Materials Innovation and Cell Development for Room Temperature Sodium-Sulfur Batteries

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U.S. DEPARTMENT of ENERGY

PROJECT PROFILE
Topic: Sodium Batteries | Vertical: Materials and Systems Innovation
Strategic Pathway: Grow: Long-term expansion by enabling innovation, advancing new technologies, and building capacity for a future-ready electricity system.
Project start and finish: FY25-FY27

PROBLEM

- Room-temperature sodium-sulfur (RT Na-S) batteries suffer polysulfide shuttling and rapid capacity degradation.
- Large sulfur volume expansion also damages the structural and electrochemical stability of the cathode.
- Recent efforts in carbon hosts and electrolyte engineering still lack durable RT Na-S cycling stability.

APPROACH

- APPROACH 1 – Elucidating RT Na-S battery chemistry using multimodal synchrotron X-ray techniques.
- Utilized X-ray tomography and absorption spectroscopy during battery operation to provide fundamental insight into the sulfur reaction scheme, addressing the lingering challenges before establishing inexpensive Na-S batteries for broad applications.

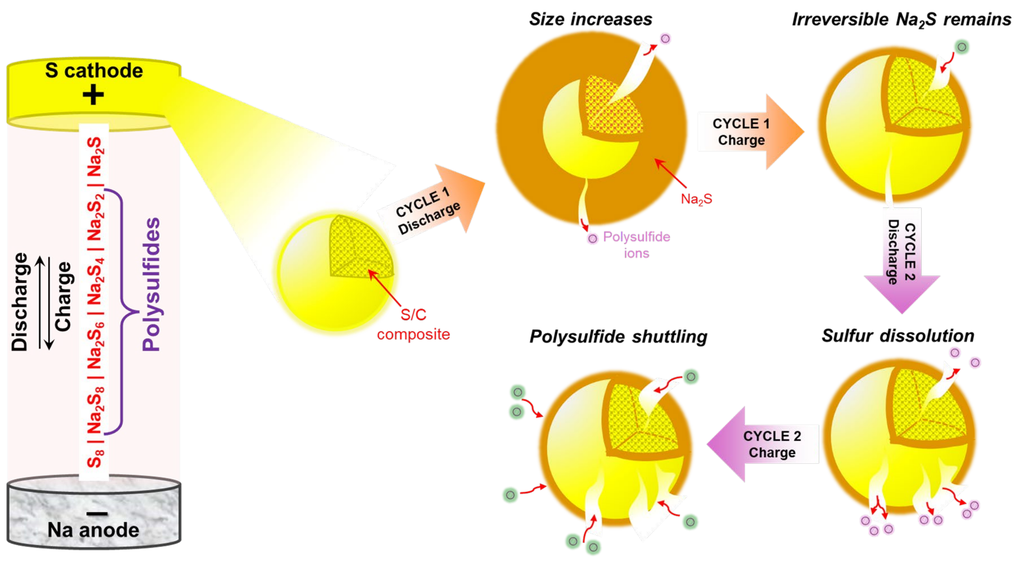

Fig. 1. Schematic illustration of a sulfur particle undergoing structural degradation and PS dissolution during battery cycling.[1]

- APPROACH 2 – Redox kinetics accelerated by catalytic supports.
- We designed a porous carbon host with the in-situ embedded Nb_2O_5 catalyst for accelerating sulfur redox kinetics along a quasi-solid-state conversion mechanism.
- Operando sulfur K-edge X-ray absorption spectroscopy demonstrates the catalytic role of the in-situ embedded Nb_2O_5.

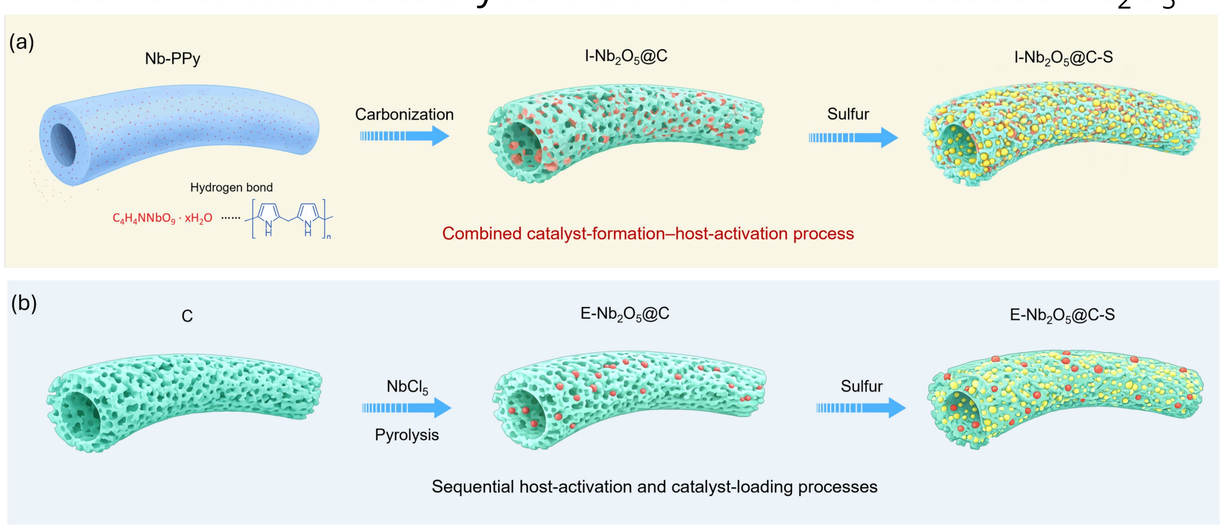

Fig. 2. Schematic fabrication routes and resulting structure for (a) catalytic host and sulfur cathode, and (b) control samples with deficient catalytic function.

RESULTS

- I-Nb_2O_5@C−S delivers among the most promising sulfur utilization in literature, achieving 1540 mAh g^{-1} at 0.1 C, and 971 mAh g^{-1} at 1 C with a low-capacity decay of 0.046% per cycle over 1000 cycles.
- I-Nb_2O_5@C−S displays faster sulfur redox kinetics, achieving nearly complete conversion of sulfur to Na_2S_4 and subsequently to Na_2S_2 at around 25% depth of discharge (DOD) and 50% DOD.
- In contrast, the other two control samples show kinetically hindered S reduction and Na_2S oxidation.

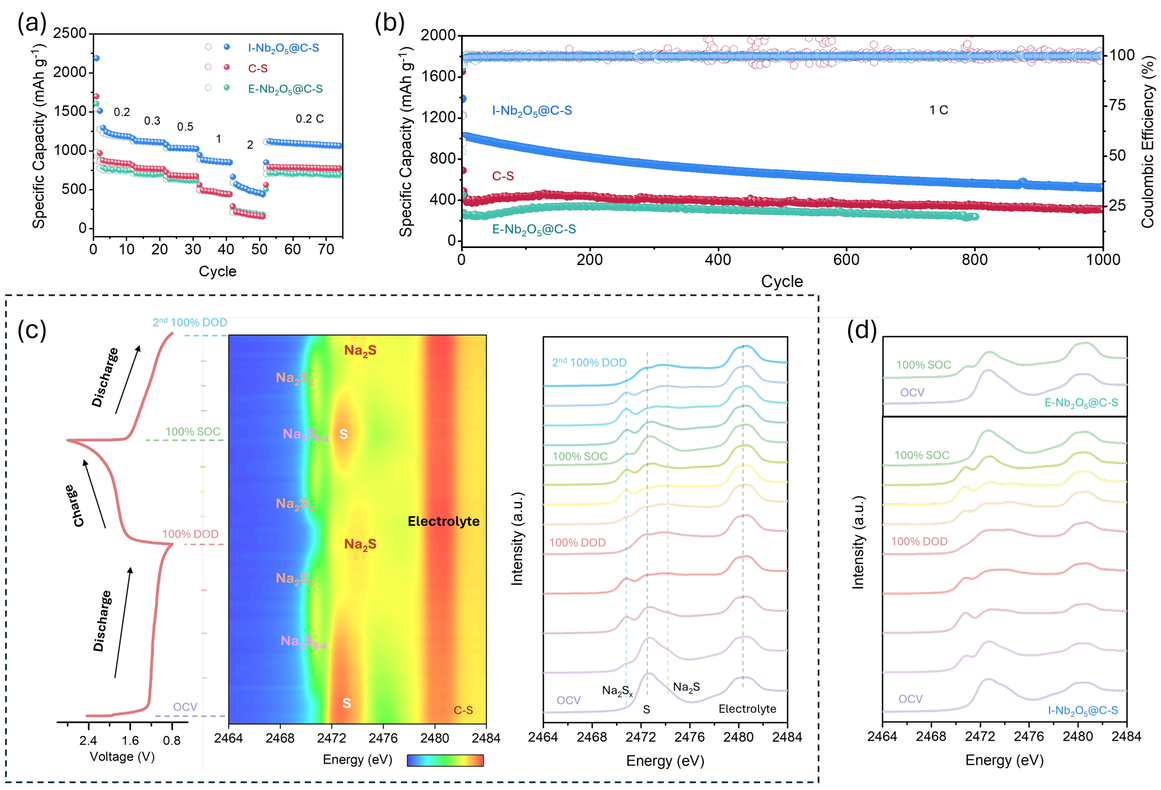

Fig. 3. Results suggest that the I-Nb_2O_5@C−S cathode delivers improved sulfur utilization and Na-S cell capacities.

CONCLUSIONS & IMPACT

- The project helps us identify the lingering concerns to address in the material design and calls for the innovation of alternative Na-S cell materials with lower polysulfides dissolution and improved redox kinetics.
- The project brings catalyst accessibility into focus and demonstrate that a host-synthetic strategy based on in situ embedded catalytic sites maximizes catalytic accessibility and efficiency.
- The project offers a guidance of how catalytic sites can be effectively accessible to polysulfides especially when pursuing a highly confined sulfur redox pathway.

FUTURE DIRECTIONS

- Combine machine learning and experimental efforts on developing low-cost and earth-abundant materials to boost the Na-S battery performance for grid-scale energy storage (in collaboration with LLNL).
- Engineer the cell architecture and integrate high-loading sulfur cathodes for practical energy storage applications (in collaboration with ORNL).
- Utilize the Grid Storage Launchpad to validate high-performance Na-S batteries at scale.

References

[1] Zheng X*, Nanda J*, et al., 2025, J. Electrochem. Soc. 172, 110508.
[2] Zheng X*, Nanda J*, et al., 2026, under review

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