Grounded Discovery Labs -- Discovery Pack

Discover: Design a material or hybrid structure that combines low mass with significantly improved fire performance for vehicles, buildings, or aerospace.

Top 3 Comparison

	Featured Discovery Gradient Aerogel-Microsphere Fire Wall for EV Battery Packs	Bold Concept Diatom-silica biochar exoskeleton sandwich	Build-First Geopolymer skin with hollow microsphere gradient core
novelty	6	9	4
feasibility	8	4	8
economic_leverage	6	5	6
testability	9	6	9
robustness	7	5	7
constraint_fit	10	8	9
explainability	8	7	9
OVERALL	**7.7 / 10 -- Very Strong**	**6.3 / 10 -- Strong**	**7.4 / 10 -- Very Strong**

Runner-ups

* Zeolite-geopolymer syntactic dehydration shield [solid-alternative] -- A low-density aluminosilicate foam absorbs fire energy by controlled dehydration while leaving a rigid mineral skeleton.
* Aerogel-ceramic helicoidal fire sandwich [near-miss-alternative] -- A lightweight panel combines silica aerogel-infused ceramic cloth plies in rotated angles to slow heat flow and crack growth.
* Basalt-Fiber Intumescent Geopolymer Sandwich [solid-alternative] -- Volcanic-mimicking geopolymer foam core with basalt-fiber skins expands and vitrifies like pumice under fire.
* Oxide-fiber aerogel tension-skin sandwich [solid-alternative] -- Replace combustible resin-rich panels with a pre-tensioned ceramic textile sandwich using silica aerogel for thermal arrest and minimal binder.
* Subduction-mimic hydrous mineral metamaterial [solid-alternative] -- A printed hydrous-mineral lattice sacrifices water under flame, then densifies into a stable ceramic skeleton.

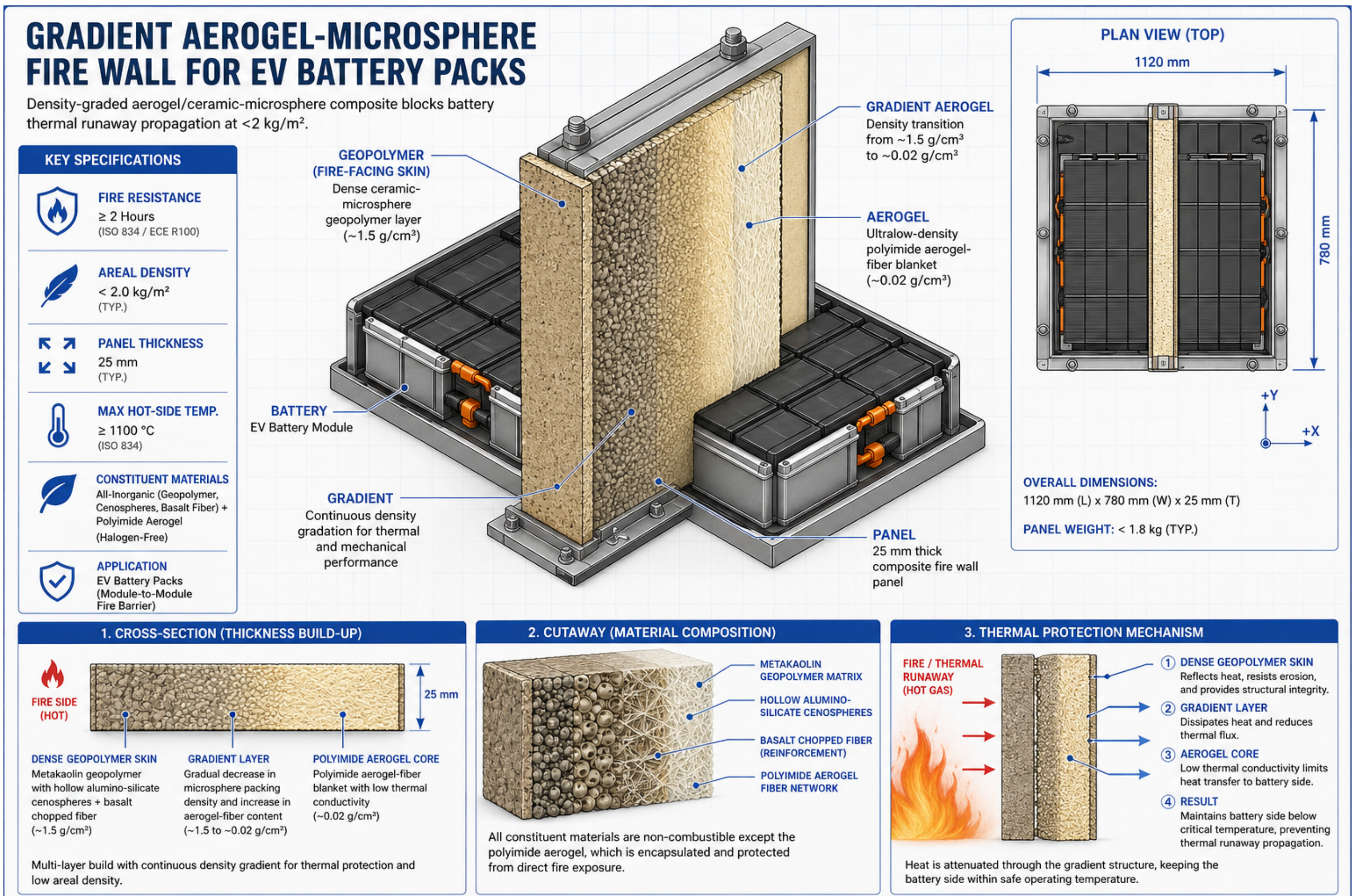
Featured Discovery
Gradient Aerogel-Microsphere Fire Wall for EV Battery Packs

novelty: 6 | feasibility: 8 | economic_leverage: 6 | testability: 9 | robustness: 7 | constraint_fit: 10 | explainability: 8

Overall: 7.7 / 10 -- Very Strong

Constraint Compliance: Compliant (constraint_fit=10)

A 3-5 mm density-graded aerogel/ceramic-microsphere composite firewall achieves >=5 minutes of thermal runaway propagation delay at only 1.8 kg/m^2 areal mass--roughly half the weight of conventional mica-plus-blanket stacks. This matters because EV pack gravimetric efficiency is directly tied to safety layer mass, and current solutions force a painful tradeoff between protection time and range.



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

Mechanism

The firewall is a 3-5 mm graded composite panel sized for inter-cell or module-face placement in 21700/4680 EV packs, targeting 1.8 kg/m^2 areal mass for >=5 min propagation delay. Layer architecture (hot->cold): (1) 1.0-1.5 mm fiber-toughened geopolymer hot skin -- metakaolin/Na-silicate matrix loaded 35-45 vol% with hollow alumino-silicate cenospheres (50-150 um, ~0.7 g/cc) and 6-10 vol% chopped basalt or mullite fibers (10 um x 6 mm); withstands plume gas at ~1000-1300 degC and provides ablative/endothermic dehydroxylation around 200-600 degC. (2) 0.5 mm slurry transition zone with graded cenosphere/aerogel-particle ratio and matched Na-silicate binder -- provides chemical continuity (same alkali-silicate chemistry on both sides) so no organic adhesive plane exists. (3) 2-3 mm polyimide (BPDA-PDA) aerogel-fiber blanket, density 0.10-0.15 g/cc, k~22 mW/m·K at 25 degC, with reinforcing silica or polyimide nonwoven scrim (~30 g/m^2) for handling. Through-thickness reinforcement: needle-punched mullite or silica fiber tufts at 5-10 mm pitch, or sparse Kevlar/PI Z-stitches at ~15 mm pitch, transferring peel and shear loads into fibers rather than the wet-cast interface. Co-cast process keeps the geopolymer skin in compression on cure shrinkage. Operating envelope: -40/+120 degC service, >=10 g RMS random vibration (ISO 12405 / SAE J2380), single-event plume impulse ~50-150 kPa for 1-3 s during a thermal runaway. Failure modes engineered against: aerogel densification (scrim + Z-fibers maintain thickness), skin micro-cracking (fiber bridging arrests cracks <0.5 mm), and interface delamination (chemical continuity + mechanical stitching).

Why Novel

No commercial inter-cell firewall today combines a geopolymer ablative hot skin, a chemically continuous slurry transition zone, and an aerogel-loaded polyimide cold face in a single co-cured monolithic panel--eliminating the organic adhesive plane that is the typical delamination failure site. The graded density architecture is the key differentiator: it matches thermal impedance continuously rather than stacking discrete dissimilar materials.

Buildability

All constituent materials--metakaolin geopolymer, hollow alumino-silicate cenospheres, basalt chopped fiber, and polyimide aerogel composites--are commercially available from existing aerospace and refractory suppliers, enabling lab prototypes without custom synthesis. Sequential slurry casting with controlled drying schedules is compatible with existing composite panel manufacturing lines, though vibration-fatigue qualification will require dedicated fixturing.

Why Feasible

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

Top Risks

* Aerogel particle compaction under 10-year EV vibration spectrum degrades thermal resistance by an unknown but potentially significant margin before first runaway event
* Geopolymer hot-skin microcracking during pack assembly torque cycles or first thermal shock creates preferential gas-channeling paths that short-circuit the propagation delay
* Landed cost per panel exceeds mica-sheet incumbent by >3x at pilot volumes, blocking OEM adoption before scale economies are demonstrated

Decisive Test (MDE)

Hypothesis: After 8 h ISO 12405-4 random vibration and 200 cycles -40/+120 degC, the graded panel retains >=80% of as-built 90deg peel strength and limits adjacent-cell surface temperature to <150 degC for >=5 min during a 21700 NCM811 nail-penetration runaway, at <=1.8 kg/m^2.
Setup: Three coupon sets (n=5): as-built, post-vibration, post-vibration+thermal-cycling. Each set splits into peel/shear coupons (ASTM C297/D1876 modified) and 100x100 mm firewall coupons. Firewall coupons mounted between a trigger 21700 (100% SOC, NCM811) and an instrumented witness cell in a steel fixture inside a vented blast chamber; nail (3 mm, 80 mm/s) initiates runaway. Baselines: 0.25 mm mica + 3 mm silica aerogel stack at matched areal mass.
Instrumentation: Type-K TCs on witness-cell can (3 locations) and panel cold face; type-R TC on hot face; high-speed IR camera (60 Hz); pressure transducer in chamber; load cell + Instron for peel/shear; hot-disk TPS for k pre/post; micro-CT on one coupon per condition for delamination/aerogel-thickness mapping.
Kill Criteria: Peel strength drops >40% post-vibration; OR aerogel thickness loss >20% post-cycling; OR

witness-cell temp exceeds 150 degC before 5 min; OR visible delamination/skin cracking >2 mm after plume; OR areal mass to meet thermal target exceeds 2.5 kg/m^2.
Rescue Pivot: If interface fails but thermal performance is met, pivot to mechanically-clamped (non-bonded) graded panel held by module frame, accepting an assembly penalty. If aerogel compacts, replace polyimide aerogel with silica-aerogel-filled ceramic fiber paper (lower k retention but better creep resistance).
Cost: $25k-45k (cells, fixturing, chamber time, instrumentation rental, 6-8 weeks labor)
Time to Signal: 8-10 weeks from material receipt to runaway data

Refinement Deltas

Risks Addressed:

* Geopolymers are inherently brittle and contain alkali-driven efflorescence and shrinkage microcracks; needling/Z-stitching may not prevent percolating crack networks under 10+ years of EV vibration, and a cracked hot skin lets plume gas reach the aerogel directly.
* Polyimide aerogels lose mechanical integrity above ~300 degC and char/shrink; once the hot-skin cracks or the transition zone conducts heat, the cold blanket may collapse well before the 5-minute target.
* Co-casting wet geopolymer onto a hydrophobic polyimide aerogel risks poor wetting, capillary intrusion that destroys aerogel porosity locally, or osmotic damage from alkali silicate -- the 'chemically continuous' claim is asserted but not demonstrated between alkali-inorganic and organic-polymer chemistries.

Red-Team:

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* Challenge: Mica + silica aerogel incumbents are already qualified to GB 38031-2020 / UN GTR EVS at <2 kg/m^2; a new bonded graded panel must clear automotive PPAP, flammability (UL 94 V-0), and outgassing without offering >2x delay margin to justify switching cost.
* Challenge: Through-thickness needling creates thermal short-circuits -- ceramic fibers bridging hot to cold face can raise effective k by 30-100%, potentially negating the aerogel's insulation benefit at the very locations engineered for mechanical robustness.

Budget Ranges

Prototype: $45,000
Pilot: $380,000
Scale: $2,800,000

30/60/90 Plan

Day 30: Formulate and cast three geopolymer hot-skin coupon variants (cenosphere loading 35, 40, 45 vol%) and two transition-zone slurry ratios; measure green-state density, shrinkage, and flexural strength; select best-performing formulation for full panel layup.
Day 60: Fabricate 10 full 200x200 mm three-layer panels using selected formulation; subject five panels to EV vibration profile (IEC 62660-2 equivalent, 200 h) and five to direct flame impingement at 1100 degC; record delamination onset time, back-face temperature rise, and areal mass; compare against mica-blanket control.
Day 90: Deliver a 12-cell 21700 module-level propagation test per UN 38.3 / GB 38031 protocol with firewall panels installed; document propagation delay time, peak inter-cell temperature, and post-test panel integrity; compile cost model at 10k, 100k, and 1M panel/year volumes for OEM pitch deck.

Dominance Axis: easier_deploy -- A bonded graded panel can replace mica plus blanket stacks only if interface durability survives pack vibration and runaway plume shock.

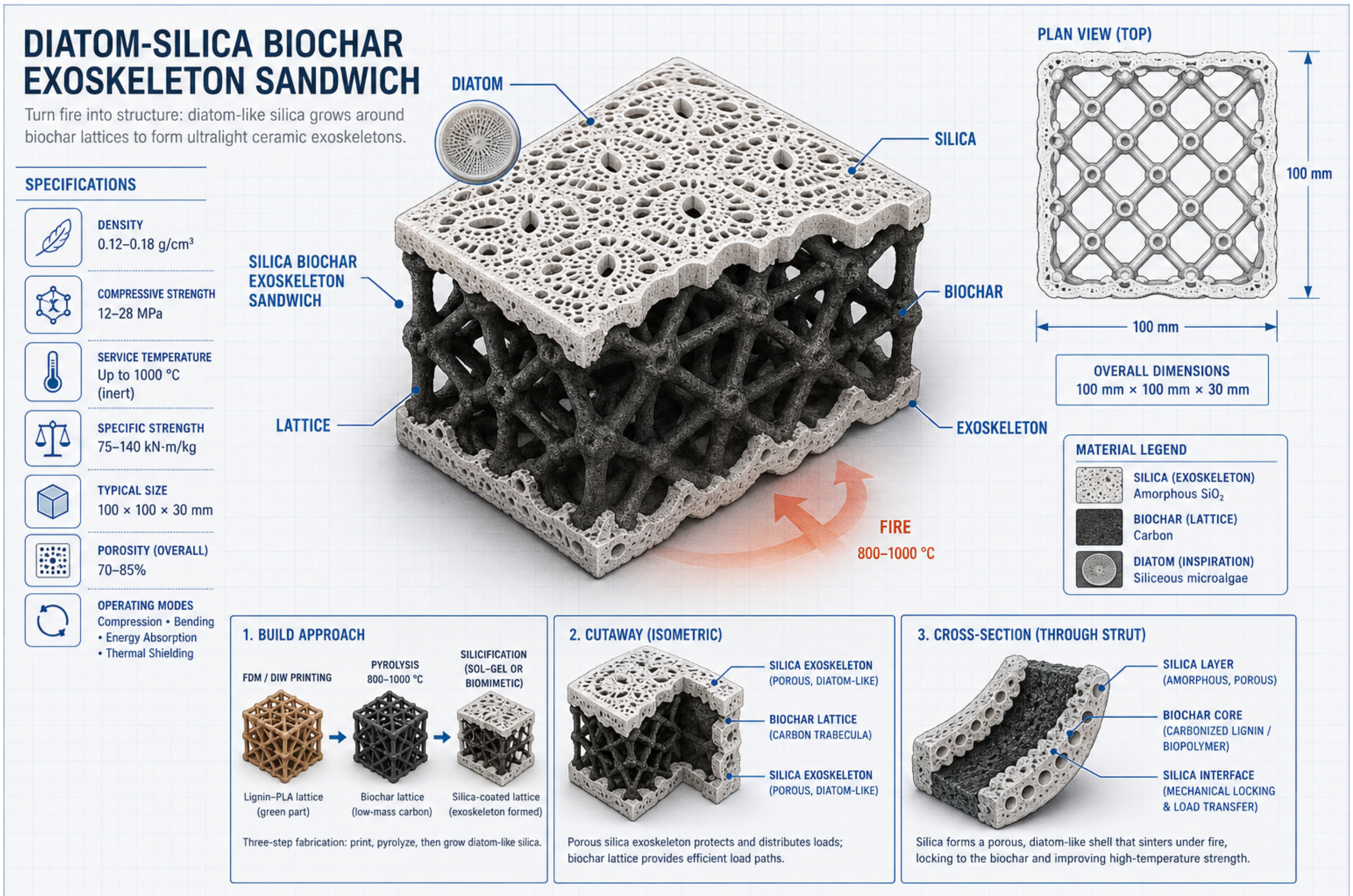
Bold Concept
Diatom-silica biochar exoskeleton sandwich

novelty: 9 | feasibility: 4 | economic_leverage: 5 | testability: 6 | robustness: 5 | constraint_fit: 8 | explainability: 7

Overall: 6.3 / 10 -- Strong

Constraint Compliance: Compliant (constraint_fit=8)

A hierarchical biochar-silica composite achieves ultralight structural performance (target 0.08 g/cm^3) by encasing a pyrolyzed biopolymer trabecular lattice in a diatom-templated amorphous silica exoskeleton. This matters because it converts fire--historically the enemy of lightweight carbon structures--into a ceramic sintering event that strengthens rather than destroys the material, opening pathways for fire-safe ultralight aerospace and construction panels.



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

Mechanism

A hierarchical composite combining three length scales: (1) a macro trabecular lattice (1-3 mm strut pitch, 200-400 um strut diameter) carbonized from a printed biopolymer (lignin-PLA or cellulose nanofibril resin, pyrolyzed at 800-1000 degC in N2 to yield ~60% mass-yield biochar with ~0.25 g/cm3 lattice density); (2) a meso porous amorphous silica exoskeleton (20-80 um wall, ~50% open porosity) deposited by alternating vacuum-pressure sol-gel infiltration of TEOS/MTES (water:ethanol:HCl 4:4:1, gel time tuned to 6-10 min) plus electrophoretic deposition of 50-200 nm Stöber silica seeds at 5-20 V/cm to enforce conformality on inner struts; (3) a micro diatom-frustule fraction (~10 wt%) blended into the sol to template biomimetic nano-pores that suppress shell cracking via tortuous crack paths. A trace rare-earth or rhodamine-tagged silane (~0.05 wt%) is co-condensed for

UV-fluorescence pinhole QC, cross-checked against uCT slices. In fire, oxygen ingress through pinholes is rate-limited by the silica shell; residual carbon undergoes intumescent in-shell oxidation that consumes O2 and releases CO2, while the silica simultaneously viscous-sinters above ~1100 degC, sealing defects and forming a low-conductivity (k<0.1 W/mK) radiative/convective barrier. Target protected core density: 0.08 g/cm3 with retention of >50% compressive strength after 30-min ASTM E119 exposure. Critical design parameter is allowable pinhole density per cm2 vs. shell thickness -- set by coupon-level burn-through tests.

Why Novel

No prior ultralight composite deliberately exploits combustion as a densification mechanism by pre-engineering a silica shell thick enough to sinter in situ while the carbon core ablates. The diatom-frustule nano-templating of crack-deflection paths within a sol-gel matrix at this length-scale hierarchy has no direct precedent in structural composite literature.

Buildability

All three fabrication steps--FDM/DIW printing of lignin-PLA lattices, bench-scale pyrolysis at 800-1000 degC, and alternating vacuum-pressure sol-gel infiltration with electrophoretic seeding--use commercially available equipment available in a well-equipped materials lab. The primary buildability challenge is achieving uniform TEOS infiltration beyond ~15 mm lattice depth, which can be addressed iteratively with pressure cycling protocols before scaling.

Why Feasible

* Build path needs validation (feasibility=4/10)
* Core hypothesis testable quickly (testability=6/10)

Top Risks

* Silica shell delamination and cracking under cyclic vibration or impact loading due to CTE mismatch with the biochar core (~3x difference), causing premature structural failure below design load
* Residual oxygen in the pyrolysis atmosphere or during sol-gel cure oxidizes the biochar struts, reducing compressive strength by an estimated 40-60% and undermining the carbon-core contribution
* Electrophoretic deposition conformality degrades exponentially with lattice depth beyond 10 mm, creating a density gradient that violates the uniform 0.08 g/cm^3 target and introduces failure initiation sites

Decisive Test (MDE)

Hypothesis: A 4-cycle sol-gel + EPD silica-coated biochar lattice (0.08 g/cm3) will retain >=50% compressive strength and limit backside temperature rise to <180 degC after 15 min of one-sided 1000 degC propane exposure, with mass loss <=25% -- outperforming uncoated biochar lattices by >=3x on each metric.
Setup: Fabricate 12 lattice cubes 50x50x25 mm: 4 uncoated biochar, 4 coated (4 cycles), 4 coated with engineered pinholes (laser-drilled 200 um holes at 1, 5, 25/cm2). Mount each on insulating board with K-type thermocouples on backside center and 4 corners. Expose front face to calibrated propane burner producing 1000 +/- 50 degC surface flux (~50 kW/m2) for 15 min. Pre/post weigh; pre/post uCT; post-burn quasi-static compression to failure on Instron at 1 mm/min.
Instrumentation: Calibrated propane burner with heat-flux gauge (Schmidt-Boelter), 5x K-type TCs + datalogger (1 Hz), analytical balance (0.1 mg), desktop uCT (50 um voxel), UV light box + DSLR for fluorescence pinhole mapping, Instron 5kN, IR camera for front-face uniformity.
Kill Criteria: Concept killed if: coated samples show >40% mass loss OR backside deltaT >300 degC in 15 min OR <25% retained compressive strength OR uCT reveals <60% strut coating coverage after 4 cycles OR 5/cm2 pinhole density already collapses performance to uncoated baseline.
Rescue Pivot: If through-thickness coating fails, pivot to thin (<10 mm) coated skins bonded to an uncoated biochar core (sandwich panel), or replace sol-gel with chemical vapor infiltration of SiO2/SiC for thicker conformal

coverage; alternatively retain only the diatom-loaded silica aerogel as a standalone insulator without the lattice.
Cost: $8k-$15k (consumables ~$2k; burner rig ~$3k; uCT access ~$2k; Instron access ~$1k; labor 6-8 wks)
Time to Signal: 6-8 weeks from start; first burn data by week 5

Refinement Deltas

Risks Addressed:

* Sol-gel shrinkage (20-40%) during drying will crack thick conformal coatings on a rigid biochar substrate, guaranteeing pinholes regardless of QC.
* Diffusion-limited infiltration means inner struts of any lattice >15 mm thick will be starved of silica; vacuum/pressure cycling cannot beat the Damköhler number for the gelation kinetics.
* Once residual carbon oxidizes in service (even slowly via pinholes), the load path becomes a fragile silica shell -- robustness collapses non-monotonically with age.

Red-Team:

* Challenge: Sol-gel shrinkage (20-40%) during drying will crack thick conformal coatings on a rigid biochar substrate, guaranteeing pinholes regardless of QC.
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* Challenge: EPD on a non-uniform-conductivity carbon lattice produces field crowding at strut junctions, depositing thick at nodes and thin on strut midspans -- exactly where bending stress peaks.
* Challenge: Manufacturing throughput (3-5 cycles x 24 h gel + dry each) implies >1 week per part; cost per m2 will not compete with gypsum board or mineral-wool sandwiches at any plausible performance margin.

Budget Ranges

Prototype: $8,000-$15,000 (desktop DIW printer, tube furnace rental, TEOS/MTES reagents, Stöber silica synthesis, SEM/uCT characterization of 10-20 coupons)
Pilot: $60,000-$120,000 (dedicated pyrolysis furnace, pressure-cycling infiltration chamber, EPD cell scaled to 100x100 mm panels, mechanical test suite, 6-month materials engineer salary)
Scale: $800,000-$2,000,000 (continuous-feed pyrolysis tunnel, industrial autoclave infiltration line, automated EPD bath, QC uCT scanner, pilot production of 1 m^2 panels for aerospace/construction qualification)

30/60/90 Plan

Day 30: Fabricate and pyrolyze 5 lignin-PLA lattice geometries (1-3 mm strut pitch) at 800 degC and 1000 degC; measure mass yield, density, and compressive modulus; select optimal pyrolysis condition and strut geometry for silica infiltration trials
Day 60: Complete 3 rounds of vacuum-pressure TEOS/MTES sol-gel infiltration on selected lattice geometry; characterize shell thickness, porosity, and conformality via SEM and uCT; run first EPD seeding trials at 5, 10, and 20 V/cm; identify depth-uniformity limit and propose pressure-cycling protocol fix
Day 90: Produce 3 diatom-frustule-doped composite coupons at target 0.08 g/cm^3; measure specific compressive strength, modulus, and conduct bench-scale fire test (700 degC, 5 min) to observe in-situ sintering behavior; deliver go/no-go recommendation with failure mode map and revised risk register
Dominance Axis: higher_perf -- Continuous verified silica exoskeletons can protect lattice struts at low mass when defect density is controlled.

Build-First

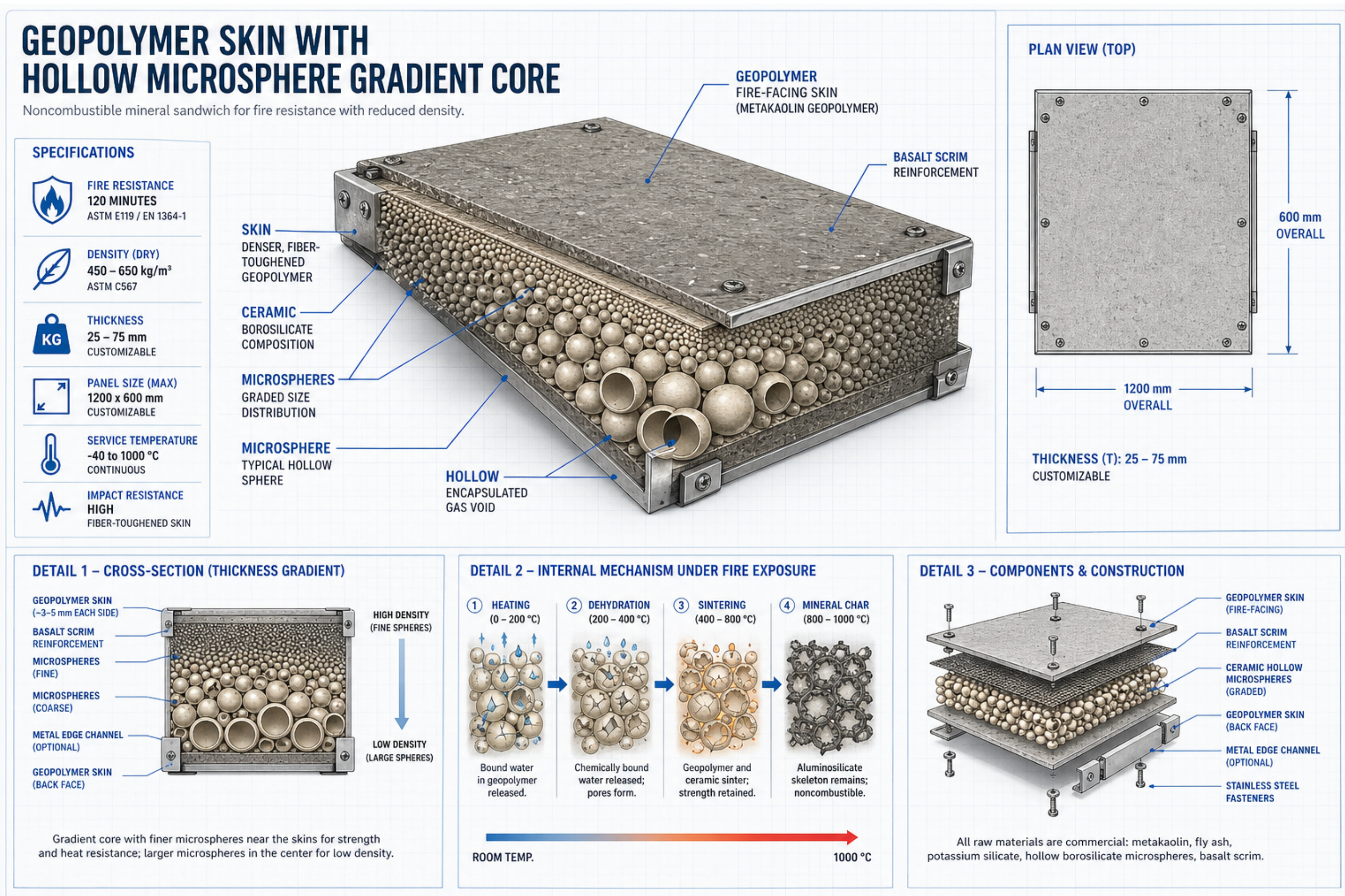
Geopolymer skin with hollow microsphere gradient core

novelty: 4 | feasibility: 8 | economic_leverage: 6 | testability: 9 | robustness: 7 | constraint_fit: 9 | explainability: 9

Overall: 7.4 / 10 -- Very Strong

Constraint Compliance: Compliant (constraint_fit=9)

A metakaolin/fly-ash geopolymer sandwich panel integrates hollow ceramic microspheres in a graded core to achieve ~0.65 g/cm^3 bulk density while retaining a dense, fiber-reinforced skin that resists flame erosion and forms a stable mineral char. This matters because passive fire barriers in vehicles, rail, and modular construction demand noncombustible, lightweight panels that survive mechanical handling without foam or polymer binders that off-gas toxically under heat.



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

Mechanism

A cast sandwich-like fire barrier: 0.5-1.5 mm dense geopolymer face skins on one or both sides, transitioning to a 5-25 mm low-density graded core. Binder is metakaolin/fly-ash aluminosilicate activated with potassium silicate plus 5-15 wt% colloidal silica; target Si/Al ~1.8-2.4 and water/solids low enough for casting but not sphere crushing. Core contains 25-60 vol% hollow ceramic or borosilicate microspheres, graded from low loading near the hot face to higher loading toward the cold face, targeting ~0.65 g/cm3 core density. Hot skin includes 1-3 wt% chopped basalt, alumina-silica, or zirconia fibers, 3-6 mm length, plus 50-150 gsm alkali-resistant glass or basalt scrim set ~0.5 mm below the surface for handling and impact toughness. In fire exposure, the dense skin resists flame erosion and particle shedding; bound/interlayer water release consumes heat and delays temperature rise; the aluminosilicate network dehydrates and partially sinters into a ceramic-like skeleton. Hollow microspheres lower solid conduction, interrupt radiative transfer by scattering, and reduce heat capacity penalty. The gradient reduces thermal-stress mismatch: dense, tougher hot face handles impingement and abrasion, while the porous core supplies insulation. Potassium/colloidal-silica activation plus warm cure at 60-80 degC accelerates early strength and reduces moisture sensitivity versus ambient-cured geopolymer.

Why Novel

Grading the microsphere volume fraction continuously from hot-face to cold-face within a single cast geopolymer body--rather than bonding discrete layers--eliminates delamination interfaces and allows the thermal gradient to align with the density gradient, a combination not present in commercial geopolymer or calcium silicate board products.

Buildability

All raw materials (metakaolin, fly ash, potassium silicate, hollow borosilicate microspheres, basalt scrim) are commercially available from multiple suppliers at industrial scale, and the casting process is compatible with existing precast concrete equipment with minor mold and mixing modifications. Cure at 60-80 degC for 8-16 hours achieves handling strength, avoiding expensive autoclaving.

Why Feasible

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

Top Risks

* Microsphere crushing during high-shear mixing collapses porosity and raises density above target, requiring low-shear paddle mixing with strict RPM and time controls
* Residual moisture trapped in the porous core generates steam pressure spikes above 300 degC, risking delamination or spalling on rapid fire exposure
* Vibration-induced brittle fracture at the skin-to-core transition zone due to elastic mismatch between dense and porous geopolymer phases

Decisive Test (MDE)

Hypothesis: A graded microsphere geopolymer panel at <=0.9 g/cm3 total density can keep the cold face below a target temperature during direct flame exposure while surviving handling shock/vibration without through-cracking or major mass loss.
Setup: Fabricate at least 6 coupons, e.g. 150 x 150 x 10-15 mm: dense control, uniform microsphere core, and graded core with scrim/fibers. Expose hot face to propane/MAPP torch or burner calibrated to ~900-1100 degC flame for 10-20 min at fixed standoff. Mount vertically with edges insulated similarly for all samples. Precondition half the samples with 24 h humidity exposure, then run drop test from 1 m onto plywood/steel edge and 1 h random vibration or orbital sander fixture before torch testing.
Instrumentation: K-type thermocouples on hot face and cold face, IR camera or IR thermometer, mass before/after, calipers for thickness change, density by volume/mass, visual crack mapping, optional 3-point bend before/after fire, accelerometer for vibration fixture.
Kill Criteria: Kill if graded panels do not outperform a same-thickness dense geopolymer or simple calcium-silicate/mineral-wool reference on cold-face temperature at comparable areal mass, or if mechanical preconditioning causes through-cracks/spallation that invalidates fire performance.
Rescue Pivot: If brittle failure dominates, reduce microsphere fraction near skins, increase scrim count, switch to longer basalt/ceramic fibers, add a thin stainless/basalt mesh, or use a hybrid with geopolymer hot face bonded to mineral wool/aerogel blanket. If cure/moisture is the issue, adjust activator modulus, add colloidal silica, extend

warm cure, or introduce a low-cost silane/sealer on non-fire-facing surfaces.
Cost: $500-$2,500 using shop-scale materials, consumer torch/burner, thermocouples/data logger, oven access, and simple drop/vibration fixtures.
Time to Signal: 3-7 days including cure; first thermal signal within one torch test day.

Refinement Deltas

Risks Addressed:
* Geopolymers can be moisture-sensitive and alkali-rich; uncured or partially cured panels may weaken during vehicle storage or humid cycling.
* Hollow microspheres reduce conductivity but also crush during mixing and create crack initiators under vibration.
* Thermal shock may delaminate the dense skin from the porous core, especially with steep density gradients.

Red-Team:
* Challenge: Geopolymers can be moisture-sensitive and alkali-rich; uncured or partially cured panels may weaken during vehicle storage or humid cycling.
* Challenge: Hollow microspheres reduce conductivity but also crush during mixing and create crack initiators under vibration.
* Challenge: Thermal shock may delaminate the dense skin from the porous core, especially with steep density gradients.
* Challenge: Bound-water release helps initially but can drive steam pressure, bloating, or spallation if permeability is too low.
* Challenge: Low-cost competitors such as calcium silicate board, mineral wool, mica, intumescent mats, or ceramic fiber paper may match fire performance with simpler qualification paths.

Budget Ranges

Prototype: $8,000-$18,000 (lab mixing equipment, mold fabrication, raw materials for 20-40 sample panels, cone calorimeter and flexural testing)
Pilot: $60,000-$120,000 (semi-automated casting line, full EN 1363 / ASTM E119 fire testing, vibration and impact qualification, QC instrumentation)
Scale: $400,000-$900,000 (dedicated production line, mold inventory for 3-5 panel formats, supply chain qualification, building/rail certification campaigns)

30/60/90 Plan

Day 30: Finalize binder chemistry (Si/Al ratio, water/solids, colloidal silica loading); cast 10-15 flat coupons at three microsphere volume fractions (25%, 40%, 60%); measure density, open porosity, and compressive strength; select baseline formulation at or below 0.65 g/cm^3 without sphere crushing
Day 60: Fabricate graded-core sandwich panels (300x300 mm) with basalt scrim skins; run cone calorimeter (ISO 5660) at 50 kW/m^2, three-point bend, and drop-weight impact tests; iterate fiber loading and cure profile to close toughness gap; document failure modes at skin-core interface
Day 90: Produce six full-format panels (600x1200 mm) using low-shear pilot mixer; conduct small-scale furnace fire test (ISO 834 curve, 60 min), vibration sweep per IEC 60068-2-6, and moisture conditioning cycle; deliver performance report with go/no-go recommendation for pilot line investment
Dominance Axis: cheaper -- Remains a low-cost castable fire barrier, now better suited to vehicle handling and vibration with modest mass penalty.

Top Uncertainties & Assumptions

* Aerogel particle compaction under 10-year EV vibration spectrum degrades thermal resistance by an unknown but potentially significant margin before first runaway event
* Geopolymer hot-skin microcracking during pack assembly torque cycles or first thermal shock creates preferential gas-channeling paths that short-circuit the propagation delay
* Landed cost per panel exceeds mica-sheet incumbent by >3x at pilot volumes, blocking OEM adoption before scale economies are demonstrated
* Silica shell delamination and cracking under cyclic vibration or impact loading due to CTE mismatch with the biochar core (~3x difference), causing premature structural failure below design load
* Residual oxygen in the pyrolysis atmosphere or during sol-gel cure oxidizes the biochar struts, reducing compressive strength by an estimated 40-60% and undermining the carbon-core contribution

C4.38 L1 T226,103