Nick Clark · Published April 25, 2026 · PDF

How a Separator-Free Metal-Hydrogen Energy Cell Architecture Is Designed

If you are an energy-storage architect asking how a rechargeable cell could hold charge without an internal separator, this guide walks through the architecture that answers it: a sealed, bulk-equipotential cell that stores energy as electron-stabilized metal-hydrogen surface bonds. It describes an architecture disclosed in U.S. Provisional Application No. 64/055,649, not a shipping library or a benchmarked product. The home inventive step is the Hydrogen-Aluminum Energy Cell inventive step.

What You Are Building

You are designing the architecture of a rechargeable electrochemical cell that does not use an internal separator to hold its charge. In a conventional cell, an anode sits at one potential, a cathode at another, and a thin ion-conducting, electron-insulating separator between them is the only thing stopping the two electrodes from shorting. That separator is load-bearing for charge retention, and it carries mass, volume, cost, and a failure mode.

The architecture described here removes the separator entirely. The whole interior is one continuous, electronically and ionically conductive medium, and charge is held not by insulation but by saturation. Energy is stored as atomic hydrogen bonded directly to the surfaces of dispersed metal nanoflakes. This guide teaches how the pieces fit together so a skilled engineer can approach building it. It is an architecture disclosed in a patent filing, not a product that has been built or benchmarked. Every performance figure below is quoted from the disclosure as projected or as-disclosed, never as measured.

Why the Obvious Approaches Fall Short

The standard rechargeable chemistries (lithium-ion and sodium-ion intercalation, lead-acid, nickel-metal-hydride, lithium-sulfur, redox-flow, and the metal-air family) each pair two electrodes of different potential across an ion-conducting, electron-insulating barrier. Charge is retained because that barrier blocks direct electron flow. This is a real and well-proven approach. Its structural cost is that any breach of the barrier is a self-discharge or safety event, and the separated-electrode geometry concentrates strain, heat, and aging at interfaces.

Metal-hydride hydrogen storage is also mature, but in its conventional form it operates at thermodynamic equilibrium with hydrogen gas pressure as the controlled variable, storing hydrogen in interstitial lattice sites throughout the metal bulk. That bulk-lattice storage brings diffusion-limited kinetics and lattice-strain fatigue. Proton-conducting carbon gels, electrochemical exfoliation of metal nanoparticles, and mechanochemical repair are each established in the literature too. The materials science underneath is all prior art.

The gap the disclosed architecture targets is not new physics. It is that no prior design combined bulk-equipotential retention without a separator, surface-bonded (not bulk-lattice) metal-hydrogen storage, and a single conductive gel medium into one sealed cell. The novelty is the combination.

The Architecture

Start with the cell body. A sealed hermetic enclosure holds two carbon current collectors at opposite interior faces, a bulk volume of dual-domain proton-conducting carbon gel filling the space between them, and a population of metal nanoflakes dispersed through that gel. Two external terminals connect to the two collectors. There is no internal separator, membrane, or barrier other than the gel itself.

Bulk-equipotential retention. Because the gel is both electronically and ionically conductive, the charged cell settles into an equipotential state: every nanoflake sits at the same electrochemical potential, so no internal gradient exists to drive self-discharge. The disclosure frames this as retention by saturation rather than by insulation. There is no defined anode and cathode at rest; the two terminals are electrically equivalent until an external circuit closes. Closing that circuit is what creates an asymmetric electron path and a potential gradient, and the cell then discharges only as fast as the external load allows.

Surface-bond storage chemistry. Energy is stored as electron-stabilized metal-hydrogen surface bonds on the nanoflakes. During charging, a proton from the gel and an electron from the charging circuit combine at a flake surface (proton-coupled electron transfer) to form atomic hydrogen bonded to a surface metal atom. The disclosure distinguishes this from bulk metal-hydride formation, from physisorption, and from intercalation: the hydrogen sits on the surface, held by the bonding electron pair. Remove that electron through a load and the bond destabilizes and releases the hydrogen as a proton. At idle, the electrons stay put and the bond is stable, which is the disclosure's stated basis for its calendar-life claim. Aluminum is the preferred flake metal for cost, low mass, and binding-energy compatibility.

The dual-domain gel. The gel is not homogeneous. It carries a hydrophilic proton-conducting domain (carbon functionalized with sulfonate and similar protogenic groups, carrying protons by the Grotthuss mechanism) and a hydrophobic hydrogen-rejecting domain (fluorinated or alkylated regions that reject neutral and molecular hydrogen). The flakes live inside the hydrophobic domain while the hydrophilic channels form a continuous percolating network to the collectors.

Asymmetric ingress and egress. This dual-domain structure gives charging and discharging different paths. On charge, "hot" protons under applied bias cross the hydrophobic gate to reach a flake. On discharge, the released proton enters the hydrophilic channel directly and never crosses the gate. The gate is selective on charge state and bias, not on size: biased hot protons pass, thermalized protons and neutral species do not. That selectivity is what suppresses thermalized self-charging and blocks molecular hydrogen from forming or escaping.

Electrostatic flake isolation. The flakes carry like surface charge and repel each other (classical DLVO behavior), which keeps them spaced apart. That spacing prevents two hydrogen atoms on different flakes from recombining into escaping H2 gas, and the repulsion strengthens in the charged state, so the cell is more stable precisely when it holds the most energy.

Optional amplifiers. The disclosure layers several optional mechanisms on this base: dynamic flake expansion, in which carbon from the gel wedges into fractal-branched flakes under bias to expose more surface area (locked open by bonded hydrogen); mechanochemical self-healing, in which mobile carbon migrates to strained sites during cycling; and boron doping of the gel framework as a "precision multiplier." Each is disclosed with projected ranges only. Treat them as design options, not guarantees.

How to Approach the Build

Work outward from the gel, because the disclosure states the principal manufacturing complexity lives there and the rest is conventional battery engineering.

1. **Produce the dual-domain carbon gel.** The disclosed enabling route reduces boron-dosed biomass to turbostratic graphene under an applied static electric field, then functionalizes it with sulfonating and fluorinating agents to create the two domains. Alternative routes that reach the same compositional and electrostatic outcome are within scope.
2. **Synthesize and disperse the metal nanoflakes.** Aim for thin, high-edge-fraction flakes (the disclosure describes fractal dendritic morphology as an option for more surface area). Dispersing them into the charged gel lets them acquire surface charge and self-distribute into the hydrophobic domain without active sorting.
3. **Assemble the cell body.** Fit carbon current collectors, hermetic terminal feedthroughs, and the enclosure. The disclosure recommends an aluminum inner layer that floats at the gel's potential to extend the equipotential volume and act as an oxygen barrier and Faraday cage, but also notes a lower-cost variant without it.
4. **Cast, seal, then inject hydrogen last.** Cast the gel under inert atmosphere, seal the enclosure except for one port, then inject molecular hydrogen and seal that port. The disclosure is explicit that hydrogen must be injected into an already-sealed cell, because the gel's static-charge environment repels hydrogen and an open gel would lose it.

An illustrative interface sketch, faithful to the disclosed roles and not a working API:

```
// ILLUSTRATIVE ONLY (not a shipping library)
Cell = {
  enclosure,                  // hermetic; optional Al equipotential layer
  collectors: [c1, c2],       // carbon, Ohmic contact with gel
  gel: { hydrophilic, hydrophobic },  // one continuous conductive medium
  flakes,                     // metal, surface-charged, in hydrophobic doma
}
charge(bias): hotProton --crosses--> hydrophobicGate --bonds--> flake
discharge(load): drainElectron --> bondBreaks --> proton --> hydrophilicChan
```

You are implementing all of this yourself. There is no package to install.

What This Does Not Give You

This is an architecture, not a drop-in library, a reference cell, or a proven product. Nothing here has been built, validated, or benchmarked; the disclosure itself frames performance as projected or as-disclosed and repeatedly says actual values are to be determined empirically through prototype testing. The energy-density, cycle-life, and efficiency ranges quoted in the source are design projections tied to specific configurations, not measurements, and you should not present them to anyone as achieved numbers.

The materials science underneath (surface chemisorption of hydrogen, proton-conducting carbon gels, DLVO repulsion, mechanochemical repair, boron doping) is pre-existing prior art. The disclosed contribution is the architecture that combines them, not a new discovery about those effects. The disclosure also documents its own failure and degradation modes, including auxiliary-carbon exhaustion and long-timescale aluminum-cation migration into boron sites, and it notes that a deployed cell is not field-serviceable by gel replacement. Realizing any of this is engineering you would perform, with real synthesis, sealing, and safety work, especially around sealed hydrogen.

Disclosure Scope

The architecture described in this guide is disclosed in U.S. Provisional Application No. 64/055,649. This guide is educational: it teaches the design approach so a skilled engineer can understand and attempt it. It is not a warranty, a specification, an offer of software, or a claim that a working, benchmarked, or production-ready cell exists. Every mechanism described traces to that filing, and every quantitative range originates there as a projected or as-disclosed value.

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)
- Fast-Response Frequency Regulation and Power Quality Without a Separate Power Bank (/articles/h-al-battery/frequency-regulation-power-quality)

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)
- EnerVenue nickel-hydrogen stationary cells vs a hydrogen-aluminum equipotential cell: two ways to store hydrogen in a battery (/articles/h-al-battery/enervenue)
- Skeleton Technologies supercapacitors vs the Hydrogen-Aluminum Energy Cell: pairing high power with bulk energy storage (/articles/h-al-battery/skeleton-technologies)

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