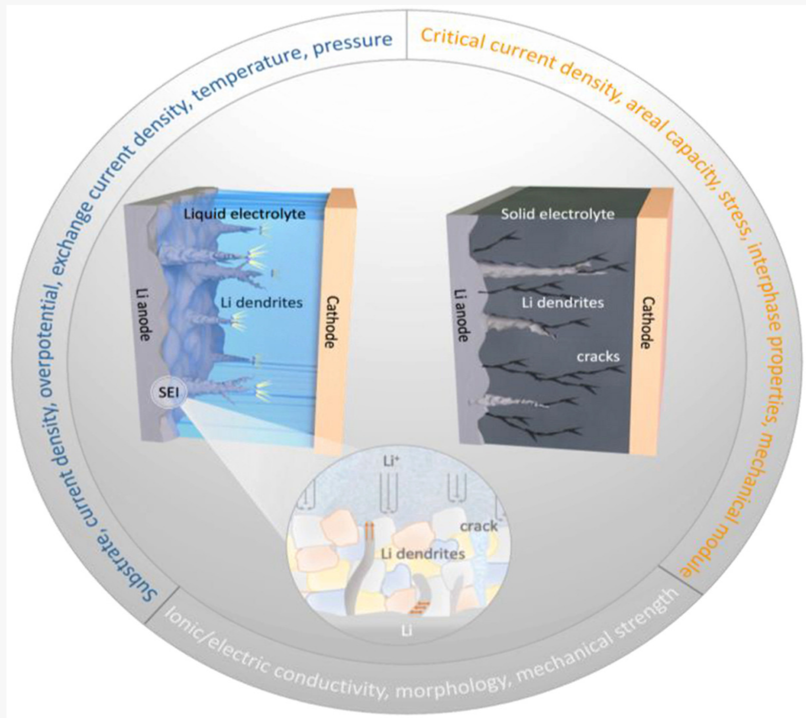
EINPRESSWIRE

Why lithium metal batteries fail—and how mechanics may hold the key

GA, UNITED STATES, February 4, 2026 /EINPresswire.com/ -- [Lithium metal batteries] promise dramatically higher energy density than today's lithium-ion systems, yet their widespread use remains limited by unstable lithium deposition, dendrite growth, and rapid capacity loss. New research synthesizes emerging evidence that these failures cannot be explained by electrochemistry alone. Instead, lithium plating and stripping are governed by tightly coupled electrochemical, chemical, and mechanical processes that evolve dynamically during battery operation. By integrating insights across interfacial reactions, stress accumulation, ion transport, and structural deformation, the study reveals how lithium metal behavior is shaped by multiphysics interactions. Understanding these electro-chemo-mechanical mechanisms offers a unified framework for diagnosing failure and designing safer, longer-lasting lithium metal batteries.



Electro-Chemo-Mechanical Origins of Lithium Dendrite Growth

The demand for higher-capacity energy storage is accelerating with the growth of electric vehicles, grid-scale storage, and emerging applications such as electric aviation. Lithium metal is considered as an ideal anode material due to its exceptionally high theoretical capacity and low electrochemical potential. However, during repeated charging and discharging, lithium tends to deposit unevenly, forming dendrites, inactive "dead lithium," and unstable interfacial layers. These phenomena trigger safety risks, reduce efficiency, and shorten battery lifespan. Traditional approaches focusing only on electrolyte chemistry or electrochemical kinetics have proven insufficient. Based on these challenges, it is necessary to conduct in-depth studies on the coupled electro-chemo-mechanical processes governing lithium metal anodes.

Researchers from Chalmers University of Technology, Kunming University of Science and Technology, and the Wallenberg Wood Science Center reported their views in December 2025 in eScience. The study provides a comprehensive review of lithium metal anode behavior by framing lithium plating and stripping as a coupled electro-chemo-mechanical process. Covering both liquid-state and solid-state battery systems, the work systematically analyzes how electrochemical reactions, mechanical stress, and interfacial chemistry jointly dictate lithium morphology, stability, and failure mechanisms.

The study shows that lithium metal deposition begins with ion desolvation and nucleation, followed by growth processes strongly influenced by current density, overpotential, temperature, pressure, and substrate properties. Low overpotential and controlled current densities favor lateral lithium growth, forming dense, moss-like structures that are more reversible during cycling. In contrast, high overpotentials promote vertical growth and dendrite formation.

A central focus is the solid electrolyte interphase (SEI), which acts as both a chemical barrier and a mechanical constraint. The authors highlight that an ideal SEI must combine high lithium-ion conductivity, low electronic conductivity, mechanical robustness, and structural uniformity. Fragile or heterogeneous SEIs crack under stress, exposing fresh lithium and accelerating parasitic reactions, while mechanically stable SEIs can suppress dendritic growth.

In solid-state batteries, the challenges intensify. Mechanical mismatch between lithium metal and solid-state electrolytes leads to void formation, crack propagation, and lithium filament penetration. The review emphasizes that neither high mechanical stiffness nor electrolyte stability alone is sufficient; instead, interfacial stress evolution, defect distribution, and ion transport pathways must be considered simultaneously. Advanced imaging and multiphysics modeling are identified as critical tools for visualizing and predicting these coupled processes.

"The behavior of lithium metal cannot be understood through electrochemistry alone," the authors note. "Mechanical stress, interfacial chemistry, and ion transport are inseparably linked during battery operation." They emphasize that lithium deposition is inherently a multiphysics phenomenon, where local stress concentrations can redirect ion flux and trigger failure. According to the researchers, adopting an electro-chemo-mechanical perspective enables more rational battery design strategies, moving beyond trial-and-error approaches toward predictive control of lithium metal stability.

By clarifying the fundamental mechanisms behind lithium metal instability, this work provides a roadmap for next-generation battery design. The findings support strategies such as stress-engineered interfaces, mechanically optimized SEI layers, pressure-controlled cycling protocols, and electrolyte formulations tailored to regulate ion transport and stress distribution. These insights are especially relevant for high-energy solid-state batteries, where safety and longevity remain critical barriers. More broadly, the electro-chemo-mechanical framework outlined in this study may accelerate the transition of lithium metal batteries from laboratory prototypes to practical energy storage solutions.

References
DOI
10.1016/j.esci.2025.100429

Original Source URL
https://doi.org/10.1016/j.esci.2025.100429

Funding information
This project has received funding from The Swedish Electricity Storage and Balancing Centre, The Swedish Energy Agency and Wallenberg Wood Science Center. The work was financially supported by the National Natural Science Foundation of China (22479067).

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