Nick Clark · Published April 25, 2026 · PDF

Ambri liquid-metal battery vs a solid-state hydrogen-aluminum energy cell: architectural comparison for stationary storage

Ambri builds a liquid-metal battery, using a molten calcium-antimony electrochemistry, for long-duration stationary and grid-scale energy storage. The domain problem is the same one every stationary storage developer confronts: how to retain charge over long idle periods and survive many years of deep cycling at acceptable cost. This article positions that shipping product against a different structural answer to the same problem, the Hydrogen-Aluminum Energy Cell, disclosed in U.S. Provisional Application No. 64/055,649, which stores energy as surface-bonded hydrogen on metal nanoflakes suspended in a solid conductive gel at ambient temperature.

What Ambri Does

Ambri is a stationary energy storage company that develops and manufactures a liquid-metal battery. The design traces to work on molten-electrode electrochemistry, and the commercialized chemistry pairs a calcium-based alloy electrode with an antimony-based electrode, separated by a molten salt electrolyte. In operation the active layers self-segregate by density into three liquid strata inside a sealed steel container, with the molten salt sitting between the two metal electrodes.

The engineering logic behind this arrangement is sound. Because the electrodes and electrolyte are liquid at the operating temperature, there are no solid interfaces to crack, no intercalation lattice to fatigue, and no dendrites to grow through a rigid separator. The developers have publicly emphasized durability and long service life as central selling points, and the all-liquid interior is a well-reasoned route to those goals. The cells are built from abundant, low-cost materials and are aimed squarely at the long-duration, daily-cycling stationary market, where footprint and calendar cost matter more than gravimetric energy density. Ambri operates at commercial and pilot scale, ships hardware to real projects, and has accumulated the kind of operational track record that a disclosed architecture, by definition, has not. Those are real strengths and should be read as such throughout what follows.

The comparison below is not a critique of that product. It is a contrast between two structurally different ways of solving the same stationary storage problem.

The Architectural Axis

The axis this comparison turns on is the physical state and operating temperature of the charge-bearing medium, and what that state choice implies for how charge is retained.

A liquid-metal battery achieves its durability by making the interior liquid. That is a deliberate and coherent design choice, but it carries a structural consequence: the electrodes are only liquid, and only self-segregated, above a sustained elevated operating temperature. The system is defined by maintaining that thermal state and by relying on a physical electrolyte layer between two electrodes of different potential. Charge retention, in that family, is a matter of keeping the two liquid electrodes at their distinct potentials with the electrolyte layer between them.

The disclosed hydrogen-aluminum energy cell sits on the opposite end of that axis. It is a solid-state architecture that operates at ambient temperature, with no molten phase, no density-segregated strata, and, most consequentially, no internal separator or membrane of any kind. Framed as a difference rather than a defect: the two designs make opposite bets about where durability and retention come from. One bets on an all-liquid, thermally-maintained interior; the other bets on a solid, room-temperature medium that retains charge by a different physical principle entirely.

How the Disclosed Approach Differs

Per the filed specification, the hydrogen-aluminum energy cell stores energy not in a separated electrode pair but as electron-stabilized metal-hydrogen surface bonds on a population of metal nanoflakes, in preferred embodiments aluminum, dispersed throughout a single continuous medium. That medium is a dual-domain proton-conducting carbon gel that is simultaneously electronically and ionically conductive and fills the interior between two carbon current collectors.

The load-bearing architectural idea is what the specification terms bulk-equipotential charge retention. Because the gel conducts electrons throughout its volume, there is no internal potential gradient to drive self-discharge and no separator holding two electrodes apart. In the charged state at open circuit, substantially every nanoflake sits at the same electrochemical potential, so there is no internal terminus for electron flow. The specification describes charge retention "by saturation rather than by insulation": the cell holds its charge because there is no driving force for internal current, not because a barrier blocks it. A potential gradient, and therefore discharge, arises only when an external circuit is closed across the two terminals.

Several further mechanisms distinguish the disclosed approach on this axis, all traceable to the specification. Charging proceeds by proton-coupled electron transfer in which the incoming proton is in an applied-bias-driven "hot" transit state; without applied bias, thermalized ground-state protons lack the energy to reach a flake surface, which the specification recites as the kinetic basis for idle-state stability. The specification also describes reversible dynamic expansion of nanoflake surface area under bias via carbon intercalation at coordination-asymmetry boundaries, and a mechanochemical self-healing pathway in which mobile carbon migrates to strained sites during cycling. To be precise, these mechanisms are disclosed as architecture, and the associated performance behaviors are recited in the specification as projected, based on published data for the underlying materials, and explicitly "to be determined empirically."

The structural contrast, then, is concrete. Where the liquid-metal design maintains an elevated-temperature, three-layer liquid interior with an electrolyte between two electrodes, the disclosed cell provides a single solid gel medium at ambient temperature with no separator and retention by equipotential saturation.

Where They Fit Together

These two are best understood as competing answers within the same category, stationary electrochemical storage, rather than as components that naturally compose. Both aim at grids and long-duration applications; both would connect to a system through comparable external power electronics. At the level of a storage installation, either could occupy the same rack position and serve the same duty cycle, which is precisely why the comparison is a comparison rather than an integration.

Where they differ, and where a system designer would choose between them, is in the operating envelope rather than the interface. A thermally-maintained liquid battery brings a proven, shipping, all-liquid interior optimized for stationary duty. The disclosed cell offers an ambient-temperature, sealed, separator-free architecture. A portfolio operator might reasonably view them as alternatives to be evaluated on installed cost, thermal management burden, and maturity. One is a product available to buy today and the other is an architecture disclosed in a provisional filing; those are not interchangeable procurement options, and this article does not pretend otherwise.

Boundary Conditions

The honest limits of the disclosed approach fall into two groups.

First, the underlying materials science is pre-existing and is presented as such in the specification. Hydrogen chemisorption on metal surfaces, proton-conducting sulfonated carbon gels, turbostratic graphene, electrochemical exfoliation of metal nanoparticles, and mechanochemical effects at strained interfaces are all drawn from published research literature. The disclosed novelty is not a newly discovered chemistry or basic physical effect. It is the combination and architecture: the integration within one sealed, separator-free, ambient-temperature cell of bulk-equipotential retention, surface-bonded hydrogen storage, electrostatic flake isolation, asymmetric charge and discharge paths, dynamic flake expansion, and mechanochemical healing.

Second, this is a provisional disclosure of an architecture, not a built or benchmarked product. The specification is explicit that its energy-density, efficiency, and cycle-life figures are projected and prophetic, based on the disclosed mechanisms and on published data for the underlying materials, and "have not been empirically verified" and are "to be determined empirically." No claim is made here that the cell has been fabricated, validated, or measured. This is the central and unavoidable asymmetry of the comparison: Ambri ships mass-produced hardware with an operational record; the hydrogen-aluminum energy cell is at the disclosure stage. A fair reader should weigh the two accordingly and should not treat projected numbers as demonstrated ones.

Disclosure Scope

The invention described here is disclosed in U.S. Provisional Application No. 64/055,649, and the technical statements about the invention are grounded in that filing. All references to Ambri, its liquid-metal calcium-antimony battery, and the stationary storage market are provided as external context to orient the reader; they are not representations made in, or claims of, the provisional application, and nothing in this article should be read as characterizing the scope of that filing by reference to any third party. This article does not assert that Ambri's product is defective, deficient, or unsuitable for its intended use; the liquid-metal battery is a capable, shipping technology, and the contrast drawn here is one of architecture and operating principle, not of quality. Statements about the invention's behavior are, per the filing, disclosed as an architecture with projected performance to be determined empirically, and should not be read as claims of a built or benchmarked device.

Hydrogen-Aluminum Energy Cell (/h-al-battery)

All 40 steps → (/inventive-steps)

Sealed electrochemical cell storing energy as reversible covalent hydrogen bonds on carbon electrodes.

Provisional application

PRIMARY TECHNICAL DISCLOSURE

- A Hydrogen-Aluminum Surface-Bond Storage Cell with Bulk-Equipotential Charge Retention (/articles/a-hydrogen-aluminum-surface-bond-storage-cell-with-bulk-equipotential-charge-retention)

SECONDARY TECHNICAL

- Charge Retention by Bulk-Equipotential Saturation Without an Internal Separator (/articles/h-al-battery/bulk-equipotential-charge-retention)
- Storing Energy as Electron-Stabilized Metal-Hydrogen Surface Bonds Formed by Proton-Coupled Electron Transfer (/articles/h-al-battery/hydrogen-metal-surface-bond-storage)
- Electron-Mediated Bond Stability: The Kinetically Trapped Idle State Behind Indefinite Calendar Life (/articles/h-al-battery/electron-mediated-bond-stability)
- Hot-Proton Charging Versus Cold-Proton Discharge: The Bias-Gated Asymmetry That Blocks Self-Charge and Self-Discharge (/articles/h-al-battery/hot-cold-proton-asymmetry)
- Asymmetric Dual-Domain Proton Paths: Separate Ingress and Egress Routes in a Hydrogen-Aluminum Storage Gel (/articles/h-al-battery/asymmetric-dual-domain-paths)
- Hydrophobic Gating: Rejecting Neutral and Molecular Hydrogen While Admitting Only Biased Protons (/articles/h-al-battery/hydrophobic-gating)

- The Storage Gel as a Polarized Electrochemical Switch: Coherent Alignment, Equipotential Locking, and Load-Proportional Discharge (/articles/h-al-battery/gel-polarized-switch)
- Flake-Flake Electrostatic Isolation: DLVO Repulsion as a Self-Discharge Barrier in a Separator-Free Hydrogen-Aluminum Cell (/articles/h-al-battery/flake-electrostatic-isolation)
- Dynamic Flake Expansion: Carbon-Intercalation Wedging to Expose Buried Metal Surface Under Bias (/articles/h-al-battery/dynamic-flake-expansion)
- Hydrogen-Locked Expanded State: Surface-Energy Inversion as a Positive-Feedback Capacity Mechanism (/articles/h-al-battery/hydrogen-locked-expanded-state)
- Secondary Carbon-Hydrogen Storage on Transmuted Intercalated Carbon (/articles/h-al-battery/secondary-carbon-hydrogen-storage)
- Mechanochemical Strain Self-Healing and Use-Positive Aging in a Bulk-Equipotential Hydrogen-Aluminum Cell (/articles/h-al-battery/mechanochemical-self-healing)
- Boron Doping of the Carbon Framework as a Multi-Function Precision Multiplier (/articles/h-al-battery/boron-doping-precision-multiplier)
- The Floating Aluminum Equipotential Extension Layer: A Multifunctional Inner Case for the Bulk-Equipotential Cell (/articles/h-al-battery/aluminum-equipotential-extension-layer)

APPLICATIONS · GENERAL

- Grid-Scale and Renewable-Firming Storage with the Hydrogen-Aluminum Energy Cell (/articles/h-al-battery/grid-scale-storage)
- Building-Integrated and Behind-the-Meter Storage: Putting Energy Cells Inside the Structure With the Hydrogen-Aluminum Energy Cell (/articles/h-al-battery/building-integrated-storage)
- Stationary Backup and UPS Reserve Power for Data Centers, Hospitals, and Telecom (/articles/h-al-battery/backup-and-ups)
- Storage for Microgrids, Islands, and Off-Grid Sites: A Stationary Cell Built From Abundant Materials (/articles/h-al-battery/microgrid-and-off-grid)
- Electric Mobility and Transport: How a Hydrogen-Aluminum Cell Architecture Maps to Vehicle Constraints, and Where It Does Not (/articles/h-al-battery/ev-and-mobility)
- Marine and Rail Energy Storage: A Bulk-Equipotential Hydrogen-Aluminum Cell for Mass-Tolerant Heavy Transport (/articles/h-al-battery/marine-and-rail)
- Supply-Chain-Resilient Field Power: An Abundant-Material Energy Cell for Defense and Expeditionary Operations (/articles/h-al-battery/defense-and-field-power)

APPLICATIONS · SPECIFIC

- CATL (Contemporary Amperex Technology Co. Limited) alternative: a hydrogen-aluminum cell architecture vs LFP, NMC, and sodium-ion at the chemistry-category and materials-sourcing level (/articles/h-al-battery/catl)

- LG Energy Solution NCM/NCMA lithium-ion cells vs the Hydrogen-Aluminum Energy Cell: an architectural comparison (/articles/h-al-battery/lg-energy-solution)
- Form Energy iron-air multi-day grid storage vs a sealed bulk-equipotential hydrogen-aluminum cell: an architectural comparison (/articles/h-al-battery/form-energy)
- ESS Inc, maker of long-duration iron flow batteries vs a sealed solid-state cell: comparing the flow architecture to the Hydrogen-Aluminum Energy Cell (/articles/h-al-battery/ess-inc)
- **Ambri liquid-metal battery vs a solid-state hydrogen-aluminum energy cell: architectural comparison for stationary storage (/articles/h-al-battery/ambri)**
- QuantumScape solid-state lithium-metal battery vs a bulk-equipotential hydrogen-aluminum surface-bond cell: an architecture comparison (/articles/h-al-battery/quantumscape)
- Natron Energy sodium-ion (Prussian-blue-electrode) batteries vs a hydrogen-aluminum surface-bond cell: an abundant-materials architecture comparison (/articles/h-al-battery/natron-energy)
- Eos Energy Enterprises Znyth zinc long-duration storage vs a hydrogen-aluminum equipotential cell: an abundant-materials architecture comparison (/articles/h-al-battery/eos-energy)

Hydrogen-Aluminum Energy Cell overview → (/h-al-battery)