

Supporting Information

Dual-Active Ca - Li Alloy Anodes Enable Ultra-Stable and Ultra-Low-Cost Liquid Metal Batteries

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Supporting Figures

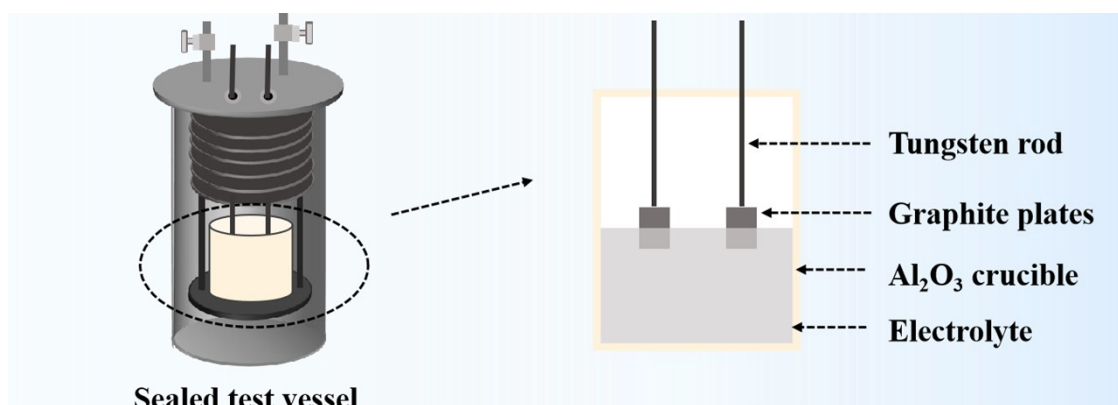


Figure S1. Schematic diagram of pre-electrolysis device.

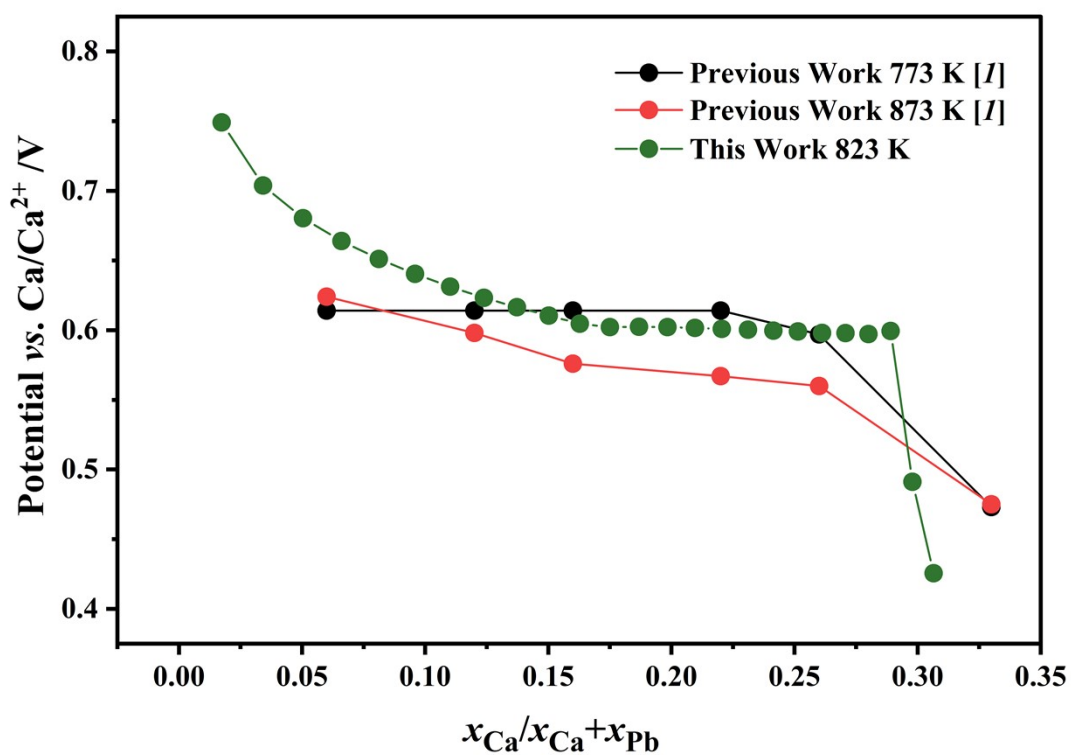


Figure S2. Equilibrium cell voltage values of the WE and comparison with previously reported values⁸ as a function of composition of the Ca-Pb electrode at 550°C.

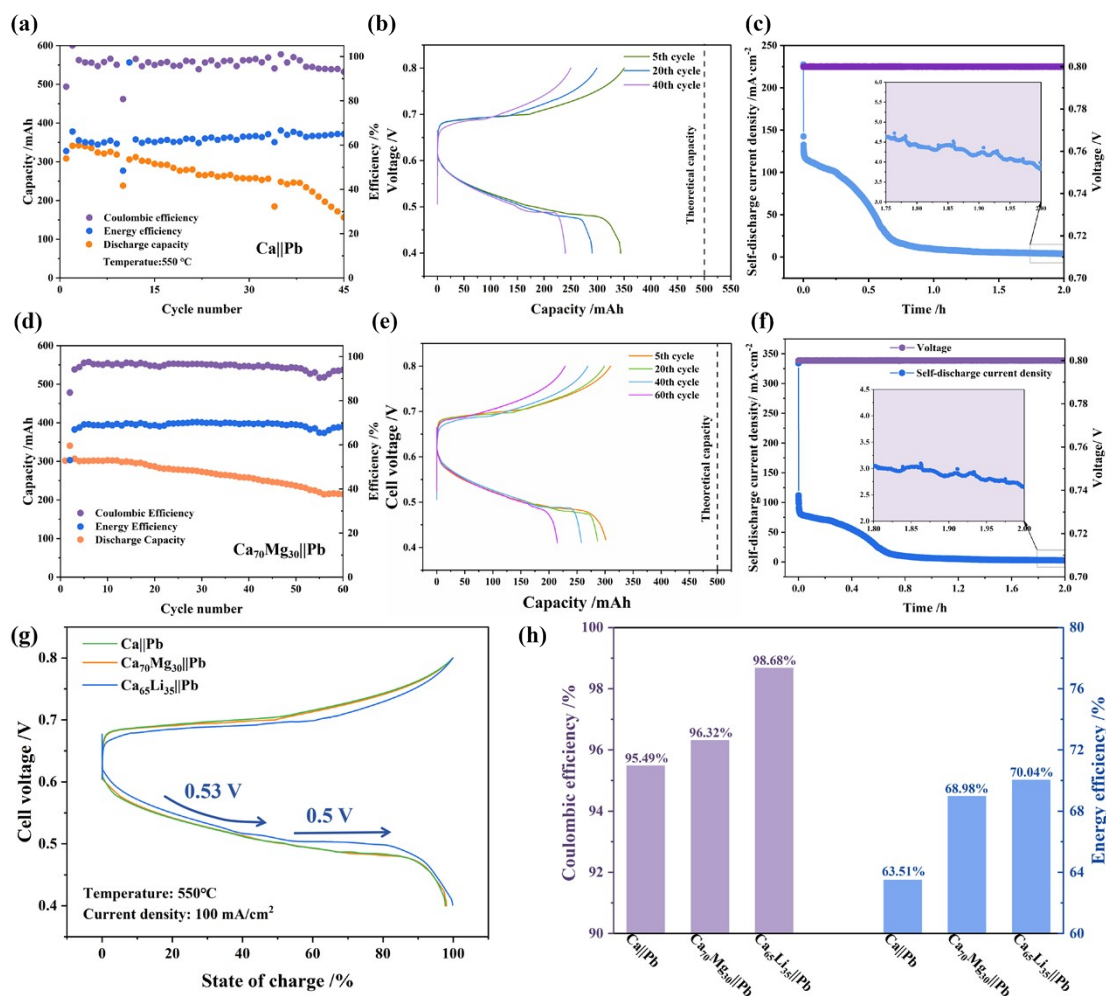


Figure S3. Electrochemical performance of control group. (a) The cycling performance of the Ca||Pb cell at 100 mA/cm² under 550°C. (b) The charge-discharge voltage profiles at the 5th, 20th, and 40th cycle. (c) Self-discharge curve at the fully charged state of the 5th cycle. (d) The cycling performance of the Ca₇₀Mg₃₀||Pb cell at 100 mA/cm² under 550°C. (e) The charge-discharge voltage profiles at the 5th, 20th, 40th, and 60th cycle. (f) Self-discharge curve at the fully charged state of the 5th cycle. (g) The charge-discharge voltage profiles and (h) the efficiency comparison of the Ca||Pb, Ca₇₀Mg₃₀||Pb, and Ca₆₅Li₃₅||Pb cell.

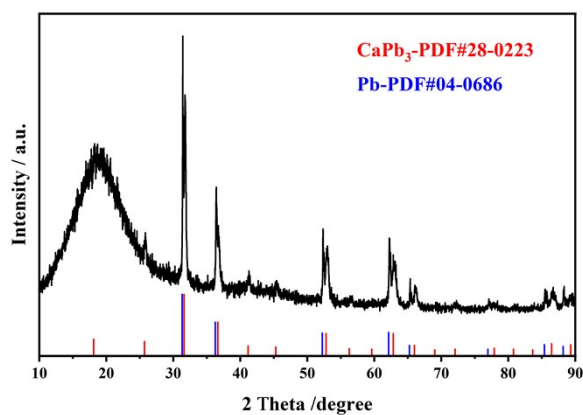


Figure S4. The X-ray diffraction pattern of the cathode at 100% DOD in the $\text{Ca}_{70}\text{Mg}_{30}\|\text{Pb}$ cell.

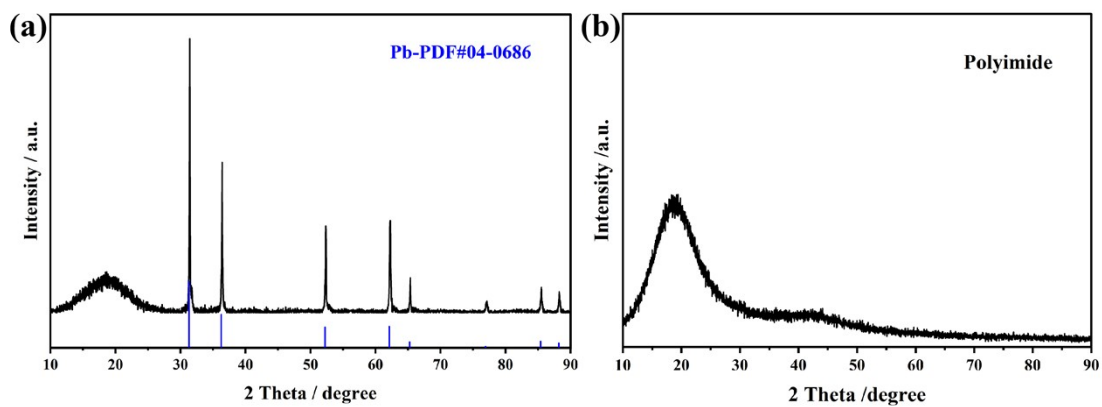


Figure S5. The X-ray diffraction pattern of (a) the Pb cathode at the initial state and (b) the PI type.

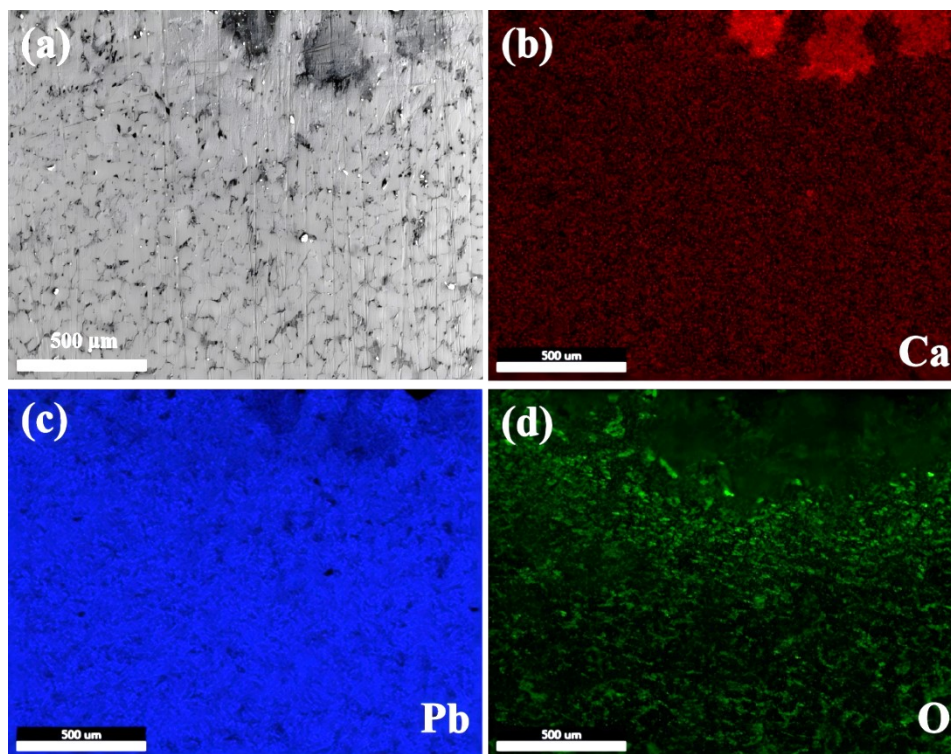


Figure S6. Energy-dispersive X-ray spectroscopy (EDS) analysis of the cathode at 100% DOD in the $\text{Ca}_{65}\text{Li}_{35}\|\text{Pb}$ cell.

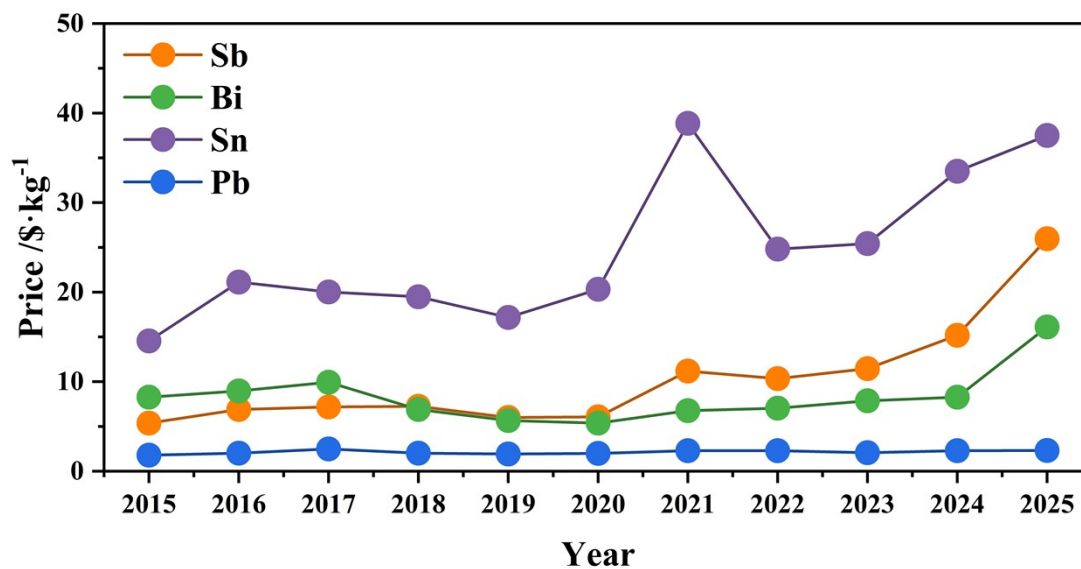


Figure S7. The price variation of major cathode candidates over the past decade. (Data sourced from mainstream commodity trading website www.asianmetal.cn for August 2025.)

Supporting Tables

Table S1 The Electronegativity, equilibrium potential versus Ca^{2+}/Ca , melting point, electrical conductivity, and cost of Sb, Bi, Sn and Pb.

| Element | Electronegativity | Equilibrium potential /V | Melting point /°C | Electrical conductivity×10 ⁶ /S m ⁻¹ | Cost ^(a) /\$ kg ⁻¹ |
|---------|-------------------|---------------------------|-------------------|--|--|
| Sb | 2.05 | 0.94-1.04 ² | 631 ³ | 2.56 | 25.97 |
| Bi | 2.02 | 0.79-0.90 ^{2, 4} | 271 ³ | 0.93 | 16.11 |
| Sn | 1.96 | 0.51-0.77 ² | 232 ³ | 8.69 | 37.5 |
| Pb | 2.33 | 0.50-0.69 ² | 327 ³ | 5.21 | 2.32 |

(a) Data sourced from mainstream commodity trading website www.asianmetal.cn for August 2025.

Table S2 Mass loading of materials involved in the cells.

| Cell | Achieved discharge capacity /Ah | Mass/g | | | | |
|--|---------------------------------|--------|--------|--------|---------|-------------------------|
| | | Ca | Mg | Li | Pb | CaCl ₂ -LiCl |
| Ca ₇₀ Mg ₃₀ Pb | 0.35 | 0.3739 | 0.0971 | 0 | 5.8088 | 20 |
| Ca ₆₅ Li ₃₅ Pb | 0.13 | 0.1066 | 0 | 0.0100 | 2.0069 | 20 |
| Ca ₆₅ Li ₃₅ Pb | 4.08 | 3.3805 | 0 | 0.3195 | 47.3201 | 185 |
| Ca Pb | 0.35 | 0.3738 | 0 | 0 | 5.7983 | 20 |

Table S3 Summary of metal prices for the anode and cathode. (Data sourced from

mainstream commodity trading website www.asianmetal.cn for August 2025.)

| Element | Ca | Li | Mg | Sb | Bi | Sn | Pb |
|----------------------------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Price/ \$ kg⁻¹ | 9.03 | 86.11 | 2.53 | 25.97 | 16.11 | 37.5 | 2.32 |

References

- 1 N. D. Smith, N. E. Orabona, J. P. Soldan Palma, Y. Kong, C. Blanchard and H. Kim, *Journal of Power Sources*, 2020, 451.
- 2 J. Delcet, A. Brune and J. J. Egan, *Journal of Metals*, 1979, 31, F37-F37.
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- 4 J. J. Egan, *Journal of Nuclear Materials*, 1974, 51, 30-35.