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FROM COMPOSITE DESIGN TO SCALED DEMONSTRATORS

A Multiscale Approach to the Sustainable Development of Lithium–Sulfur Batteries

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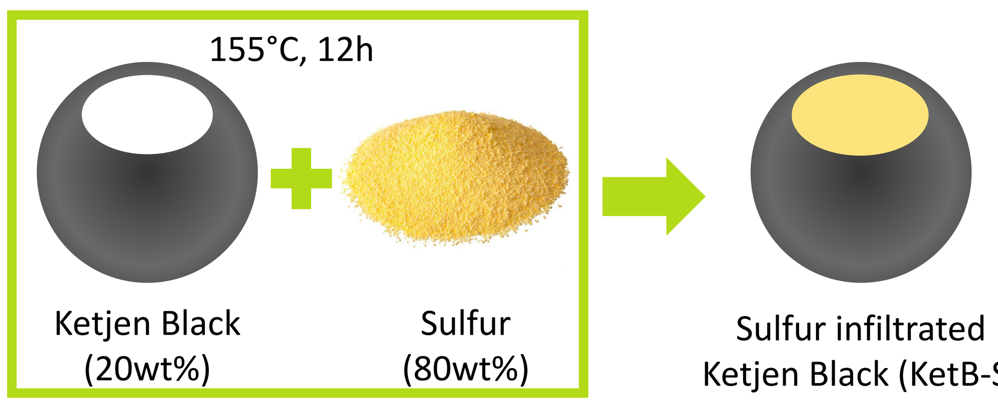
ABSTRACT: Lithium–sulfur (Li–S) batteries are a promising next-generation energy storage technology due to their exceptionally high gravimetric energy density of up to ~600 Wh kg^{-1}, far exceeding that of conventional lithium-ion batteries (~250–300 Wh kg^{-1}) [1]. This makes them especially attractive for weight-sensitive applications such as drones, aviation, and electric aircraft. In addition, Li–S batteries benefit from the high abundance and wide availability of sulfur—often as an industrial byproduct—resulting in improved supply-chain security compared to transition-metal-based cathodes [2]. With the potential for sustainable, aqueous-based material processing, Li–S technology combines high energy density with environmentally benign and resource-efficient chemistry.

Motivation

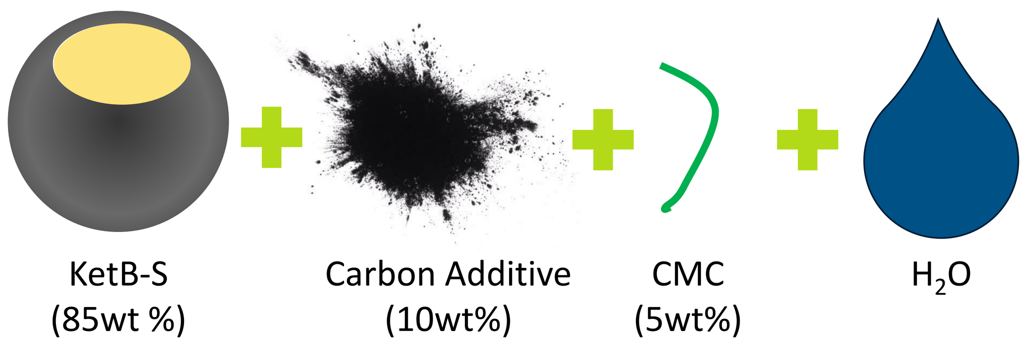
100% aqueous cathode processing—sustainable by design
Multi-format performance testing: coin cells to pouch cells
Electrode engineering drives superior sulfur utilization

Cathode Engineering

Melt Infiltration:

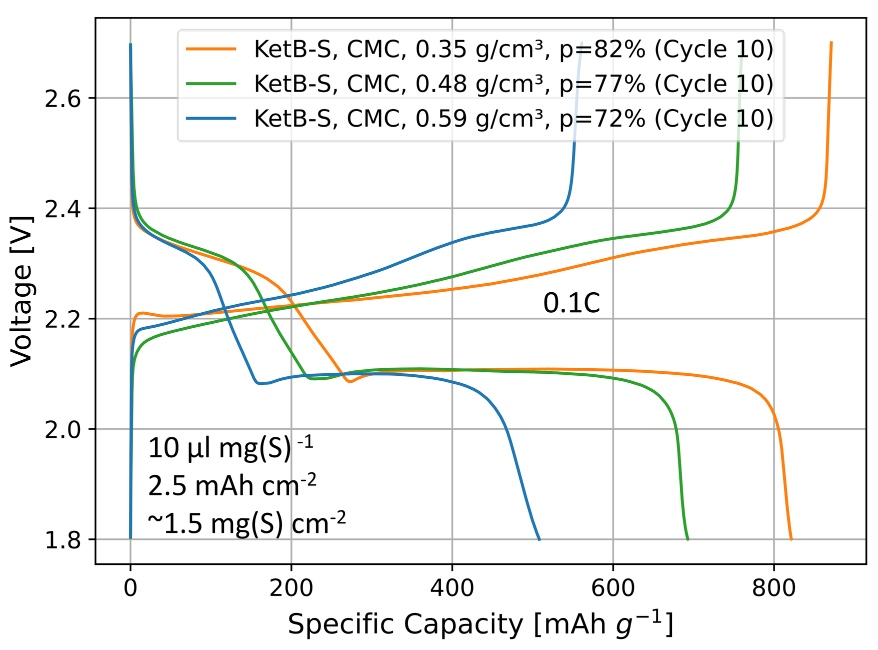


Electrode slurry preparation:



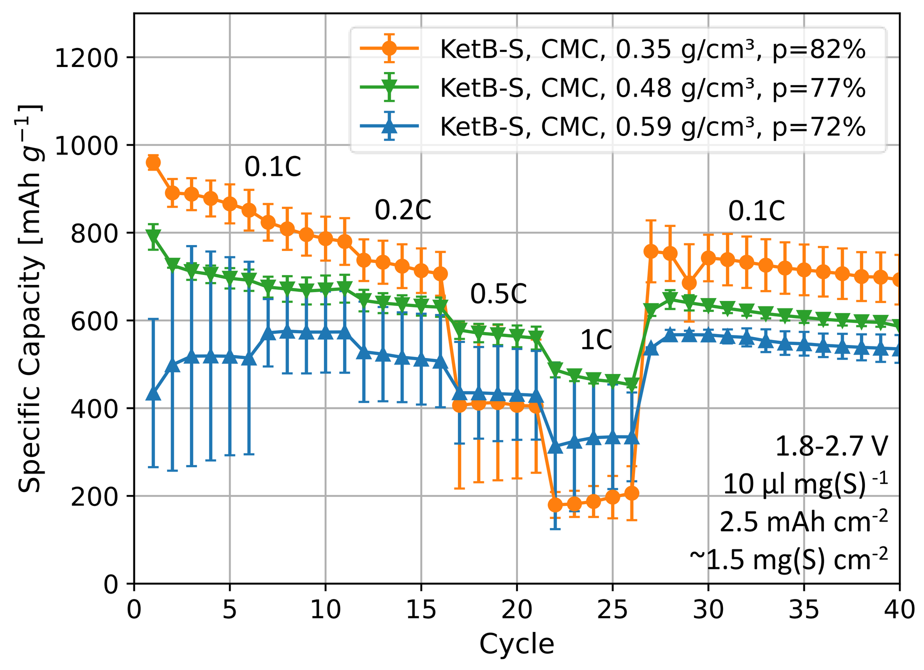
Discharge-Charge Profiles

Anode: Li metal (Ø: 15mm); **Separator:** Celgard 2325 (Ø: 18mm); **Cathode:** KetB-S cathode (Ø: 12mm); **Electrolyte:** 1M LiTFSI and 0.2M $LiNO_3$ in 1,3-dioxolane (DOL) and dimethoxyethane (DME) (50:50 vol%)



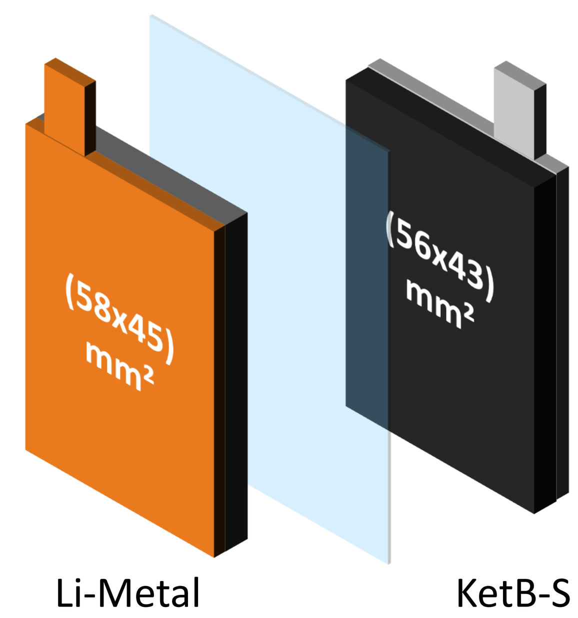
→ Electrode design drives sulfur utilization
→ Insufficient porosity restricts critical sulfur-to-polysulfide conversion [3]

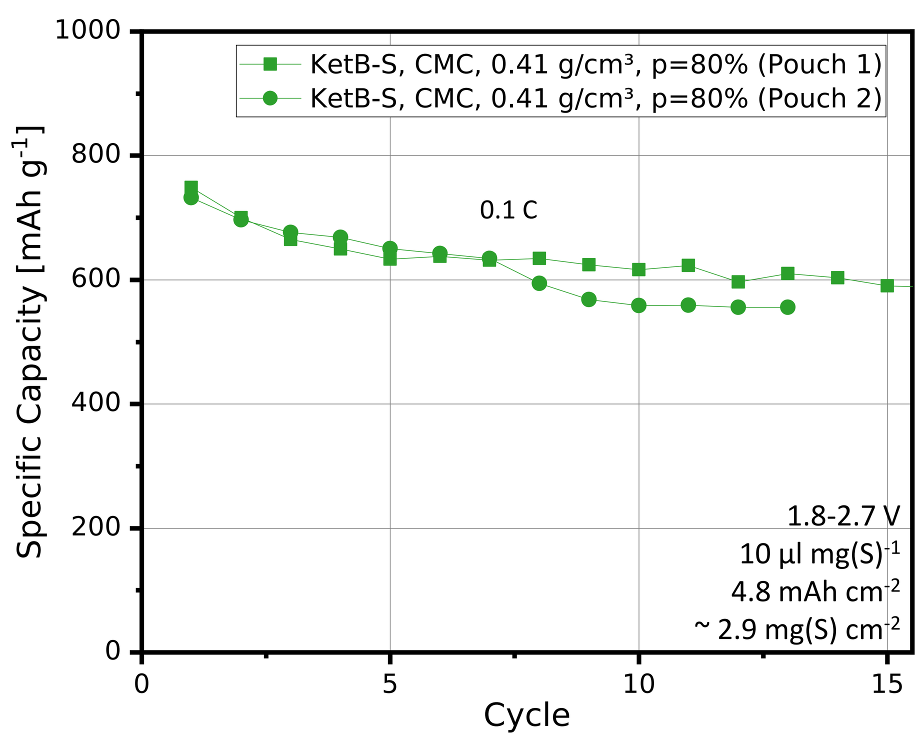
Rate Capability Analysis



→Porosity engineering yields ~900 mAh g^{-1} in coin cells with successful translation to pouch cell format

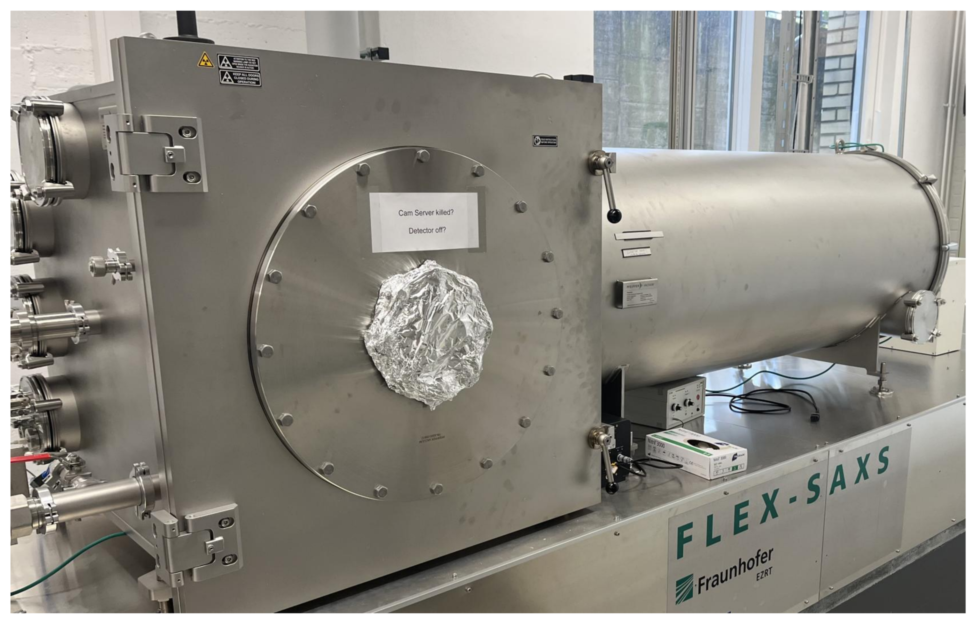
Pouch Cell Performance Validation



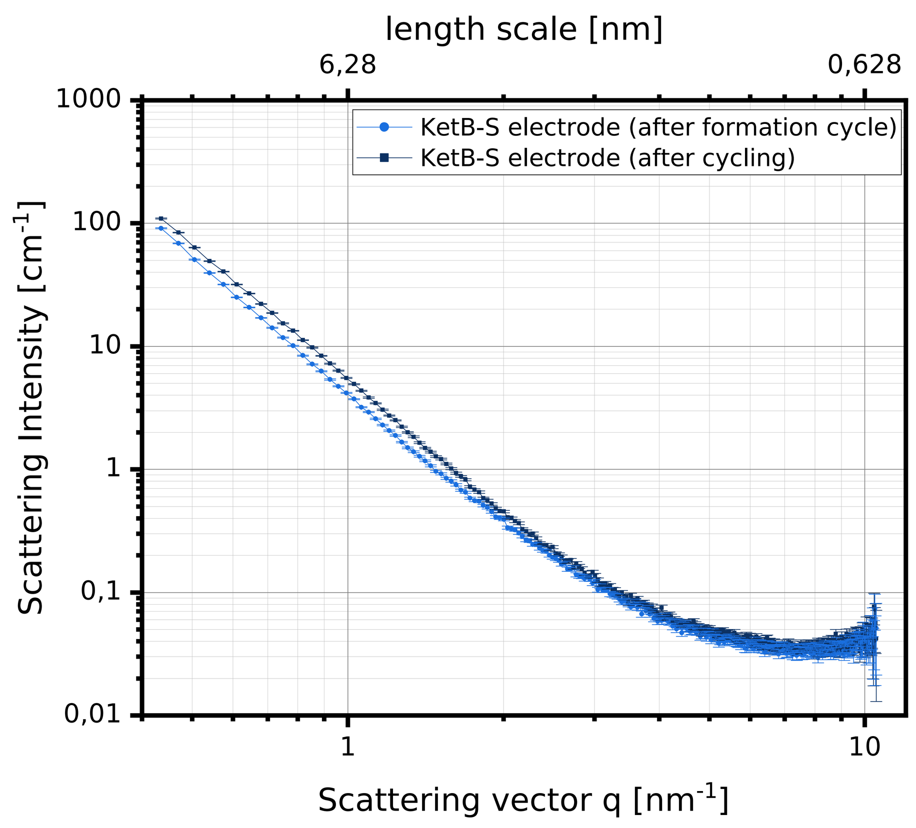


→Performance validated at multiple scales
→Practical scale demonstration: 750 mAh g^{-1} capacity in pouch cell configuration

Small Angle X-Ray Scattering



Tracking Sulfur Movement in Cathodes



→ The fundamental relationship $I(q) \propto (\Delta\rho)^2$ enables monitoring of sulfur utilization - higher scattering intensity confirms Sulfur depletion from Ketjen Black nanopores

Results at a Glance:

Fully aqueous cathode processing eliminates organic solvents

Cathode design drives sulfur accessibility and utilization

750 mAh g^{-1} pouch cell performance confirms scalability

SAXS reveals sulfur migration from the Ketjen Black nanoporous network

1. H. Pan et al., Nano-Micro Letter, **2023**, 15, 165
2. Borchardt L., Chem. Eur. J., **2016**, 22, 7324
3. N. Kang et al., Nature Communications, **2019**, 10, 4597

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