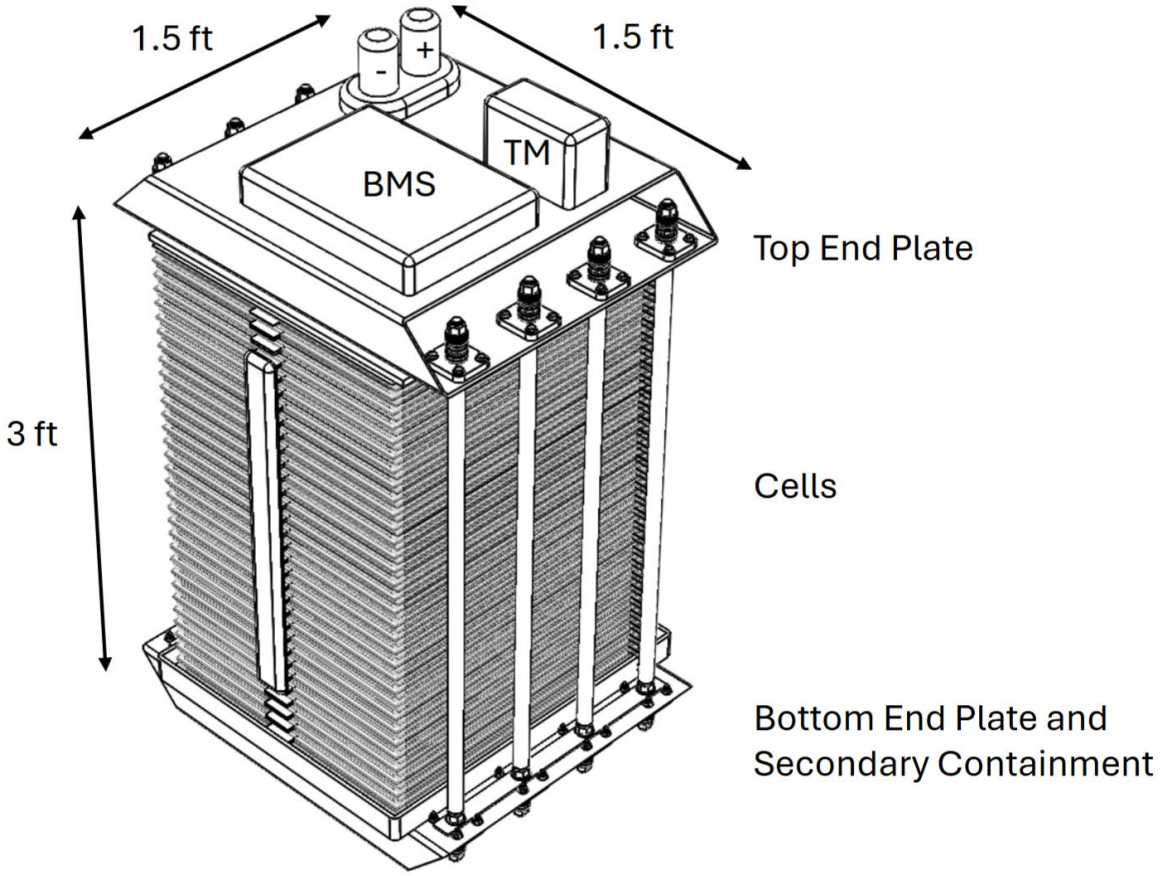
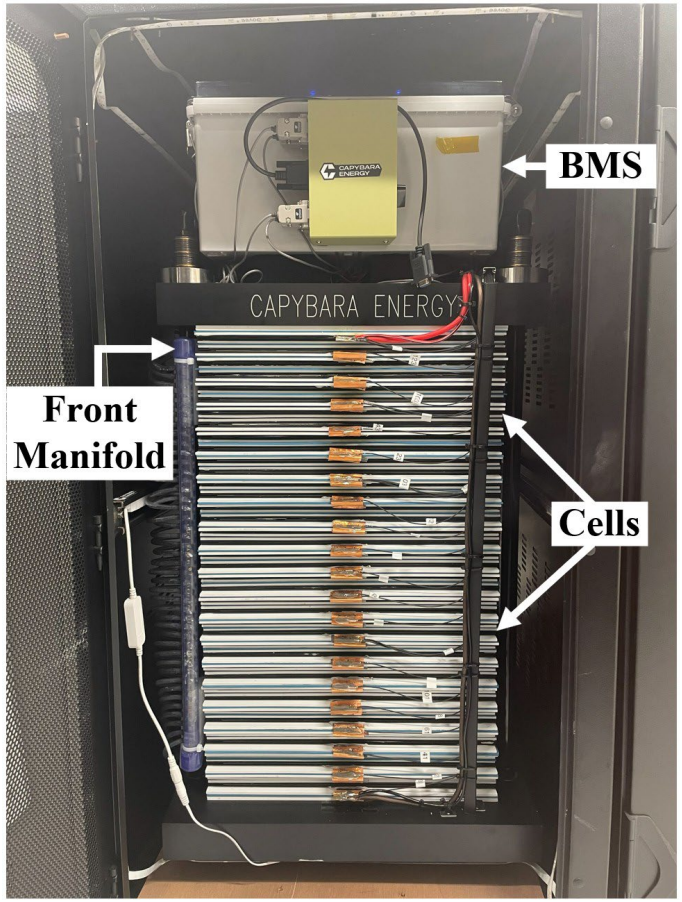
CAPYBARA ENERGY: TECHNOLOGY OVERVIEW

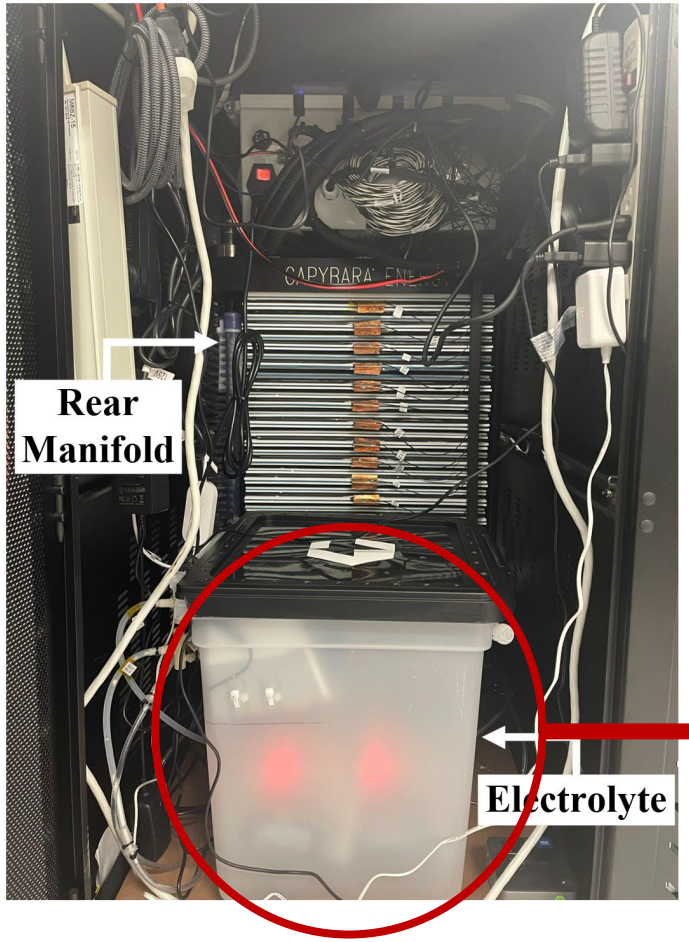


- Aqueous supercapacitor
- Sodium Sulfate Solution with a pH range between 6-8
- Thick carbon electrodes derived from low-cost waste feedstocks
- Modular prismatic cell architecture
- Rated Capacity: 33.3Ah
- Nominal Voltage: 1.5V
- Min. Voltage: 0.2V, Max. Voltage: 1.8V
- Min. Temperature: 18°C, Max. Temperature: 55°C
- Min. Current: 250mA, Max. Current: 2A
- Energy: 50Wh

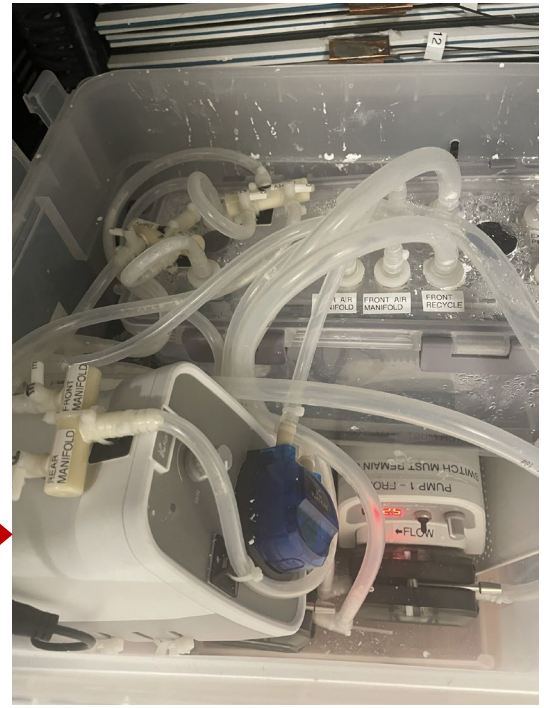
CAPYBARA ENERGY MODULE PROTOTYPE



Module Front View



Module Rear View



Electrolyte Pump

Fig. 4. Prototype containing 32 cells in series & managed by Nuvation BMS

SYSTEM INTEGRATION & OPERATION

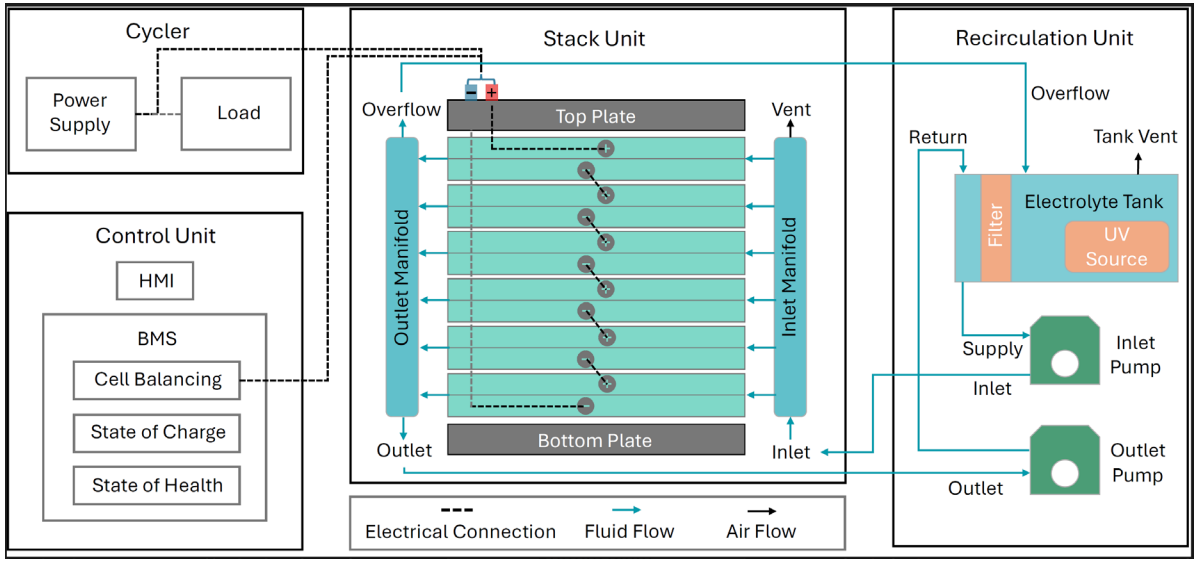
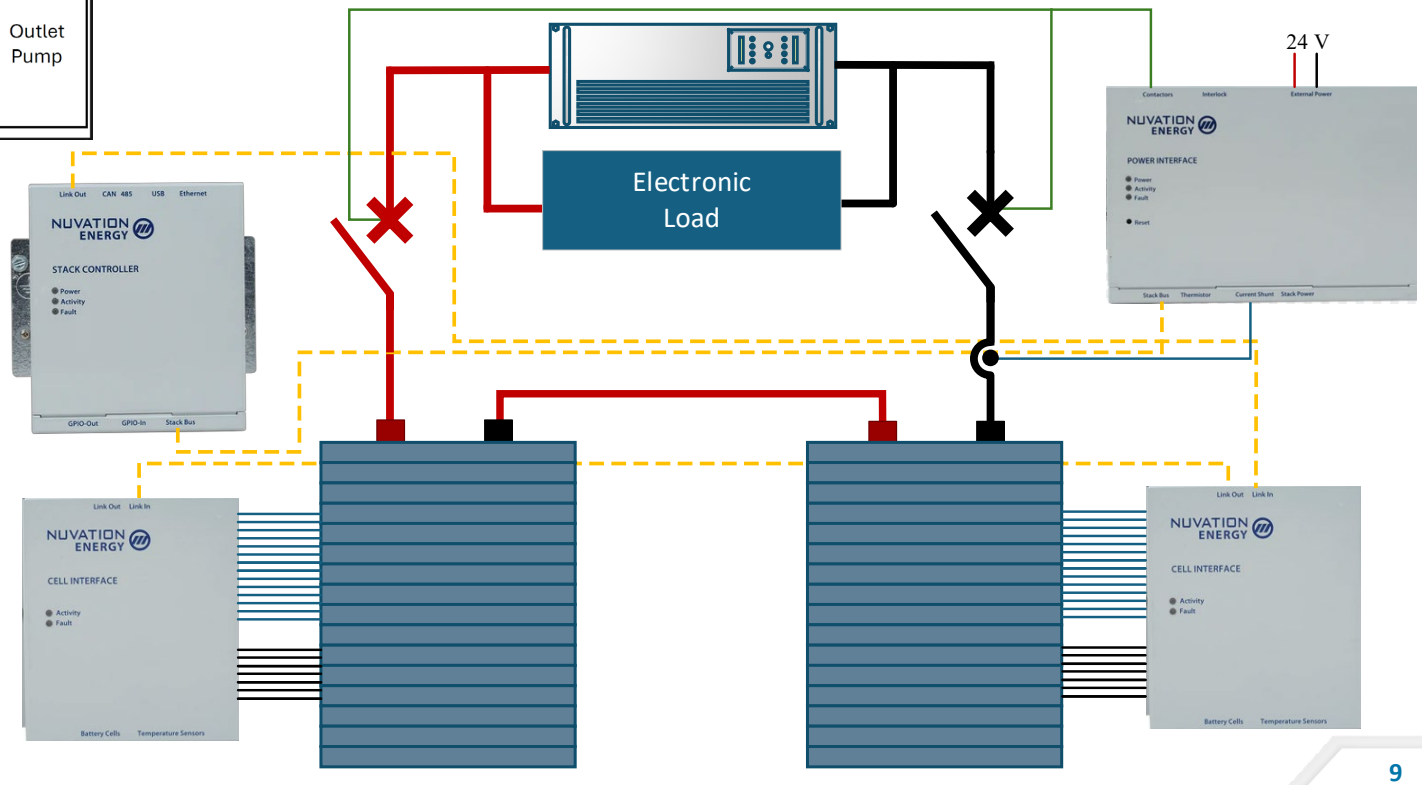


Fig. 5. Balance of System (BoS) Components

Fig. 6. System Integration Schematic



CAPYBARA ENERGY: TEST RESULTS

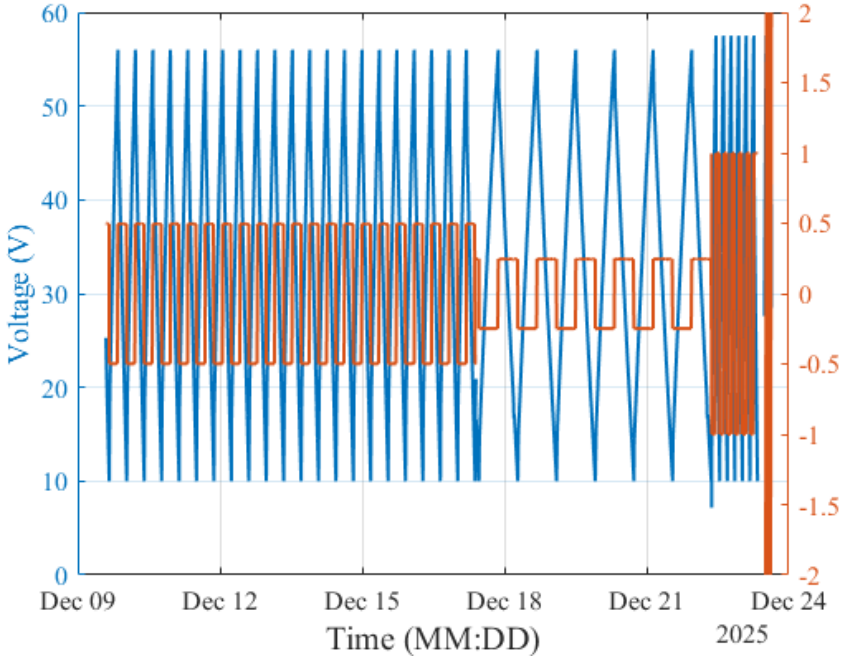


Fig. 7. Voltage and Current at different C-rates

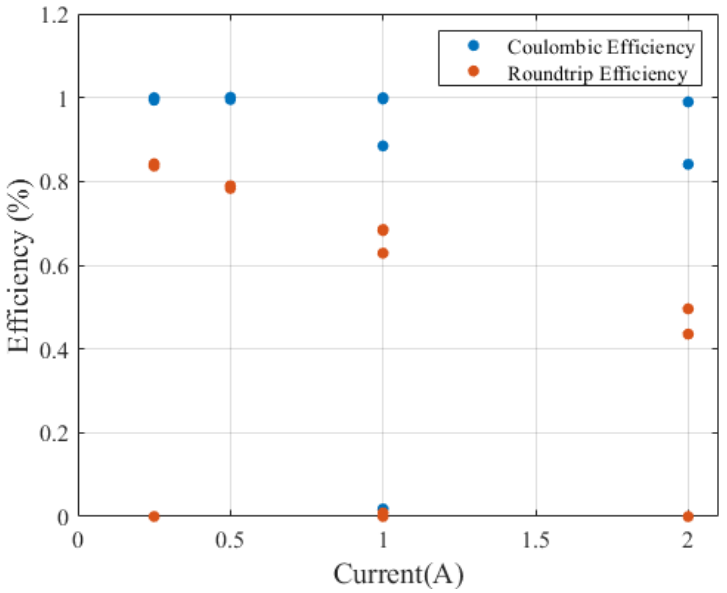


Fig. 8. Round Trip and Coulombic efficiencies at different C-rates

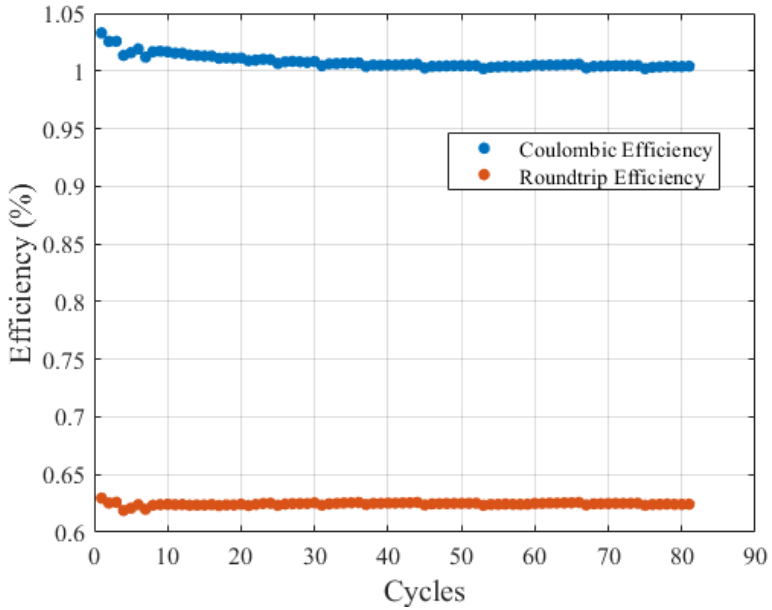


Fig. 9. Round Trip and Coulombic efficiencies at 2C

CAPACITECH ENERGY: TECHNOLOGY OVERVIEW

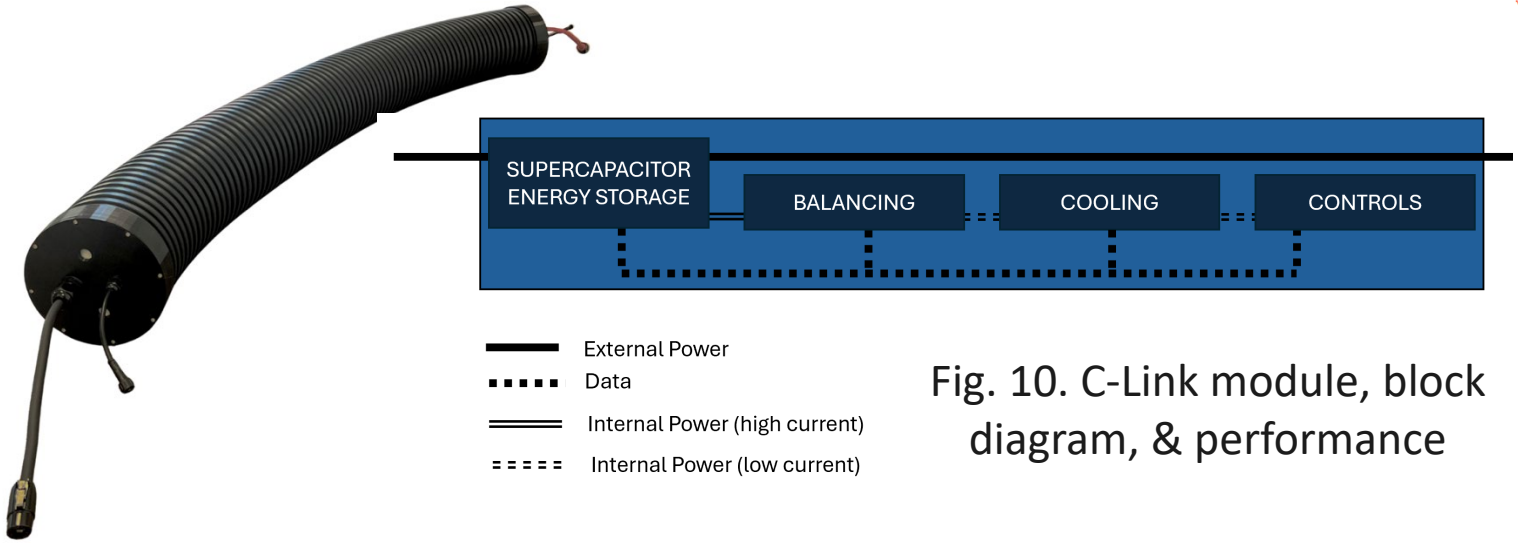


Fig. 10. C-Link module, block diagram, & performance

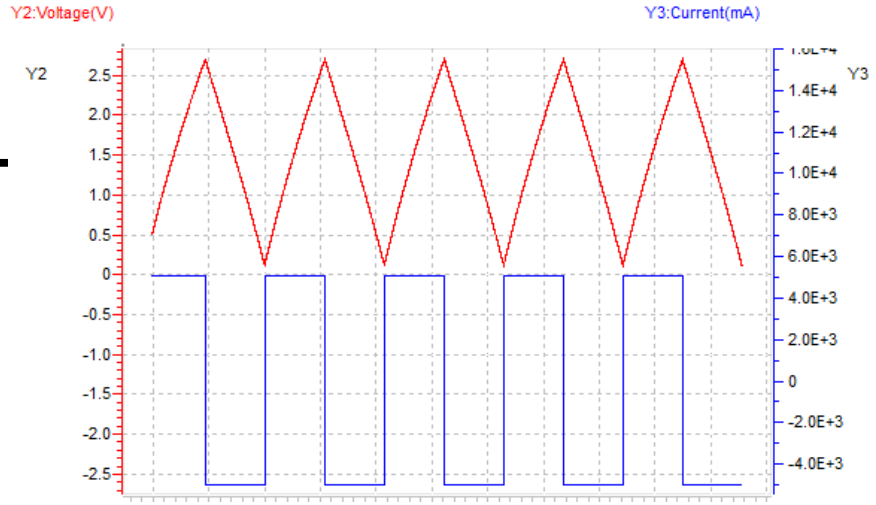
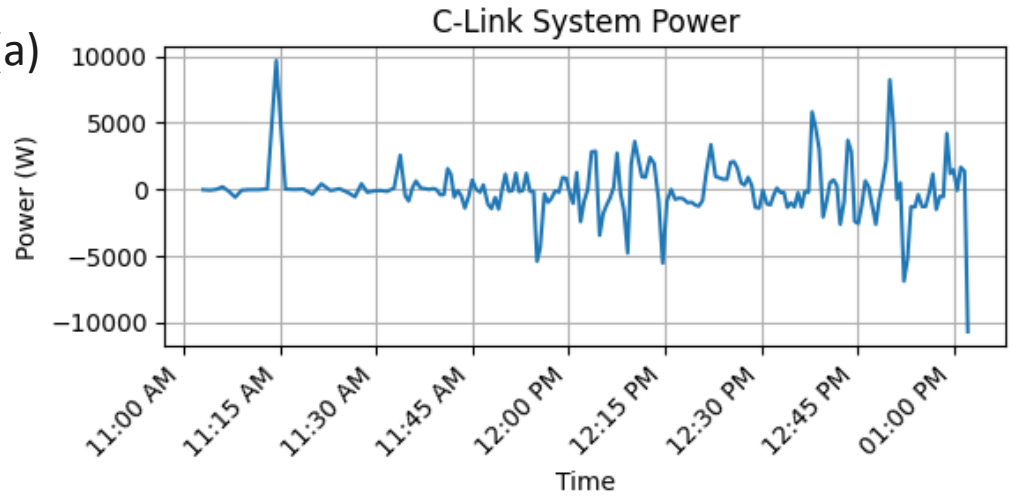


Fig. 11. System comprising 36 C-Link modules. System specs: 3.6F, 720V, 302 kW, 0.26 kWh

CAPACITECH ENERGY: TEST RESULTS

(a)



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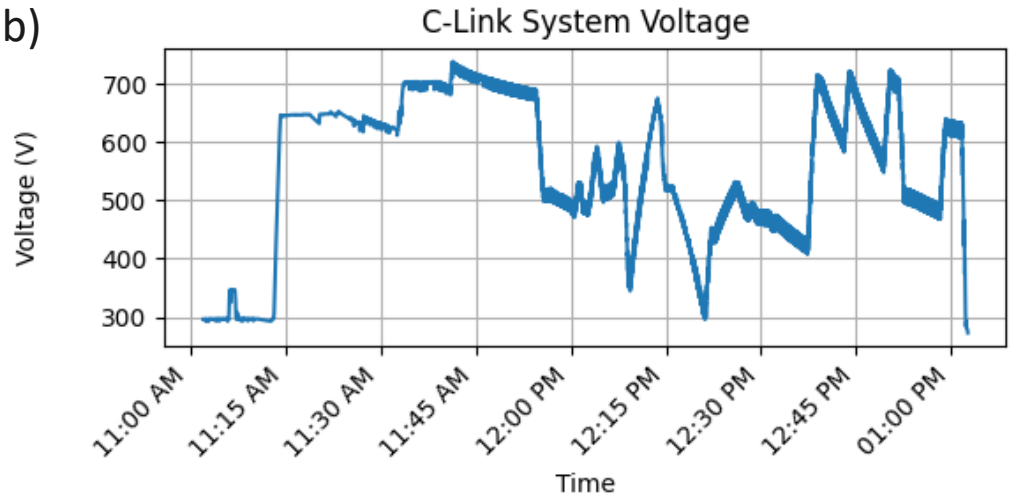

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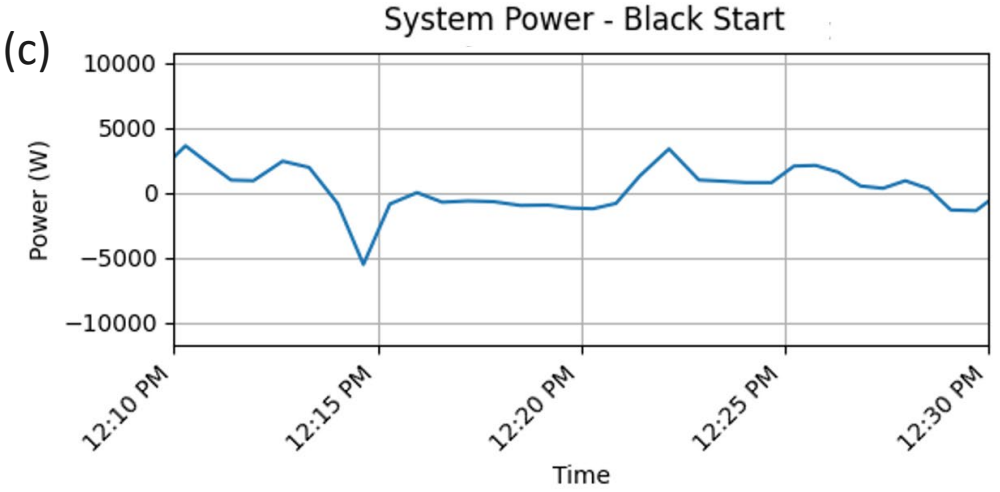

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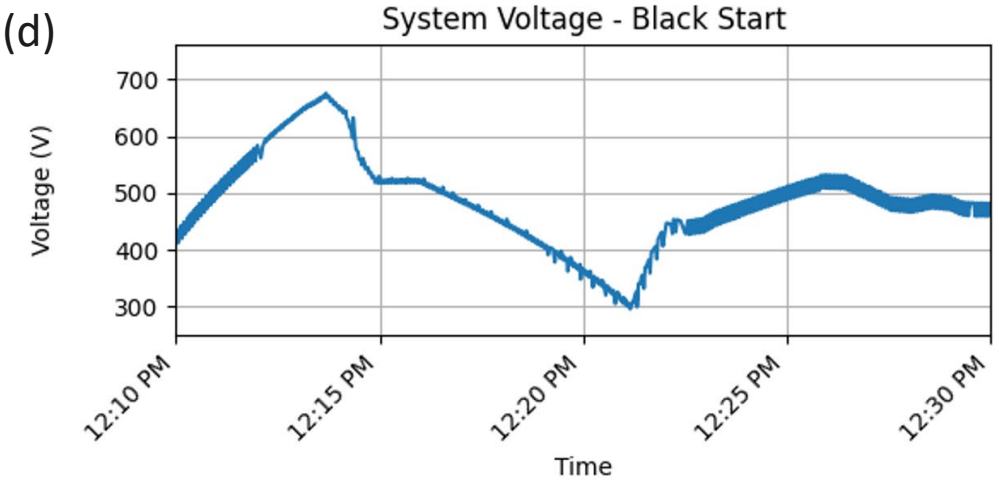

FUTURE DIRECTION

- Perform testing of non-Li technologies by interfacing the technology with modular power electronics and various load profiles to standardize a modular system integration platform.
- Characterize graphene based technology for application in fast ramp rate and used as a hybrid system with BESS.
- Sandia will continue supporting non-Lithium manufacturers in getting their technology demonstrated at utility scale. These endeavors will facilitate the diversification of battery chemistries, standardize chemistry-agnostic system integration, & support widely diverse load profiles. This will minimize demonstration cost and enable faster deployment of non-Li technologies.

ACKNOWLEDGEMENTS

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THANK YOU!!

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