

# **Hydrophobic Gating: Rejecting Neutral and Molecular Hydrogen While Admitting Only Biased Protons**

Hydrophobic gating is a secondary inventive step of the Hydrogen-Aluminum Energy Cell disclosed in U.S. Provisional Application No. 64/055,649, documenting how a hydrogen-rejecting gel domain blocks neutral and molecular hydrogen while admitting only biased protons, together with the hot-proton charging versus cold-proton discharge asymmetry and the asymmetric dual-domain ingress and egress paths that make it work. A hydrogen storage cell that bonds hydrogen to metal flake surfaces faces a constant leak risk: bonded hydrogen can wander off as neutral atomic hydrogen, surface hydrogen pairs can recombine into molecular hydrogen and escape as gas, and thermalized protons sitting in the cell at rest can drift onto flake surfaces and self-charge without any applied bias. The disclosed cell addresses these decay pathways with a hydrophobic gating region built into the gel itself. The hydrophobic, hydrogen-rejecting domain rejects neutral atomic hydrogen and molecular hydrogen at engineering-realistic permeation rates, while admitting charged protons only when an applied bias gives them enough energy to cross. This charge-and-bias selectivity is a kinetic lock: it

holds the stored metal-hydrogen bonds in place, blocks hydrogen gas formation and escape, and prevents thermalized self-charging at idle.

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## **The Leak Problem in Surface-Bond Hydrogen Storage**

A cell that stores energy as hydrogen bonded to metal flake surfaces must keep that hydrogen where it was placed. The disclosure identifies three ways the stored state would otherwise decay. First, bonded surface hydrogen could migrate away from the flake surface as neutral atomic hydrogen. Second, two hydrogen atoms could recombine into molecular hydrogen, which then escapes the cell as gas. Third, in the absence of any applied bias, thermalized protons resting in the gel could reach a flake surface and bond there, self-charging the cell uncontrolled. Each of these pathways drains the stored state or vents hydrogen. The hydrophobic gating region is the structural feature the disclosure recites to close them.

## **A Hydrogen-Rejecting Domain Inside the Gel**

The cell's bulk volume is a continuous carbon gel with two principal compositional domains arranged as a phase-separated nanostructure. One domain is hydrophilic and proton-conducting, functionalized with proton-donating groups including sulfonate, phosphonate, and carboxylate. The other is a hydrophobic, hydrogen-rejecting domain built from carbon framework regions functionalized with non-protogenic groups, including fluorinated regions, perfluoroalkyl chains, and alkylated regions. Per the disclosure, this hydrophobic domain rejects neutral hydrogen and molecular hydrogen at engineering-realistic permeation rates. The metal nanoflakes reside substantially within the hydrophobic domain, so each flake is substantially surrounded by hydrophobic gel, while the hydrophilic channels form a continuous percolating network connecting the collectors.

## **Selectivity by Charge and Bias State**

The gating is selective, and the disclosure states the operating principle directly: the asymmetry between charged and neutral hydrogen species is what makes the gate function. Charged species, protons, have sufficient potential energy to traverse the gate only when an applied bias supplies that energy. Charged species under thermalized conditions do not cross, and neutral species do not cross under any conditions. The disclosure frames a proton crossing the gate as a hot proton: a proton in a non-thermalized, high-energy transit state induced by an applied electrochemical bias. A cold proton is a thermalized proton that lacks the capacity to traverse the hydrophobic gating region. The hot proton has enough energy both to overcome the flake's repulsive surface potential and to cross the hydrophobic gate; the thermalized proton has neither.

## **The Three Decay Pathways the Gate Blocks**

The disclosure ties each rejection directly to a decay pathway it prevents. Migration of bonded surface hydrogen as neutral atomic hydrogen away from the flake is prevented because the surrounding hydrophobic region rejects neutral hydrogen. Recombination of surface hydrogen pairs into molecular hydrogen, followed by gas-phase escape, is prevented because the hydrophobic region rejects molecular hydrogen as well as atomic hydrogen. Thermalized-proton self-charging in the absence of applied bias is prevented because thermalized protons in the hydrophilic channels lack the energy to cross the hydrophobic gate to reach the flake. Together these constitute one of the cell's multiple kinetic locks holding the storage state against decay.

## **Why Charging Still Works: The Hot Proton Crosses**

The gate is not a wall; it is a one-condition pass. During charging, the applied bias creates a potential gradient concentrated at the hydrophilic channel network. Protons in those channels are accelerated and acquire excess kinetic and electronic energy, becoming hot protons. A hot proton traverses the hydrophobic gating region from the

channel network to the flake surface. The disclosure describes this traversal as energetically uphill in the absence of bias but downhill under sufficient applied bias, because of the additional energy the hot proton carries. Without applied bias, thermalized protons cannot traverse the gate; with applied bias above a threshold value, hot protons traverse it at engineering-relevant rates. At the flake surface the hot proton combines with an electron from the charging circuit in a proton-coupled electron transfer event, forming a stable metal-hydrogen bond. When charging terminates and the bias is removed, the thermalized protons in the channels lose their hot-proton character and no further bond formation occurs.

### **Asymmetric Paths: Discharge Does Not Cross the Gate**

The disclosure separates the charging and discharging paths. Charging hot protons cross the hydrophobic gate to reach the flake. Discharging released protons do not cross the gate at all. When an external load removes the bonding electron, the destabilized bond releases hydrogen as a hot proton at the moment of cleavage, and that proton enters the hydrophilic channel network directly at the flake-channel interface. It then thermalizes through Grotthuss-mechanism hopping and migrates to the opposite terminal. The two paths are spatially distinct and traverse distinct compositional regions of the gel: a hydrophobic gating path for charging ingress, and a hydrophilic channel path for discharging egress. The disclosure distinguishes this from conventional membrane asymmetry on several grounds, including that the asymmetry is created by structural domains within a single continuous gel rather than a discrete membrane, that it is selective on species charge and bias state rather than on size or geometry, and that it provides per-flake gating co-located with the flake population rather than cell-wide separator gating.

## **Cooperation With Flake Isolation to Suppress Hydrogen Gas**

The gate does not act alone in suppressing molecular hydrogen. The disclosure describes two complementary mechanisms. Cross-flake recombination is prevented by the electrostatic separation between flakes: two hydrogen atoms on two different flakes cannot recombine because the flakes are held apart by the gel medium plus the electrostatic separation distance, consistent with the like-charged DLVO repulsion of the disclosure, and atomic hydrogen at the cell's binding energies does not migrate between flakes. Same-flake recombination is suppressed by the surrounding hydrophobic gel region, which rejects molecular hydrogen, in cooperation with the spatial distribution of binding sites across the flake surface. The disclosure states that these operate together to comprehensively suppress molecular hydrogen formation throughout the cell. Per the path-selection summary, molecular hydrogen at any state is rejected by the hydrophobic region and cannot form within the cell.

## **The Kinetic Basis for Idle Stability**

The net effect at rest is a storage state that does not spontaneously decay. The disclosure recites that without applied bias, thermalized ground-state protons in the gel lack the energy to reach a flake surface, so no hydrogen bonding occurs, which it identifies as the kinetic basis for the storage state's stability against thermalized self-charging or self-discharging. Bonded hydrogen at idle remains bonded, because the electron-mediated bond is stable and the surrounding hydrophobic region prevents alternative escape pathways. The gate thereby converts what would be a leaky surface-bond store into a kinetically locked one, in concert with the cell's other recited mechanisms.

## Disclosure Scope

This article describes subject matter disclosed in U.S. Provisional Application No. 64/055,649. It addresses the hydrophobic gating mechanism for rejecting neutral and molecular hydrogen while admitting biased protons. Every mechanism, term, and behavior stated here is drawn from that disclosure. The application is an early-stage provisional that discloses concepts and mechanisms, and this article states no numeric value, material property, or performance figure beyond what the application itself recites.

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## Hydrogen-Aluminum Energy Cell ([/h-al-battery](#)) [All 40 steps → \(/inventive-steps\)](#)

### al-battery)

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>).

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[Hydrogen-Aluminum Energy Cell overview](/h-al-battery) → (</h-al-battery>).