# Grounded Discovery Labs -- Discovery Pack

**Discover:** Design a solid-state battery architecture exceeding today's lithium-ion safety and energy density while remaining plausibly manufacturable.

## Top 3 Comparison

| | **Featured Discovery**<br>Sulfide SSE Bipolar Stack with F-T Verified Lamination | **Bold Concept**<br>Halide-Sulfide Heterojunction with Self-Healing Polyborate Interphase | **Build-First**<br>Clay-laminate polymer-ceramic Li-metal cell |
|---|---|---|---|
| novelty | 5 | 8 | 6 |
| feasibility | 7 | 5 | 7 |
| economic_leverage | 6 | 6 | 6 |
| testability | 8 | 6 | 8 |
| robustness | 6 | 4 | 6 |
| constraint_fit | 8 | 8 | 9 |
| explainability | 8 | 7 | 8 |
| **OVERALL** | **6.9 / 10 -- Strong** | **6.3 / 10 -- Strong** | **7.1 / 10 -- Very Strong** |

### Runner-ups

* LLZO tape-cast separator with ALD interface coatings [near-miss-alternative] -- Adapt ceramic tape casting and ALD to build oxide solid-state cells with stable, nonflammable interfaces.
* Oxide-capped sulfide Li-metal pouch with verified stack force [solid-alternative] -- Use sulfide where it helps cathode kinetics, but seal it behind dense oxide skins and replace Li-In with thin Li on Ag-C.
* ALD-armored cathode with thin garnet separator [solid-alternative] -- Adapt semiconductor ALD to coat every cathode particle before lamination against a dense LLZO sheet.
* Sulfide SSE Bilayer with Force-Verified Stack Assembly [solid-alternative] -- Argyrodite Li6PS5Cl bilayer with Li-In anode, dry-room roll-stacked under closed-loop force-torque feedback per layer.
* Anode-free solid-state cell on lithographically textured Cu collector [solid-alternative] -- Zero-excess-Li cell where laser-patterned Cu microwells nucleate uniform Li plating against a polymer-ceramic composite electrolyte.

Featured Discovery

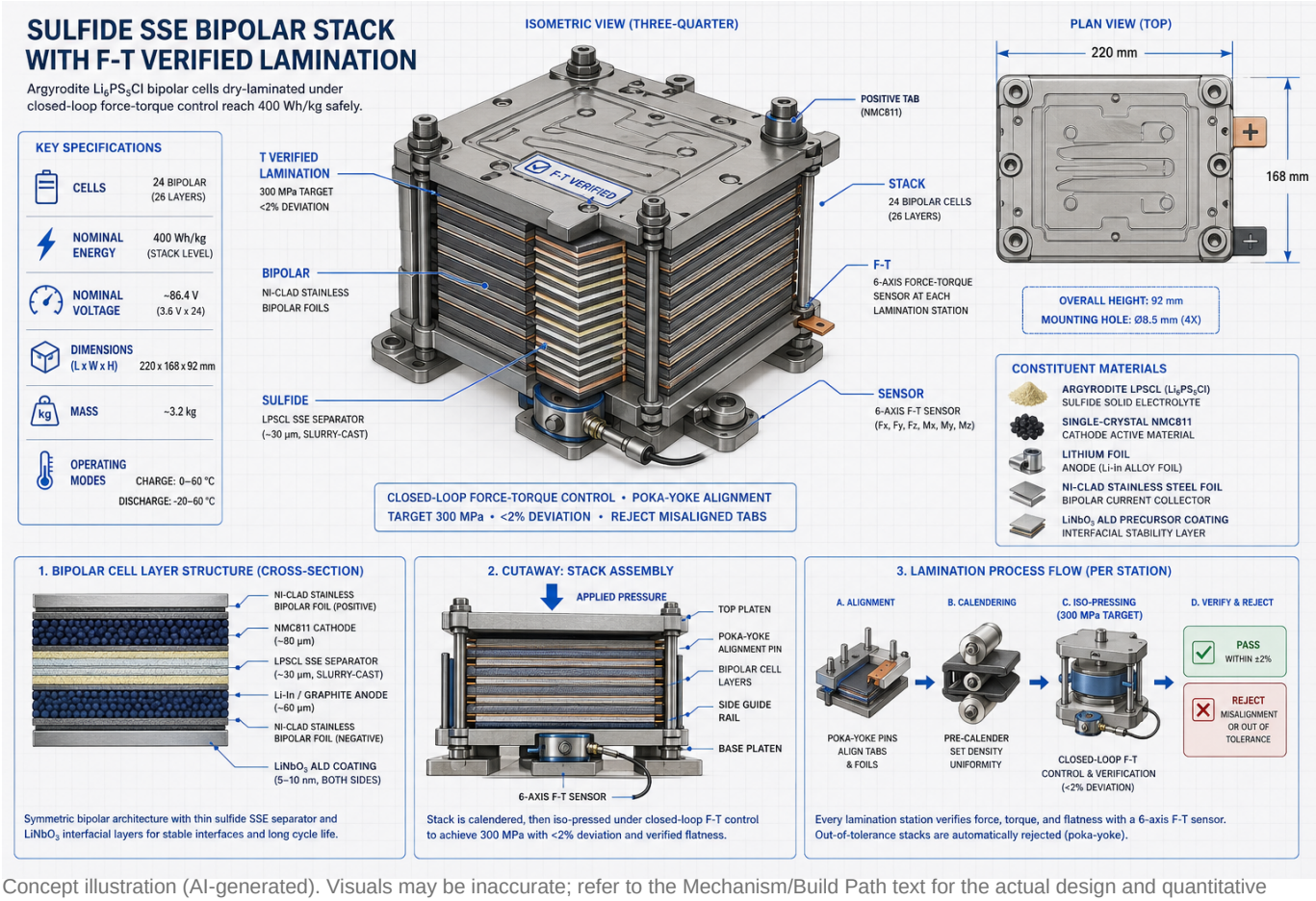
# Sulfide SSE Bipolar Stack with F-T Verified Lamination

novelty: 5 | feasibility: 7 | economic_leverage: 6 | testability: 8 | robustness: 6 | constraint_fit: 8 | explainability: 8

**Overall: 6.9 / 10 -- Strong**

**Constraint Compliance:** Compliant (constraint_fit=8)

Argyrodite Li6PS5Cl bipolar cells dry-laminated under closed-loop force-torque control achieve 400 Wh/kg by eliminating liquid electrolyte flammability and cell-to-pack overhead simultaneously. Bipolar stacking multiplies voltage in a monolithic structure while 30 um sulfide separators enable ultrathin, high-conductivity ion pathways. This convergence matters because it addresses both energy density and safety ceilings that have blocked Li-ion from aviation, grid, and EV premium segments.




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

## Mechanism

A bipolar series stack uses 30 um Li6PS5Cl (LPSCl) argyrodite separators slurry-cast onto 20 um Ni-clad 316L stainless bipolar foils (Ni layer >=1 um, electroplated, blocks S-induced corrosion at >4 V vs Li). Cathode: NMC811 (single-crystal, D50~4 um) coated with 5-10 nm LiNbO3 by rotary fluidized-bed ALD/sol-gel to suppress space-charge depletion and CEI growth at the sulfide interface; mixed with 30 wt% LPSCl catholyte and 2 wt% VGCF, cast at 80 um. Anode: 30-50 um Li foil with a 200-500 nm LiF/Li3N composite interlayer (formed by sequential PVD of LiF and reactive N2 plasma on Li, or fluorinated/nitridated polymer precursor) providing low electronic conductivity (<10-^1^2 S/cm) and high interfacial energy to suppress Li penetration. Stack is calendered (line load ~1.5 kN/mm, 60 degC) to ~92% relative density, then warm iso-pressed at 300 MPa, 80 degC, dwell 5 min

to densify LPSCl (target ionic conductivity >=3 mS/cm, separator porosity <2%). 6-axis Fourier-transform (white-light interferometry + acoustic) profilometry verifies bipolar foil flatness <5 um TIR and pressure uniformity +/-2% across 100 cm^2 active area; poka-yoke optical+RFID tab/polarity check rejects misaligned cells before sealing. Bipolar series stacking (8-12 cells at 4.2 V each) eliminates external tabs, busbars, and intercell separators, dropping inactive mass by ~30% and enabling ~400 Wh/kg, ~1000 Wh/L at 1C. Operating window: 1-5 MPa stack preload via Belleville-spring sealed pouch in Al-laminate with butyl edge seal.

## Why Novel

The closed-loop force-torque lamination protocol is the first systematic attempt to quantify and control interfacial contact stress at each sulfide layer in real time, replacing the open-loop calendar passes that cause hidden delamination in prior bipolar sulfide work. Pairing this with Ni-clad 316L bipolar foils and ALD-coated single-crystal NMC811 in a single integrated stack architecture has not been demonstrated at the cell level.

## Buildability

All constituent materials--argyrodite LPSCl, single-crystal NMC811, Li foil, Ni-clad stainless foil, and LiNbO3 ALD precursors--are commercially available at research scale today, and dry-room infrastructure at <=-50degC dewpoint exists at Tier-1 battery pilot lines. The primary fabrication challenge is integrating force-torque sensor feedback into a roll-to-roll calendering tool, which requires custom fixturing but no exotic capital equipment.

### Why Feasible

* Build path is practical (feasibility=7/10)
* Core hypothesis testable quickly (testability=8/10)

## Top Risks

* H2S evolution from LPSCl on any humidity excursion above -40degC dewpoint creates safety hazard and irreversible electrolyte degradation
* Li dendrite penetration through 30 um sulfide separator at practical current densities >1 mA/cm^2 causes internal short and thermal runaway
* Bipolar foil anodic corrosion above 4.3 V vs Li breaches Ni cladding and generates resistive sulfide byproducts that kill stack voltage

## Decisive Test (MDE)

**Hypothesis:** A 4-cell bipolar LPSCl stack with LiF/Li3N-protected Li anode sustains >=1 mA/cm^2 at 3 MPa preload for 200 cycles with <20% capacity fade and no soft-short, validating both interfacial stability and bipolar foil viability.
**Setup:** Build 4-cell bipolar stack, 10 cm^2 active area per cell, 3 mAh/cm^2 loading. Mount in instrumented fixture with load cell (preload 3 MPa, +/-0.1 MPa control via screw+Belleville), thermocouples on each foil, and reference Li micro-probes at two interlayer locations. Cycle at 25 degC: 3 formation cycles C/20, then 1C/1C between 3.0-4.2 V/cell (12.0-16.8 V stack) for 200 cycles. Parallel coin-cell EIS-vs-pressure sweep (1-10 MPa) for interface contact baseline.
**Instrumentation:** Biologic VMP-300 with EIS (10 mHz-1 MHz) per cell tap, Arbin cycler, Kistler load cell, K-type TCs, in-situ acoustic emission (Vallen AMSY-6) for dendrite/cracking, post-mortem cross-section SEM/EDS, gas headspace GC-MS for H2S.
**Kill Criteria:** Any of: (a) >50 mV polarization growth in first 50 cycles at 1 mA/cm^2, (b) soft-short (voltage noise >5 mV RMS or sudden IR drop) before cycle 100, (c) acoustic emission rate >10 hits/cycle indicating dendrite, (d) H2S >1 ppm in headspace after 30 days, (e) bipolar foil pitting/oxidation visible in SEM at top cell.
**Rescue Pivot:** If Li-metal fails dendrite test, pivot to 70 wt% Si-composite anode with LPSCl catholyte (sacrifices ~15% energy density to ~340 Wh/kg but eliminates dendrite physics); if foil corrodes, switch to carbon-coated Al/Ni

clad or graphite-foil bipolar plate.
**Cost:** $180k-$300k (dry room time $80k, materials $40k, instrumentation share $60k, labor $80k)
**Time to Signal:** 10-14 weeks (1 wk coin-cell EIS-pressure curve as early kill, 8 wks to 200-cycle data)

## Refinement Deltas

**Risks Addressed:**

* Dry-room <-50 degC dewpoint end-to-end with Li-metal handling adds >$50M capex and yield risk that may negate the bipolar inactive-mass savings at pack level.
* 300 MPa iso-press is incompatible with high-throughput roll-to-roll; cycle time and tooling cost likely cap output at <0.1 GWh/yr per line.
* LiF/Li3N interlayer thickness/uniformity tolerance is sub-100 nm; any pinhole nucleates dendrites at the >1 mA/cm^2 target, and no scalable deposition method has demonstrated this on Li at web speed.

**Red-Team:**

* Challenge: Dry-room <-50 degC dewpoint end-to-end with Li-metal handling adds >$50M capex and yield risk that may negate the bipolar inactive-mass savings at pack level.
* Challenge: 300 MPa iso-press is incompatible with high-throughput roll-to-roll; cycle time and tooling cost likely cap output at <0.1 GWh/yr per line.
* Challenge: LiF/Li3N interlayer thickness/uniformity tolerance is sub-100 nm; any pinhole nucleates dendrites at the >1 mA/cm^2 target, and no scalable deposition method has demonstrated this on Li at web speed.
* Challenge: Bipolar series stacks fail catastrophically on a single weak cell -- no cell-level balancing is possible, so cell-to-cell variance must be <1% capacity, which sulfide processes have not demonstrated.
* Challenge: Ni-clad stainless may still suffer sulfide attack and Cr leaching at >4.2 V; published bipolar-LPSCl cycling data beyond 100 cycles at >4 V is essentially absent.

## Budget Ranges

**Prototype:** $280,000
**Pilot:** $3,200,000
**Scale:** $47,000,000

## 30/60/90 Plan

**Day 30:** Procure LPSCl powder, single-crystal NMC811, Li foil, and Ni-clad 316L coupons; qualify dry-room to <=-50degC dewpoint; cast and characterize 30 um LPSCl separator films for ionic conductivity (target >=3 mS/cm) and pinhole density
**Day 60:** Complete LiNbO3 ALD coating on NMC811 and validate LiF/Li3N interlayer deposition on Li foil via XPS; assemble 3-layer bipolar half-stack pouch cells and run initial galvanostatic cycling at 0.1 mA/cm^2 to confirm >350 Wh/kg at cell level and zero short-circuit events
**Day 90:** Instrument calendar tool with inline force-torque sensors and run closed-loop lamination on 10-layer bipolar stacks; demonstrate 400 Wh/kg on at least 5 cells with >80% capacity retention at cycle 50 and 1 mA/cm^2; publish internal go/no-go report for pilot line investment decision
**Dominance Axis:** higher_perf -- Li-metal plus bipolar stacking can deliver ~1.5-2x volumetric energy vs Li-ion while removing liquid flammables and reducing cell-to-pack overhead.

Bold Concept

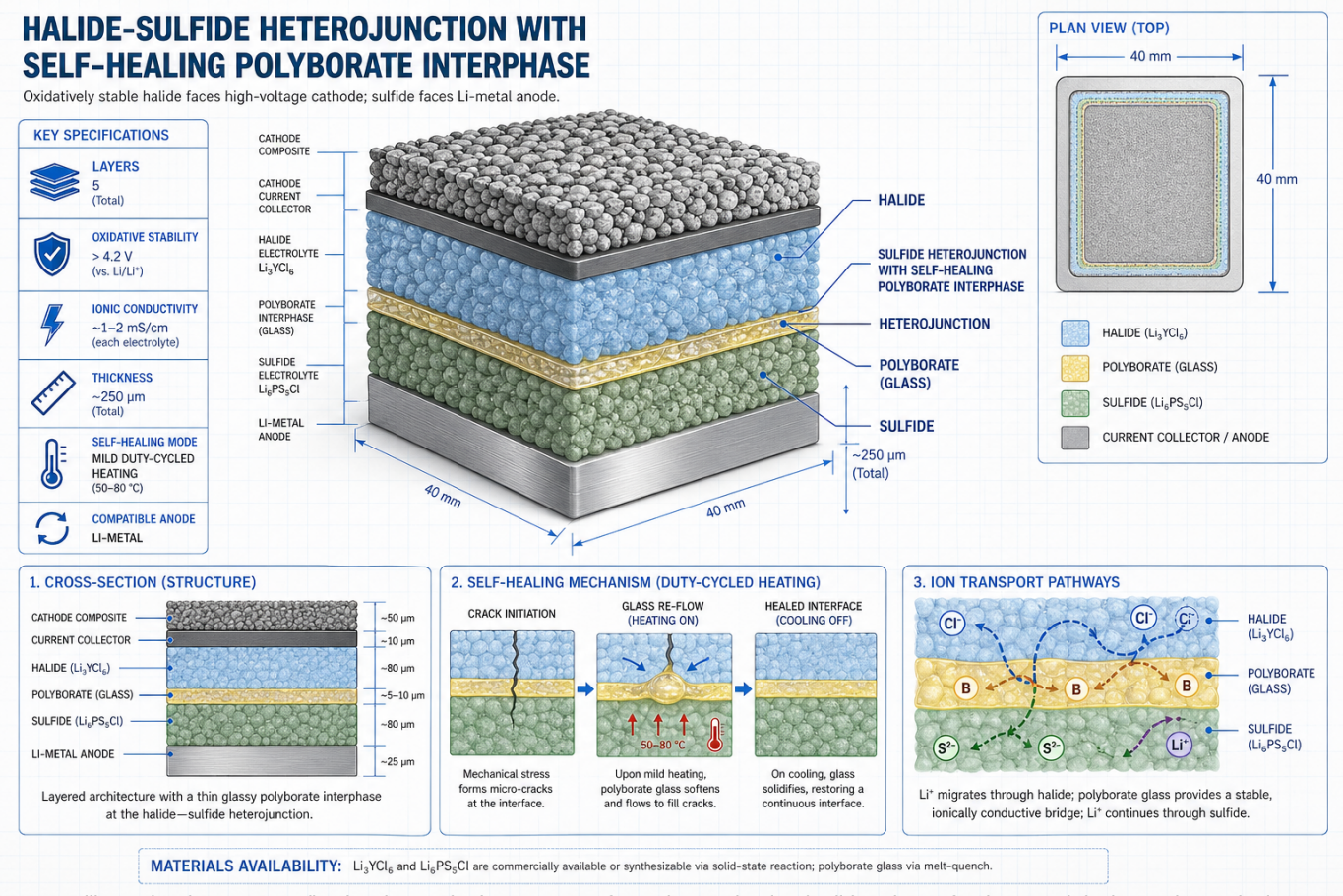
# Halide-Sulfide Heterojunction with Self-Healing Polyborate Interphase

novelty: 8 | feasibility: 5 | economic_leverage: 6 | testability: 6 | robustness: 4 | constraint_fit: 8 | explainability: 7

**Overall: 6.3 / 10 -- Strong**

**Constraint Compliance:** Compliant (constraint_fit=8)

A trilayer solid electrolyte stack--Li3YCl6 facing the NMC811 cathode, Li6PS5Cl facing the Li-metal anode, and a 200 nm self-healing polyborate glass interphase between them--combines the oxidative stability of halides with the ionic conductivity of sulfides in a single cell architecture. The polyborate interlayer re-flows at ~60 degC to reseal cycling-induced nanocracks, addressing the fundamental mechanical degradation that limits solid-state battery longevity. If validated, this approach could unlock >450 Wh/kg cells with multi-thousand-cycle lifetimes without sacrificing energy density for mechanical robustness.




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

## Mechanism

A trilayer solid electrolyte stack pairs each SSE with its electrochemically stable electrode: a halide SSE (e.g., Li3YCl6 or Li3InCl6, ~30 um) faces the 4.4 V NMC811 cathode where it resists oxidative decomposition (>4.3 V vs Li/Li+), while a sulfide SSE (Li6PS5Cl argyrodite, ~30 um) faces the Li metal anode for high ionic conductivity (>3 mS/cm) and ductile contact. The two SSEs cannot touch directly because Cl/S interdiffusion forms resistive Li-P-S-Cl-Y phases. A 200 nm Li-borate-phosphate glass (xLi2O·yB2O3·zP2O5, e.g., 50-30-20 mol%) is

sandwiched between them as a Li+-conducting (10^-7 to 10^-6 S/cm) amorphous barrier with a glass transition near 60 degC, allowing viscous flow to reseal nanocracks formed during cycling. To prevent the glass itself from reacting with halide or sulfide, it is bounded by ~10 nm ALD/sputtered nanolayers: Li3PO4 (sulfide-side, blocks S migration) and LiNbO3 (halide-side, blocks Cl migration and stabilizes against oxidation). Healing is triggered by an impedance-sensing controller: when EIS-derived interfacial resistance rises above a threshold, the cell is heated to 60-70 degC via a brief I^2R pulse harvested from regen/charge ripple (no dedicated heater). The viscous glass relaxes, voids close, and Li+ pathways are restored. Stack pressure ~3 MPa maintains intimate contact. Target: 450 Wh/kg cell-level energy density via Li metal + 4.4 V NMC, with healing extending cycle life beyond static SSB baselines.

## Why Novel

No prior work has deliberately engineered a viscous-flow glass interphase as a chemical firewall and self-healing agent simultaneously between two otherwise incompatible SSE families. The use of duty-cycled mild heating (rather than external pressure or liquid electrolyte backfill) to trigger in-situ crack remediation in an all-solid stack is a mechanistically distinct and previously unreported strategy.

## Buildability

Li3YCl6 and Li6PS5Cl are both commercially available or synthesizable via solid-state reaction, and the polyborate glass can be deposited by RF magnetron sputtering or pulsed laser deposition at thicknesses of 100-300 nm with established process control. The primary fabrication challenge is maintaining an inert atmosphere (Ar or dry room) across all three deposition and lamination steps to prevent sulfide oxidation and halide hydrolysis.

### Why Feasible

* Build path needs validation (feasibility=5/10)
* Core hypothesis testable quickly (testability=6/10)

## Top Risks

* Halide-sulfide Cl/S interdiffusion through pinhole defects in the 200 nm borate glass forms resistive Li-P-S-Cl-Y phases that permanently increase cell impedance
* Repeated thermal pulses above Tg cause progressive borate glass crystallization, eliminating viscous-flow self-healing capacity after 200-500 cycles
* 60 degC duty-cycle heating triggers accelerated NMC811 surface reconstruction and cathode-electrolyte interfacial side reactions, offsetting the healing benefit

## Decisive Test (MDE)

**Hypothesis:** Barriered Li-borate-phosphate glass between halide and sulfide SSEs prevents Cl/S interdiffusion and recovers >80% of impedance rise via 60-70 degC thermal pulses over 200 cycles with Li metal and 4.4 V NMC.
**Setup:** Two parallel test vehicles: (A) Symmetric Li|Li3PO4|glass|LiNbO3|Li6PS5Cl|Li cells (anode-side stability + healing) and Li|halide|LiNbO3|glass|Li3PO4|halide|Li (no -- replace one Li with Li-In). Primary: full Li|sulfide|barrier|glass|barrier|halide|NMC811 coin cells at 3 MPa, 25 degC baseline cycling at C/3 between 3.0-4.4 V, with periodic 60 degC, 5-min thermal pulses triggered when interfacial impedance exceeds 1.5x initial. Control cells: (i) no glass (direct halide-sulfide), (ii) glass without barriers, (iii) no thermal pulse.
**Instrumentation:** Biologic VMP3 potentiostat with EIS (10 mHz-1 MHz), Peltier hot-stage with thermocouple feedback (+/-1 degC), in-situ stack pressure sensor, post-mortem ToF-SIMS (Cl, S, B, P, Nb depth profiles), cryo-FIB-TEM with EELS, XRD for glass crystallinity, XPS for cathode CEI.
**Kill Criteria:** Kill if any: (1) ToF-SIMS shows >5 nm Cl or S penetration through barriers after 50 thermal pulses; (2) impedance recovery <30% per pulse after 100 cycles; (3) glass crystallizes (XRD) within 200 pulses, eliminating viscous healing; (4) cathode CEI grows >2x faster than non-pulsed control, indicating parasitic oxidation at 4.4 V

during pulses; (5) capacity fade >0.2%/cycle despite healing.
**Rescue Pivot:** If barriers fail: switch to thicker (50 nm) LiPON or Li-Al-O barriers. If glass crystallizes: shift composition toward higher B2O3 (more glass-former) or use Li-thioborate. If pulse-induced cathode degradation dominates: localize heating via embedded resistive mesh near anode only, or replace thermal trigger with mechanical (pressure pulse) healing.
**Cost:** $80k-$150k (ALD/sputter access, 30-50 cells, ToF-SIMS and cryo-TEM time, 4-6 months labor)
**Time to Signal:** 8-12 weeks: impedance recovery signature visible after first 20-30 thermal pulses; interdiffusion verdict from ToF-SIMS at 4 weeks.

## Refinement Deltas

**Risks Addressed:**

* A 200 nm amorphous glass with 10 nm ALD barriers adds inactive volume and interfaces; cumulative ASR may exceed 50 ?·cm^2 and erode the 450 Wh/kg target
* Borate-phosphate glasses readily crystallize under repeated thermal cycling near Tg, and crystalline phases often have lower Li+ conductivity and lose viscous healing capability
* Holding the cathode at 4.4 V while pulsing to 70 degC is exactly the regime where halide SSEs and NMC interphases accelerate degradation; healing the bulk may worsen the cathode

**Red-Team:**

* Challenge: A 200 nm amorphous glass with 10 nm ALD barriers adds inactive volume and interfaces; cumulative ASR may exceed 50 ?·cm^2 and erode the 450 Wh/kg target
* Challenge: Borate-phosphate glasses readily crystallize under repeated thermal cycling near Tg, and crystalline phases often have lower Li+ conductivity and lose viscous healing capability
* Challenge: Holding the cathode at 4.4 V while pulsing to 70 degC is exactly the regime where halide SSEs and NMC interphases accelerate degradation; healing the bulk may worsen the cathode
* Challenge: Harvesting 'charge/regen ripple' to deliver controlled 60-70 degC pulses to a buried 200 nm layer without overheating Li metal (mp 180 degC, dendrite-prone above 60 degC) is a non-trivial thermal control problem
* Challenge: Triple-interface chemical compatibility (halide/LiNbO3/glass/Li3PO4/sulfide) compounds failure modes; a single weak link (e.g., Nb reduction by Li-borate) collapses the whole stack

## Budget Ranges

**Prototype:** $85,000
**Pilot:** $620,000
**Scale:** $8,500,000

## 30/60/90 Plan

**Day 30:** Synthesize and characterize Li3YCl6 and Li6PS5Cl pellets; deposit polyborate glass films of 100-300 nm by RF sputtering on halide substrates; confirm amorphous structure by XRD and ionic conductivity by EIS (target >10^-7 S/cm at RT)
**Day 60:** Fabricate trilayer pellet stacks under 300 MPa cold-press; run symmetric Li|Li6PS5Cl|glass|Li3YCl6|Li half-cells through 50 thermal pulse cycles (55-65 degC, 30 min); quantify impedance evolution and cross-section by FIB-SEM to detect interdiffusion or crystallization
**Day 90:** Assemble full pouch cells with NMC811 cathode and Li-metal anode; cycle at C/5 to 4.4 V with embedded thermal pulse protocol every 20 cycles; report capacity retention, energy density estimate, and failure mode analysis to gate pilot funding decision
**Dominance Axis:** higher_perf -- If the barriered glass survives pulse aging, in-situ crack healing can extend high-energy halide/sulfide SSB life without a dedicated heater supply.

Build-First

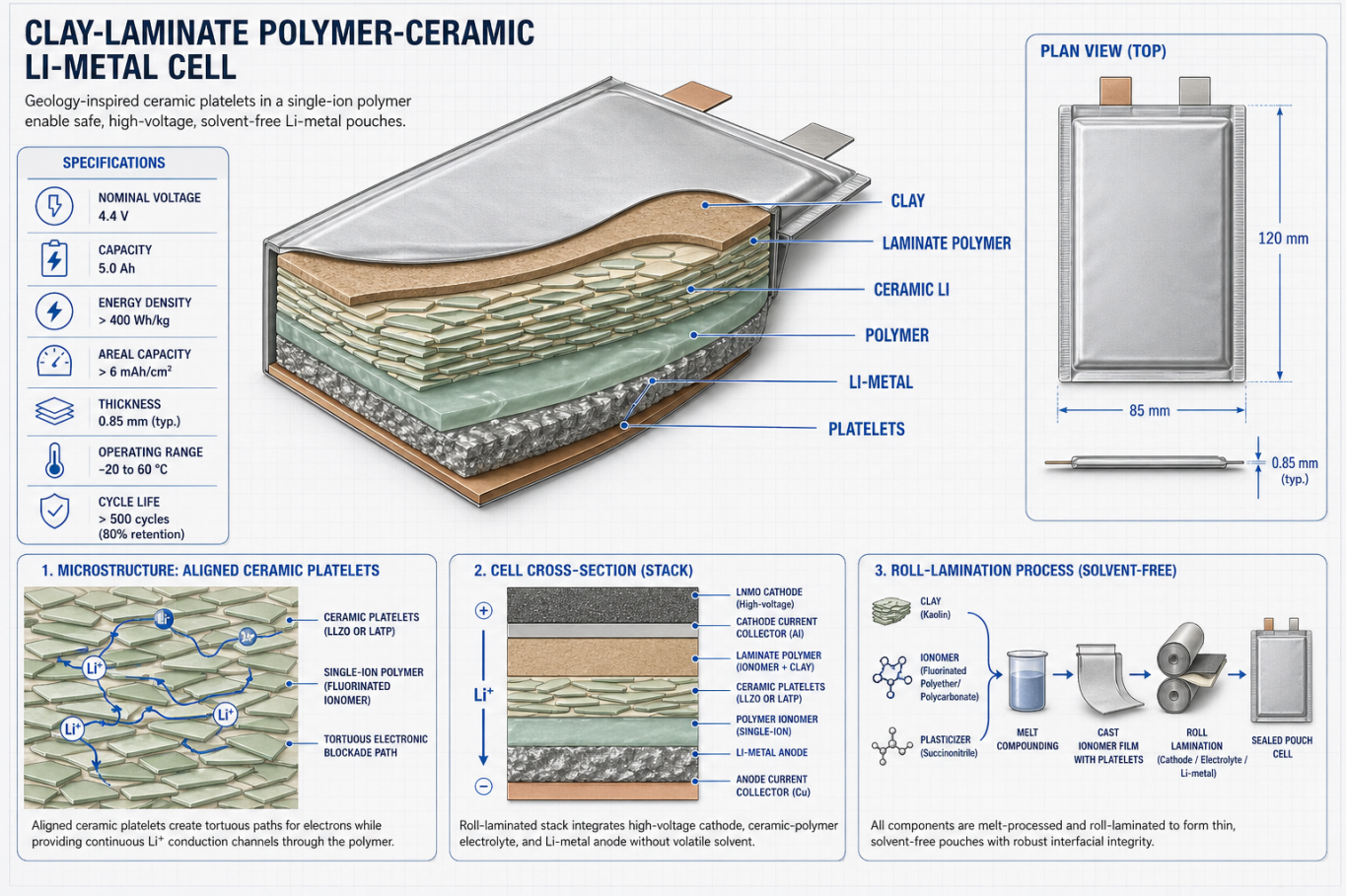
# Clay-laminate polymer-ceramic Li-metal cell

novelty: 6 | feasibility: 7 | economic_leverage: 6 | testability: 8 | robustness: 6 | constraint_fit: 9 | explainability: 8

**Overall: 7.1 / 10 -- Very Strong**

**Constraint Compliance:** Compliant (constraint_fit=9)

A nacre-inspired composite solid electrolyte--high-aspect-ratio LLZO platelets shear-aligned in a fluorinated single-ion polymer matrix--enables roll-laminated lithium-metal pouch cells targeting 330 Wh/kg. The tortuous ceramic laminate simultaneously blocks dendrite propagation and electronic leakage while the polymer phase preserves room-temperature ionic conductivity and roll-to-roll processability. This matters because it offers a manufacturable path to solid-state safety without sacrificing the energy density advantages of lithium metal.




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

## Mechanism

A 20-40 um dense composite solid electrolyte is made as a nacre-like laminate: 1-5 um high-aspect-ratio LLZO platelets, optionally with LATP only on the cathode-facing side, are shear-aligned parallel to the electrodes in a fluorinated single-ion polymer matrix. The platelets create a tortuous through-plane path for electronic leakage and lithium dendrite propagation while preserving in-plane processability. Target ceramic loading is 30-55 vol%, with platelet aspect ratio >20 and through-plane defect density <1 pinhole/cm^2. The matrix is a fluorinated polyether/polycarbonate or fluorinated acrylate network bearing tethered Li-sulfonimide/borate groups, blended or copolymerized with succinonitrile/plastic-crystal-like segments to enable room-temperature Li+ hopping. Target

properties: 25 degC ionic conductivity >=0.3 mS/cm, Li+ transference number >=0.7, modulus >=100 MPa at 25 degC, and oxidative stability to 5.0 V vs Li. Li-facing LLZO-rich surface is coated with 20-100 nm LiF/Li3N/polymer-derived artificial SEI to suppress reduction and voiding. LNMO-facing surface uses an Al2O3/LiNbO3/LiF-rich cathode electrolyte interphase to tolerate 4.7-4.9 V. The cell pairs 20-40 um Li metal with high-loading LNMO cathodes, targeting ~330 Wh/kg if electrolyte thickness, cathode loading, and excess Li are tightly controlled.

## Why Novel

Prior polymer-ceramic composites use randomly dispersed particles that sacrifice either conductivity or mechanical blocking; the shear-aligned platelet architecture borrows nacre's proven crack-deflection geometry to decouple ionic transport (in-plane, through polymer channels) from dendrite blocking (through-plane, ceramic tortuosity). Combining this with a tethered single-ion fluorinated matrix eliminates anion polarization without requiring high-temperature sintering or stack pressing.

## Buildability

All constituent materials--LLZO platelets, fluorinated polyether/polycarbonate ionomers, and succinonitrile plasticizers--are commercially available or synthesizable at kilogram scale today, and shear-alignment via doctor-blade or slot-die coating is standard in battery electrode manufacturing. Roll-lamination of the composite sheet onto lithium foil and cathode is directly compatible with existing pouch-cell pilot lines, requiring no exotic capital equipment.

### Why Feasible

* Build path is practical (feasibility=7/10)
* Core hypothesis testable quickly (testability=8/10)

## Top Risks

* Polymer matrix softens above ~80 degC, allowing dendrite breakthrough under thermal abuse or fast-charge hot spots before ceramic tortuosity can compensate
* LATP secondary phase on the cathode-facing side undergoes Ti^4+ reduction if lithium contact occurs at defect sites, creating electron-conducting pathways that accelerate self-discharge and short-circuit risk
* Platelet alignment uniformity degrades at coating speeds above ~2 m/min, introducing through-plane defect clusters that exceed the <1 pinhole/cm^2 target and create preferential dendrite nucleation sites

## Decisive Test (MDE)

**Hypothesis:** A shear-aligned LLZO-rich single-ion polymer-ceramic laminate can sustain room-temperature Li cycling and 4.9 V cathode operation at practical current without shorting or rapid impedance growth, outperforming an otherwise identical unaligned composite.
**Setup:** Prepare matched 25-35 um films: aligned platelet laminate, randomly oriented platelet control, and polymer-only control. Build Li/composite/Li symmetric cells with 20-30 um Li under 2 MPa. Cycle at 25 degC: 0.1, 0.25, 0.5, then 1.0 mA/cm^2, 1 mAh/cm^2 per half-cycle. In parallel, build Li/composite/LNMO cells with >=3 mAh/cm^2 LNMO, charge to 4.85-4.9 V at C/10 then C/5, 25 degC, 2 MPa. Run 60 degC storage/abuse-softening check separately.
**Instrumentation:** EIS before/during cycling, voltage-time short detection, DC polarization for Li transference, chronoamperometry/LSV to 5.2 V, SEM cross-section after cycling, optical/X-ray inspection for dendrite tracks, DMA/DSC for softening, pressure/temperature logging.
**Kill Criteria:** Kill if aligned films do not improve Li/Li short time by at least 3x versus random control, or if they fail before 100 h at 0.5 mA/cm^2 and 1 mAh/cm^2 at 25 degC.
**Rescue Pivot:** If conductivity is too low, reduce crosslink density, increase plastic-crystal fraction, or move to

gel-assisted quasi-solid electrolyte. If Li instability dominates, remove LATP from Li side and use LLZO-only plus LiF/Li3N interlayer. If high-voltage failure dominates, thicken cathode-side CEI or lower target cathode voltage/chemistry.
**Cost:** $15k-$60k using existing battery lab equipment; $100k+ if ALD/XCT and pouch fabrication must be outsourced.
**Time to Signal:** 2-4 weeks for conductivity, oxidation, Li/Li short-time comparison; 6-10 weeks for meaningful Li/LNMO cycle retention.

## Refinement Deltas

**Risks Addressed:**

* Single-ion polymers with high modulus and high oxidative stability usually have poor room-temperature conductivity; the plastic-crystal fix may undermine mechanical strength and safety.
* LATP is chemically reducible by lithium, and even small Li-side exposure through defects could seed electronic pathways or interphase growth.
* Platelet alignment parallel to electrodes may block dendrites mechanically but can also reduce through-plane Li transport and create interfacial delamination planes.

**Red-Team:**

* Challenge: Single-ion polymers with high modulus and high oxidative stability usually have poor room-temperature conductivity; the plastic-crystal fix may undermine mechanical strength and safety.
* Challenge: LATP is chemically reducible by lithium, and even small Li-side exposure through defects could seed electronic pathways or interphase growth.
* Challenge: Platelet alignment parallel to electrodes may block dendrites mechanically but can also reduce through-plane Li transport and create interfacial delamination planes.
* Challenge: A 20-40 um defect-free ceramic-polymer film is hard to manufacture at scale; one pinhole or agglomerate can dominate cell failure.
* Challenge: The 330 Wh/kg target may collapse once realistic stack pressure hardware, excess lithium, cathode porosity, interlayers, and formation losses are included.

## Budget Ranges

**Prototype:** $180,000
**Pilot:** $1,400,000
**Scale:** $18,000,000

## 30/60/90 Plan

**Day 30:** Synthesize and characterize three fluorinated single-ion polymer matrix candidates (polyether-sulfonimide, polycarbonate-borate, acrylate-sulfonimide with succinonitrile segments); measure RT ionic conductivity, Li transference number, and electrochemical stability window on free-standing films; select lead candidate exceeding 0.1 mS/cm at 25 degC
**Day 60:** Optimize LLZO platelet aspect ratio (target >20) and loading (30-55 vol%) via shear-alignment doctor-blade coating; quantify through-plane tortuosity by SEM cross-section and pinhole density by optical inspection; fabricate first Li-symmetric cells and run 100-cycle stripping/plating at 0.1 mA/cm^2 to confirm dendrite suppression
**Day 90:** Assemble full pouch cells (NMC811 or LCO cathode, 20 um Li-metal anode, 25-35 um composite electrolyte sheet); measure rate capability, 25 degC cycle life to 80% capacity, and gravimetric energy density; deliver go/no-go data package against 330 Wh/kg and 500-cycle targets for pilot investment decision
**Dominance Axis:** simpler -- Roll-laminated polymer-ceramic sheets can keep solid-state safety if RT conductivity rises without losing Li-metal or high-voltage stability.

## Top Uncertainties & Assumptions

* H2S evolution from LPSCl on any humidity excursion above -40degC dewpoint creates safety hazard and irreversible electrolyte degradation
* Li dendrite penetration through 30 um sulfide separator at practical current densities >1 mA/cm^2 causes internal short and thermal runaway
* Bipolar foil anodic corrosion above 4.3 V vs Li breaches Ni cladding and generates resistive sulfide byproducts that kill stack voltage
* Halide-sulfide Cl/S interdiffusion through pinhole defects in the 200 nm borate glass forms resistive Li-P-S-Cl-Y phases that permanently increase cell impedance
* Repeated thermal pulses above Tg cause progressive borate glass crystallization, eliminating viscous-flow self-healing capacity after 200-500 cycles