Grounded Discovery Labs -- Discovery Pack

Discover: Design a grid-scale energy storage system delivering 10-100 hours of discharge at lower installed cost than lithium-ion, using abundant materials and minimal fire risk.

Top 3 Comparison

	Featured Discovery Modular Gravity Storage in Decommissioned Mine Shafts	**Bold Concept** Atmospheric Humidity-Gradient Hygroscopic Salt Battery	**Build-First** Mine-shaft modular gravity storage
novelty	4	9	4
feasibility	8	3	8
economic_leverage	5	5	5
testability	8	5	9
robustness	7	3	8
constraint_fit	8	6	8
explainability	10	5	9
OVERALL	**7.1 / 10 -- Very Strong**	**5.1 / 10 -- Moderate**	**7.3 / 10 -- Very Strong**

Runner-ups

* Mine-shaft gravity storage with regenerative hoists [solid-alternative] -- Lift dense blocks in idle shafts during renewable surplus and lower them through generators for 10-100 h discharge.
* Macromolecular lignin-quinone iron flow battery [solid-alternative] -- Use polymer-bound lignin quinones and iron sulfate in neutral water so a cheap porous separator replaces costly ion membranes.
* Containerized iron-air rust battery [near-miss-alternative] -- Store multi-day energy by reversibly rusting cheap iron electrodes in alkaline aqueous electrolyte with air cathodes.
* Crushed-Basalt Packed-Bed Thermal Battery with ORC Discharge [near-miss-alternative] -- Resistively heat crushed basalt to 600degC in insulated silo; discharge via air loop driving organic Rankine cycle.
* Redox-targeted lignin-biochar packed-bed flow [solid-alternative] -- Store energy in immobilized quinone biochar beds while small iron mediator loops handle power conversion.

Featured Discovery

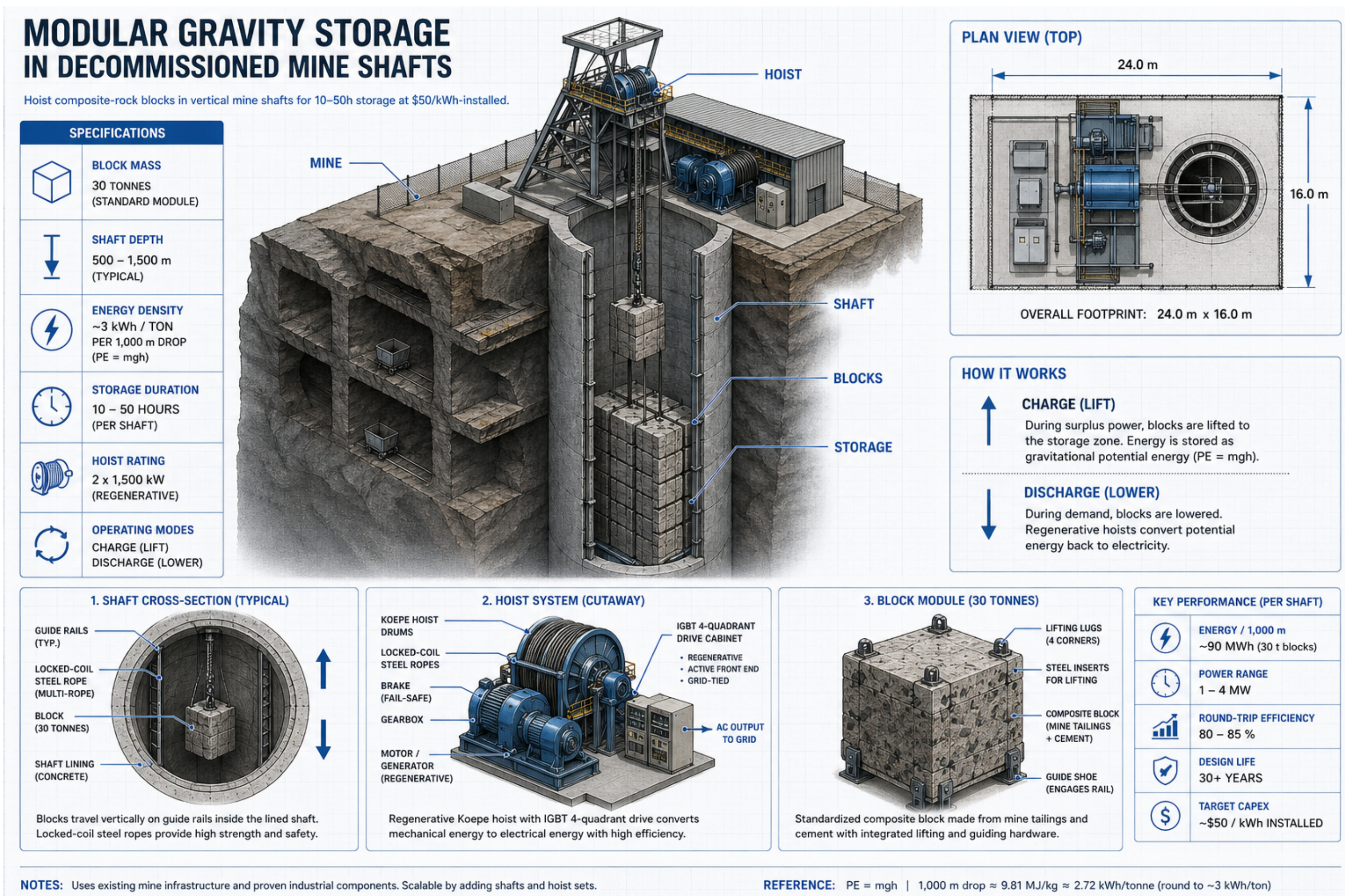
Modular Gravity Storage in Decommissioned Mine Shafts

novelty: 4 | feasibility: 8 | economic_leverage: 5 | testability: 8 | robustness: 7 | constraint_fit: 8 | explainability: 10

Overall: 7.1 / 10 -- Very Strong

Constraint Compliance: Compliant (constraint_fit=8)

Decommissioned hard-rock mine shafts represent an underutilized vertical infrastructure asset that can be converted into long-duration gravity storage at a fraction of greenfield civil costs. By hoisting 30-ton composite blocks cast from cemented mine tailings through existing shaft guideways, each installation delivers 10-50 hours of dispatchable storage at a target installed cost of ~$50/kWh. This matters because it pairs stranded industrial heritage with the grid's urgent need for multi-hour storage without new excavation.



Concept illustration (AI-generated). Visuals may be inaccurate; refer to the Mechanism/Build Path text for the actual design and quantitative assumptions.

Mechanism

Modular gravity storage repurposes decommissioned hard-rock mine shafts (>=300 m depth, >=4 m diameter) as vertical guideways for 30-ton composite blocks cast from cemented mine tailings (~2.4 t/m^3, ~3.5 m^3 per block, 1.5 m x 1.5 m x 1.6 m). Each block is hoisted by a regenerative drum or Koepe friction winch driven by a 1-3 MW permanent-magnet synchronous motor/generator with a 4-quadrant IGBT drive feeding the grid via a step-up transformer. Steel-core synthetic-rope or locked-coil steel cable (40-60 mm) carries the load against shaft guides retrofitted to the existing timber/steel sets. Energy per block: E = m·g·h·? ~ 30,000 kg x 9.81 x 800 m x 0.82 ~ 54 kWh-e usable. A 1000 m shaft with 800 m usable travel and a stack of 12 blocks delivers ~650 kWh per lane;

multiple parallel lanes (typically 2-4 in a single shaft via compartmentalized guides, or sister shafts at the same site) raise power. Power is throttled by hoist duty cycle (lift speed 4-8 m/s, ~3 min lift, ~3 min descent) yielding ~0.3-1 MW per lane continuous. Sites are sized from a per-shaft audit: depth, diameter, lining condition, water ingress (pumping load), headframe/collar reuse, ground stability (RMR/Q), and grid POI distance. RTE target 78-82% (motor 96%, drive 98%, mechanical 92%, rope/sheave 95%). Discharge durations of 10/50/100 h are reached by adding blocks and parking levels rather than power hardware, decoupling energy from power capex--the structural advantage versus li-ion at long duration. Block storage uses existing skip pockets, ore-pass landings, and surface laydown. Tailings-cement composition (70% mine tailings, 25% OPC/slag, 5% admix) consumes legacy waste and avoids virgin aggregate.

Why Novel

Unlike surface gravity storage concepts (e.g., ARES rail or Energy Vault towers), this approach exploits existing vertical depth--up to 1,500 m--that no surface system can replicate, achieving energy density per lane that compresses footprint by an order of magnitude. The use of cemented mine tailings as block feedstock simultaneously solves a mine-site waste liability while slashing block material cost to near zero.

Buildability

Core components--regenerative Koepe hoists, IGBT 4-quadrant drives, and locked-coil steel rope--are mature mining and industrial technologies available from multiple global suppliers, requiring no novel manufacturing. The primary engineering challenge is shaft condition assessment and guide-rail retrofit, which is addressable with standard mine rehabilitation contractors and geotechnical instrumentation.

Why Feasible

* Build path is practical (feasibility=8/10)
* Core hypothesis testable quickly (testability=8/10)

Top Risks

* Progressive ground relaxation and shaft wall spalling post-decommissioning may require costly re-lining that erodes the civil-cost advantage over greenfield sites
* Hoist cycle time bottleneck (one block per 8-15 minutes per lane) caps deliverable power to 200-400 kW per lane, forcing multi-lane parallelism that multiplies electrical and mechanical infrastructure cost
* Suitable shafts (>=300 m depth, >=4 m diameter, grid-proximate, clear title) are geographically sparse and concentrated in legacy mining regions far from major load centers

Decisive Test (MDE)

Hypothesis: A retrofitted single-lane hoist in an existing 800 m usable-travel shaft can deliver >=75% AC-AC round-trip efficiency and >=1000 full cycles without rope/guide degradation exceeding 10% of design margin, at an installed all-in cost <=$120/kWh for a 10 h plant.
Setup: Lease access to one already-dewatered shaft (e.g., a former Cu/Au mine in NV, ON, or Cornwall). Refurbish existing headframe and install one Koepe winch + 1 MW regen drive. Cast 20 tailings-cement blocks (5-ton scaled or 30-ton full). Run 1000 charge/discharge cycles at varied depth-of-discharge; meter AC input/output at the transformer; inspect rope (MRT NDT) and guides every 200 cycles.
Instrumentation: Revenue-grade 4-quadrant power meters at MV bus; load cells on rope termination; laser distance + encoder for block position/velocity; accelerometers on skip and headsheave; magnetic rope tester (Rotesco/NDT) every 200 cycles; thermal cameras on motor/gearbox; piezometers and inclinometers in shaft wall; vibration spectrum analyzer; SCADA logging at 100 Hz.
Kill Criteria: AC-AC RTE <70%; rope replacement interval <2 years (pushing O&M >$15/MWh); shaft convergence/spalling requiring >$10M rehab per site; installed cost extrapolation >$200/kWh at 10 h; <30 viable

shafts globally within 25 km of grid after audit.
Rescue Pivot: If shaft inventory is too thin or rehab too costly, pivot to purpose-built shallow concrete shafts (100-200 m) co-sited with new tailings-cement supply at active mines, or to slope/incline rail variants using existing decline ramps where geometry is friendlier and inspection is cheaper.
Cost: $3.5M-6M for an 18-24 month single-lane pilot including site lease, winch refurb, blocks, instrumentation, grid interconnect study, and labor.
Time to Signal: RTE and cycle time confirmable within 2-4 weeks of commissioning; rope/guide wear and ground-stability signal requires 9-12 months of cycling.

Refinement Deltas

Risks Addressed:

* Site scarcity: the intersection of deep-enough, wide-enough, dry-enough, stable-enough, and grid-adjacent shafts may be a vanishingly small set--measured in tens, not thousands--capping TAM well below grid-scale relevance.
* Liability and permitting on legacy mines (orphaned tailings, water rights, subsidence claims, indigenous consultation, MSHA reclassification) can dominate schedule and cost in ways no engineering optimization fixes.
* Hoist duty cycles in mining are 5-10 lifts/hour, not the near-continuous cycling grid storage demands; rope fatigue curves (Feyrer) predict 3-5x shorter life under storage duty, and no winch OEM warrants this regime.

Red-Team:

* Challenge: Site scarcity: the intersection of deep-enough, wide-enough, dry-enough, stable-enough, and grid-adjacent shafts may be a vanishingly small set--measured in tens, not thousands--capping TAM well below grid-scale relevance.
* Challenge: Liability and permitting on legacy mines (orphaned tailings, water rights, subsidence claims, indigenous consultation, MSHA reclassification) can dominate schedule and cost in ways no engineering optimization fixes.
* Challenge: Hoist duty cycles in mining are 5-10 lifts/hour, not the near-continuous cycling grid storage demands; rope fatigue curves (Feyrer) predict 3-5x shorter life under storage duty, and no winch OEM warrants this regime.
* Challenge: At $50/kWh anchor, li-ion at $150/kWh with 90% RTE and 15-min deployment still beats this on LCOS for <12 h durations--the only defensible niche is 50-100 h, where competitors are iron-air, CAES, and thermal, all with better siting flexibility.
* Challenge: Tailings-cement blocks may fail leaching/structural durability tests over 25-year cycling in humid shaft environments; ARD (acid rock drainage) interaction with cement matrix is poorly characterized at this scale.

Budget Ranges

Prototype: $800,000-$1,500,000 (single-lane proof-of-concept in a shallow accessible shaft: shaft inspection, one hoist unit, 3-5 blocks, instrumentation, grid-tie inverter)
Pilot: $8,000,000-$15,000,000 (full-depth 3-lane pilot at a screened mine site: shaft rehab, three 1-3 MW hoist systems, 36 blocks, SCADA, substation interconnect, ~650 kWh usable per lane)
Scale: $40,000,000-$80,000,000 (commercial 10 MW / 100-500 MWh installation: 8-12 lanes, full shaft re-lining, dedicated substation, O&M facility, targeting $50-80/kWh installed)

30/60/90 Plan

Day 30: Complete desktop screening of 200+ decommissioned hard-rock mine shafts across three target jurisdictions using public mine registry data, satellite imagery, and grid proximity GIS analysis; shortlist 8-10 candidate sites meeting depth, diameter, and title criteria; engage two geotechnical firms for shaft condition assessment RFPs
Day 60: Conduct physical inspections and LiDAR surveys of top 3 candidate shafts; complete preliminary structural and hydrogeological assessments; finalize block geometry and tailing-cement mix design with a materials lab; issue RFQ to hoist OEMs (ABB, Siemag Tecberg, Hepburn) for 1-3 MW regenerative drive packages; develop

preliminary financial model with site-specific rehab cost inputs
Day 90: Select lead pilot site and execute site-access MOU with mine owner or custodian; complete FEED-level shaft rehabilitation scope and cost estimate (+/-30%); secure letters of intent from one hoist supplier and one EPC contractor; submit grid interconnection pre-application to local utility; close seed/grant funding round targeting $1.5M prototype authorization
Dominance Axis: easier_deploy -- Mine reuse can cut civil cost where shafts pass screening; advantage depends on usable depth, hoist throughput, and rehab cost.

Bold Concept

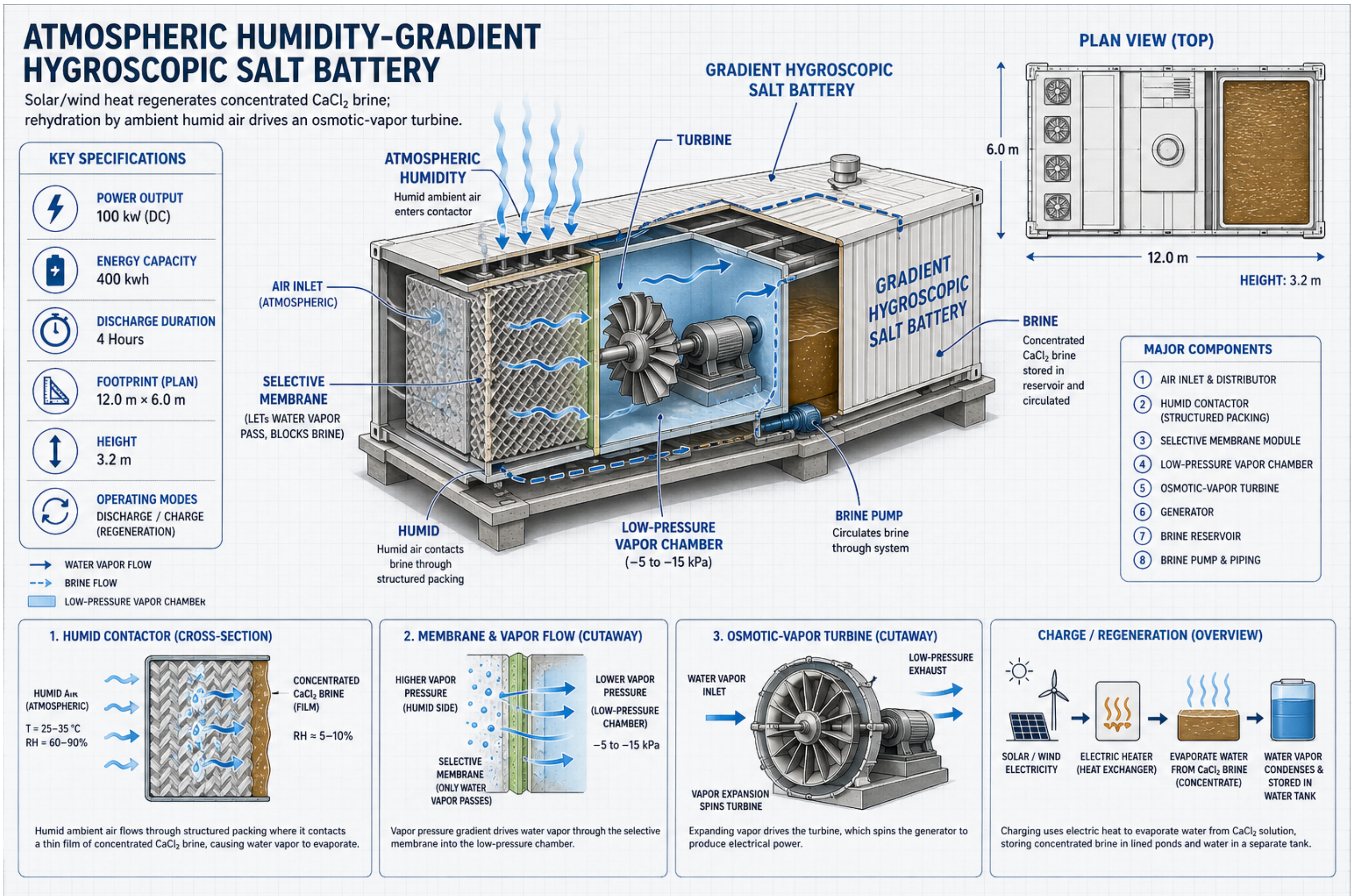
Atmospheric Humidity-Gradient Hygroscopic Salt Battery

novelty: 9 | feasibility: 3 | economic_leverage: 5 | testability: 5 | robustness: 3 | constraint_fit: 6 | explainability: 5

Overall: 5.1 / 10 -- Moderate

Constraint Compliance: Partially compliant (constraint_fit=6)

Concentrated calcium chloride brine stores energy as chemical potential between dry salt and ambient water vapor, enabling grid-scale storage using only commodity chemicals and lined ponds. This matters because it decouples storage capacity from expensive electrochemical materials, targeting sub-5 $/kWh capital cost at scale. The approach is particularly relevant for humid coastal or tropical grids where curtailed renewable electricity is abundant and land is available.



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Mechanism

The system is a thermochemical humidity battery using concentrated calcium chloride brine as the storage medium. During charge, low-value electricity drives heat pumps, resistance heaters, or mechanical vapor recompression to evaporate water from CaCl2 brine. A plausible operating window is ~25-35 wt% CaCl2 discharged brine to ~45-55 wt% charged brine, avoiding crystallization above ~60 wt% depending on temperature. Concentrated brine is stored in HDPE- or XR-5-lined ponds/tanks 0.5-2 m deep with floating covers; separated water is stored in lined reservoirs or tanks. The stored exergy is the chemical potential difference between dry/concentrated brine and ambient water vapor.

During discharge, ambient humid air is blown through stacked membrane contactors or structured packed towers. Hydrophobic microporous PTFE/PVDF membranes, ~50-200 um thick with 0.1-0.5 um pores, separate air from $CaCl_2$ brine to prevent aerosol carryover while allowing water vapor transport. Water vapor is absorbed into the brine, releasing heat of condensation plus heat of dilution. The absorption lowers local vapor pressure, sustaining mass transfer from the air. Warm diluted brine then feeds a low-temperature heat engine path: either an ORC using R245fa/R1233zd-class working fluid, an absorption heat-pump/engine hybrid, or a vacuum flash/condenser train coupled to a scroll expander. Realistic source temperatures are likely only 35-80 C, so conversion efficiency is a small fraction of Carnot. Fans, pumps, vacuum equipment, and brine circulation consume parasitic power.

The core physical limit is power density. At 30 C and 70% RH, ambient vapor content is only ~21 g/m3 dry air, and practical extraction may be a few g/m3 with modest pressure drop. Even 1 MW electric at 5% heat-to-electric efficiency requires ~20 MW thermal absorption, implying hundreds of kg/h to tonnes/h of vapor capture and very large air-handling/contacting area. $CaCl_2$ is cheap, but membranes, blowers, corrosion-resistant

Why Novel

Unlike conventional thermochemical storage, this system exploits the ambient humidity gradient itself as the discharge driver, eliminating the need for a dedicated heat source during power recovery. The pairing of osmotic-vapor turbines with hygroscopic brine ponds as a closed regeneration cycle has no direct commercial precedent.

Buildability

Core materials--$CaCl_2$, HDPE liners, structured packing, and membrane contactors--are all commercially available at industrial scale today, with no exotic manufacturing required. The primary engineering challenge is integrating low-pressure vapor turbines or pressure-retarded osmosis modules with sufficient surface area to achieve economically meaningful power density.

Why Feasible

* Build path needs validation (feasibility=3/10)

Top Risks

* Round-trip efficiency likely below 25% due to thermodynamic losses in vapor-phase energy recovery, undermining economic viability versus lithium-ion at falling prices
* Output power collapses at relative humidity below ~60%, making the system unreliable in semi-arid or seasonally dry target markets
* Membrane contactor fouling and salt crystallization at high $CaCl_2$ concentrations degrades discharge performance and drives up O&M costs unpredictably

Decisive Test (MDE)

Hypothesis: A $CaCl_2$ humidity-gradient discharge module can deliver net electric power at useful density: at least 5 W_e per m2 of contactor frontal/membrane area for 4 continuous hours at 25-35 C and 60-80% RH, with round-trip-relevant discharge parasitics below 40% of gross output and no salt carryover or crystallization.
Setup: Build a 5-20 m2 membrane or packed contactor loop using 45-55 wt% $CaCl_2$ brine, controlled humid-air feed, brine heat exchanger, and a small ORC/vacuum-scroll conversion skid. Operate at several RH points: 40%, 60%, 80%, with air velocity swept from 0.5-3 m/s. Include a bypass to separately measure absorber thermal output before connecting the conversion skid. Run a 24-hour fouling/crystallization trial at the best condition.
Instrumentation: Air inlet/outlet RH and temperature sensors, dewpoint meter, air flow station, differential pressure sensors, brine flow meter, density/conductivity for $CaCl_2$ concentration, brine inlet/outlet temperature, heat-exchanger water-side calorimetry, electrical power meters on expander/generator, fans, pumps, vacuum pump,

and controls; aerosol/salt carryover filter with ion chromatography or conductivity wash; high-resolution scale for water uptake mass balance.
Kill Criteria: Kill if net electric density is <1 W_e/m2 at 30 C, 70% RH after parasitics; or if projected installed contactor plus air-handling area exceeds ~20,000 m2 per MW_e; or if measured discharge heat-to-electric efficiency is <3% while fan/pump/vacuum parasitics exceed gross output; or if membrane salt leakage/crystallization causes >10% flux loss in 24 hours.
Rescue Pivot: If vapor-to-power density fails, pivot away from direct electric generation toward low-grade heat/cooling, industrial dehumidification with heat recovery, or use CaCl2 ponds as ultra-cheap thermal/desiccant storage paired with a separate high-efficiency heat engine only when higher-temperature regeneration heat is available.
Cost: $50k-$250k using surplus ORC/scroll hardware and custom contactor; $250k-$750k if using commercial membrane contactors and certified skid.
Time to Signal: 2-4 weeks for flux/thermal power density; 8-12 weeks for net electric result; 3-6 months for outdoor durability signal.

Refinement Deltas

Risks Addressed:
* The available exergy in ambient humidity is tiny; most captured energy is low-temperature heat with very poor conversion efficiency to electricity.
* Air handling will dominate cost and parasitics because extracting meaningful water mass flow from air requires enormous volumetric flow.
* Cheap CaCl2 does not make a cheap battery if membranes, corrosion-resistant heat exchangers, blowers, ORC skids, and land dominate CAPEX.

Red-Team:
* Challenge: The available exergy in ambient humidity is tiny; most captured energy is low-temperature heat with very poor conversion efficiency to electricity.
* Challenge: Air handling will dominate cost and parasitics because extracting meaningful water mass flow from air requires enormous volumetric flow.
* Challenge: Cheap CaCl2 does not make a cheap battery if membranes, corrosion-resistant heat exchangers, blowers, ORC skids, and land dominate CAPEX.
* Challenge: CaCl2 brine is corrosive and prone to crystallization at high concentration, threatening membranes, pumps, valves, and long-term unattended operation.
* Challenge: The system is geographically fragile: arid or cold climates provide low humidity flux, while humid climates may have land, biofouling, and condenser heat-rejection constraints.

Budget Ranges

Prototype: $120,000 -- bench-scale contactor array (10 m^2), small brine pond liner, instrumentation, and vapor recovery module to validate round-trip efficiency and fouling rates
Pilot: $2,800,000 -- 500 kWh capacity pilot with 1,000 m^2 contactor area, lined brine and water reservoirs, solar thermal regeneration skid, and grid-tie inverter for 6-month performance logging
Scale: $18,000,000 -- 10 MWh demonstration plant with optimized structured-packing towers, mechanical vapor recompression for charging, automated brine concentration monitoring, and full SCADA integration

30/60/90 Plan

Day 30: Complete thermodynamic modeling of full charge-discharge cycle across humidity ranges 40-90% RH; identify optimal brine concentration window and estimate realistic round-trip efficiency bounds; survey membrane contactor suppliers for salt-tolerant modules
Day 60: Construct bench-scale prototype with 10 m^2 contactor surface; run 20+ charge-discharge cycles measuring vapor absorption rate, power output, and fouling onset; validate or refute the 3 $/kWh capital cost

assumption with actual BOM pricing

Day 90: Publish internal techno-economic model comparing system to lithium-ion and compressed air at three humidity regimes; define go/no-go criteria for pilot funding; secure site agreement with a coastal renewable developer for a 500 kWh pilot

Dominance Axis: cheaper -- $CaCl_2$ and liners are very cheap, but system cost is dominated by contactor land area and conversion skids, not salt alone.

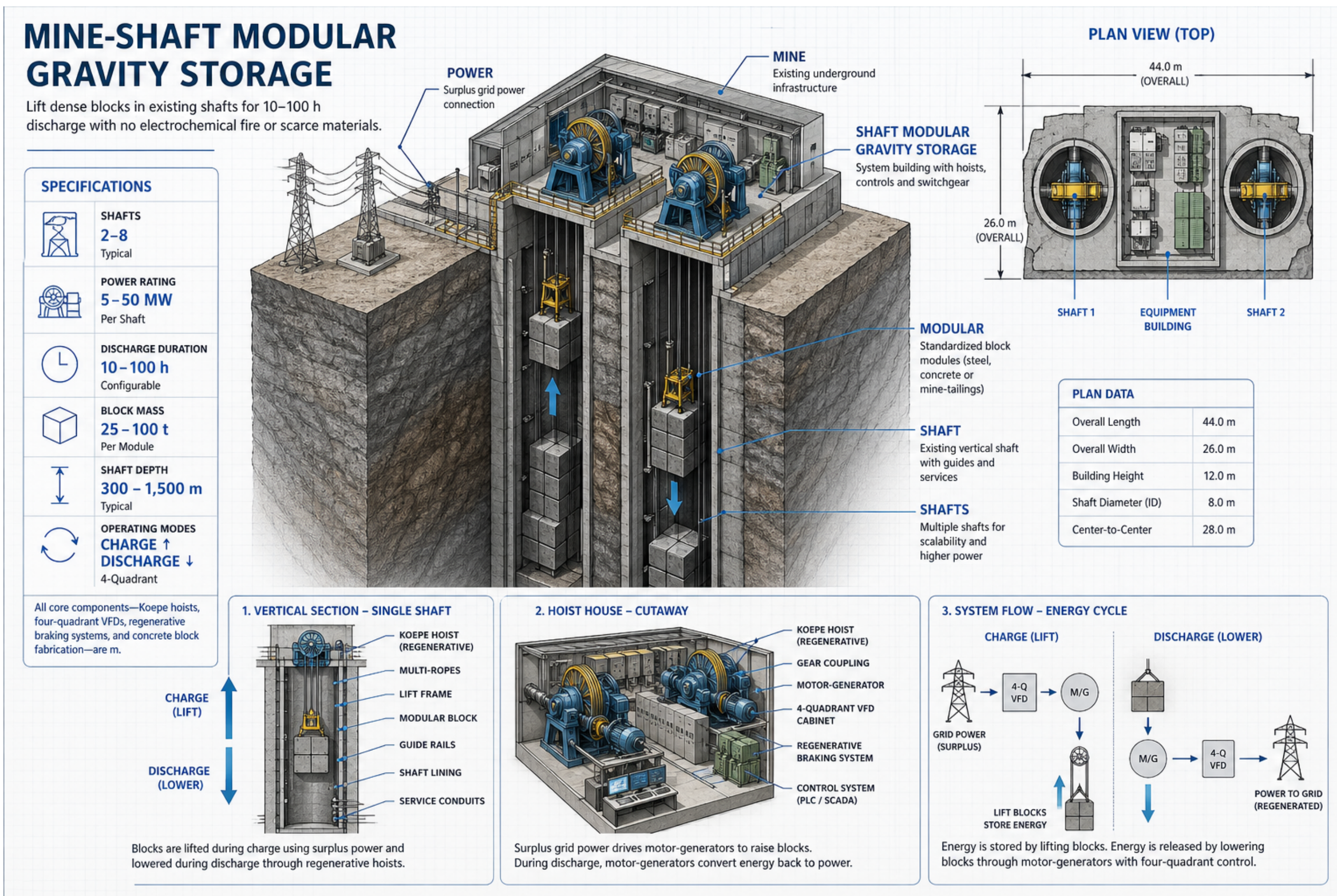
Build-First
Mine-shaft modular gravity storage

novelty: 4 | feasibility: 8 | economic_leverage: 5 | testability: 9 | robustness: 8 | constraint_fit: 8 | explainability: 9

Overall: 7.3 / 10 -- Very Strong

Constraint Compliance: Compliant (constraint_fit=8)

Repurposing decommissioned mine shafts as modular gravity batteries enables 10-100 hour energy storage using steel-encased concrete or tailings blocks lifted by regenerative hoists, with no electrochemical fire risk or reliance on scarce materials. This matters because the world has thousands of idle deep shafts representing sunk civil infrastructure worth billions, and long-duration storage is the missing link for high-renewable grids. Unlocking these assets converts stranded liabilities into grid-scale energy buffers at a fraction of greenfield construction cost.



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Mechanism

System repurposes vertical mine shafts (typically 300-1500 m deep, 4-8 m diameter) as gravity batteries. Modular masses--steel-encased concrete or compacted tailings blocks of 10-50 tonnes each, stacked into 200-1000 tonne payloads--are raised by regenerative AC hoists (Koepe friction or drum type, 2-10 MW per shaft) using existing or refurbished headframes. Hoist motors operate as motors during charging (lifting mass, consuming grid energy) and as generators during discharge (lowering mass under controlled descent, feeding grid via four-quadrant VFDs). Round-trip efficiency target ~80% accounts for motor/generator losses (~94% each way), gearbox/rope friction (~96%), and VFD conversion (~98%). Energy capacity E = m·g·h·?: a 500 t payload over 800 m yields ~872 kWh per cycle per shaft; multi-shaft sites or sequential payload swaps scale to 10-100 MWh. Power rating is decoupled from energy--set by hoist motor and rope strength (typically 50-200 mm locked-coil ropes rated 1500-4000 kN). Critical subsystems: (1) shaft liners (shotcrete + steel sets) where rock is friable; (2) redundant disc brakes and rope-arrest catch systems sized for full-payload free-fall; (3) forced ventilation (50-100 m^3/s) to manage heat from regenerative dissipation and ensure breathable atmosphere; (4) submersible dewatering pumps (100-500 L/s capacity) to handle inflow; (5) surface mass-handling yard with gantry cranes and modular storage racks; (6) grid interconnect at 11-33 kV with reactive compensation. Site selection requires: verified geotechnical stability, clear ownership/permits, <10 km to grid tie >=10 MVA, manageable inflow, and headframe load rating >=1.5x design payload.

Why Novel

Unlike purpose-built gravity storage towers or mountain-rail concepts, this approach treats existing mine shaft geometry and headframe steel as the primary capital asset, slashing civil costs and permitting timelines by reusing already-approved industrial sites. The modular block-stacking architecture--using compacted tailings as ballast--also closes a waste-management loop that no competing long-duration storage technology addresses.

Buildability

All core components--Koepe hoists, four-quadrant VFDs, regenerative braking systems, and concrete block fabrication--are mature mining and industrial technologies available from multiple global suppliers today. The primary engineering challenge is shaft condition assessment and block-guide rail installation, both of which fall within established civil and mining contractor capabilities.

Why Feasible

* Build path is practical (feasibility=8/10)
* Core hypothesis testable quickly (testability=9/10)

Top Risks

* Shaft ownership fragmentation or legacy environmental liability prevents site acquisition or permitting within viable project timelines
* Subsurface inspection reveals structural degradation--cracked linings, water ingress, or unstable geology--that makes rehabilitation costs exceed greenfield alternatives
* Hoist brake or rope failure during high-mass descent creates a catastrophic safety event that triggers regulatory shutdown of the entire asset class

Decisive Test (MDE)

Hypothesis: At least 1 in 3 surveyed candidate shafts delivers installed cost <=$250/kWh and <=$1500/kW for >=4-hour duration, beating Li-ion LCOS at >6-hour duration.
Setup: Conduct full Phase 1-4 audit on three real shafts of varying depth/condition (e.g., a 1200 m deep, well-maintained shaft; a 600 m flooded shaft; a 900 m shaft with degraded headframe). Include actual permitting engagement, utility interconnect study, and binding vendor quotes for hoist refurbishment, liner work, and civil works. Compare resulting site-level $/kW, $/kWh, and time-to-COD against published Li-ion and pumped-hydro benchmarks.
Instrumentation: Borehole camera, laser shaft-profile scan, multi-level water inflow gauges, headframe strain/load test, geotech core sampling, grid impedance study, permitting tracker. Cost outputs validated by independent EPC quote and AACE Class 3 estimate.
Kill Criteria: All three sites exceed $400/kWh installed OR civil/rehab works exceed 60% of total capex OR permitting timeline >5 years OR no shaft achieves >=4-hour duration at >=5 MW.
Rescue Pivot: If shaft economics fail, pivot to purpose-built shallow gravity (Energy Vault-style above-ground

towers) or to hybrid use: small-scale ancillary-services-only deployment at a single best-case shaft, monetizing frequency regulation rather than bulk energy arbitrage.
Cost: $600k-$1.2M for three-site audit package
Time to Signal: 6-9 months

Refinement Deltas

Risks Addressed:

* Shaft inventory is geographically scarce and rarely co-located with grid congestion or renewable generation--siting may be the binding constraint, not technology
* Mine ownership, liability transfer, and post-closure regulatory regimes (e.g., perpetual water treatment obligations) can make reuse legally toxic regardless of engineering merit
* Energy density is fundamentally low: 500 t x 800 m ~ 1 MWh; competing with a 20-ft Li-ion container (~3-5 MWh) requires massive payloads and complex mass handling

Red-Team:

* Challenge: Shaft inventory is geographically scarce and rarely co-located with grid congestion or renewable generation--siting may be the binding constraint, not technology
* Challenge: Mine ownership, liability transfer, and post-closure regulatory regimes (e.g., perpetual water treatment obligations) can make reuse legally toxic regardless of engineering merit
* Challenge: Energy density is fundamentally low: 500 t x 800 m ~ 1 MWh; competing with a 20-ft Li-ion container (~3-5 MWh) requires massive payloads and complex mass handling
* Challenge: Hoist duty cycle for storage (thousands of full-load reversals/year) is far beyond mining design (hundreds), risking accelerated rope, brake, and gearbox wear not captured in legacy cost models
* Challenge: A single catastrophic payload drop or rope failure could trigger industry-wide moratorium; insurance and bonding costs may dwarf modeled opex

Budget Ranges

Prototype: $800,000-$1,500,000 for single-shaft pilot at a shallow accessible site (200-400 m), covering shaft inspection, one hoist refurbishment, guide rail installation, VFD controls, and 3-5 block modules
Pilot: $4,000,000-$9,000,000 for a full-depth commercial demonstration (800 m, 500 t payload, ~870 kWh per cycle) including grid interconnection, safety systems, and 12-month operational validation
Scale: $15,000,000-$40,000,000 per multi-shaft cluster (5-10 shafts, 5-10 MWh aggregate capacity) at a single decommissioned mine site with shared grid connection and control infrastructure

30/60/90 Plan

Day 30: Complete desktop screening of 50+ candidate mine sites across three jurisdictions using public geological survey and mining registry data; score each on shaft depth, diameter, headframe condition, grid proximity, and ownership clarity; shortlist 5 sites for physical due diligence
Day 60: Conduct on-site shaft inspections at top 2-3 shortlisted sites using rope-access survey and LiDAR profiling; produce structural condition reports and preliminary rehabilitation cost estimates; initiate ownership and permitting conversations with site holders and regulators
Day 90: Deliver bankable feasibility study for lead site including energy capacity model, round-trip efficiency validation via hoist OEM data, CAPEX/OPEX pro forma, safety case outline, and signed letter of intent with site owner or mining company partner; secure seed funding or grant commitment for prototype phase
Dominance Axis: simpler -- Mine-shaft gravity is low-fire-risk mechanical storage, but it wins only at deep, accessible, permitted shafts with modest rehabilitation and grid costs.

Top Uncertainties & Assumptions

* Progressive ground relaxation and shaft wall spalling post-decommissioning may require costly re-lining that erodes the civil-cost advantage over greenfield sites
* Hoist cycle time bottleneck (one block per 8-15 minutes per lane) caps deliverable power to 200-400 kW per lane, forcing multi-lane parallelism that multiplies electrical and mechanical infrastructure cost
* Suitable shafts (>=300 m depth, >=4 m diameter, grid-proximate, clear title) are geographically sparse and concentrated in legacy mining regions far from major load centers
* Round-trip efficiency likely below 25% due to thermodynamic losses in vapor-phase energy recovery, undermining economic viability versus lithium-ion at falling prices
* Output power collapses at relative humidity below ~60%, making the system unreliable in semi-arid or seasonally dry target markets

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