High-Performance (R-10/inch) Clay-Cellulose-Silica Nanopore Insulation for New and Retrofit Buildings




Liatris, Inc.
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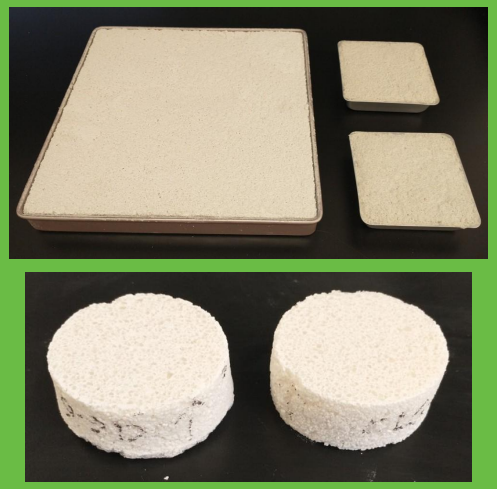
DE-EE0009700

Project Summary

Objective and outcome

- Leverage primarily inorganic nanocomposite of cellulose/clay/silica, and increase thermal performance to reach **R-10 / inch at competitive cost vs. polyiso; ambient dried aerogels + industrial-scale foaming processes**
- Readily suitable for both retrofits, where thinner insulation significantly reduces complexity of trimming around windows and doors, and new builds
- Meet key industry requirements by being easy to install (drop-in replacement for foam; fastenable), nonflammable (Class A or above), and moisture-resistant



Team and Partners

Dr. Arthur Jing-Min Yang, CTO & PI – 35+ years in insulation R&D; ran Armstrong insulation R&D & ISTN (DOE awardee; licensor)

Dr. Lida Lu, Senior Research Scientist – 25+ years in building and industrial materials R&D

Frank Yang, President & CEO – 15+ year founder and CEO in clean energy space and advisor to DOE ABC Collaborative and IMPEL+

Partners:

-- Sto Corp. – Atlanta, GA

-- Dvele – La Jolla, CA

-- Auburn University – Auburn, AL

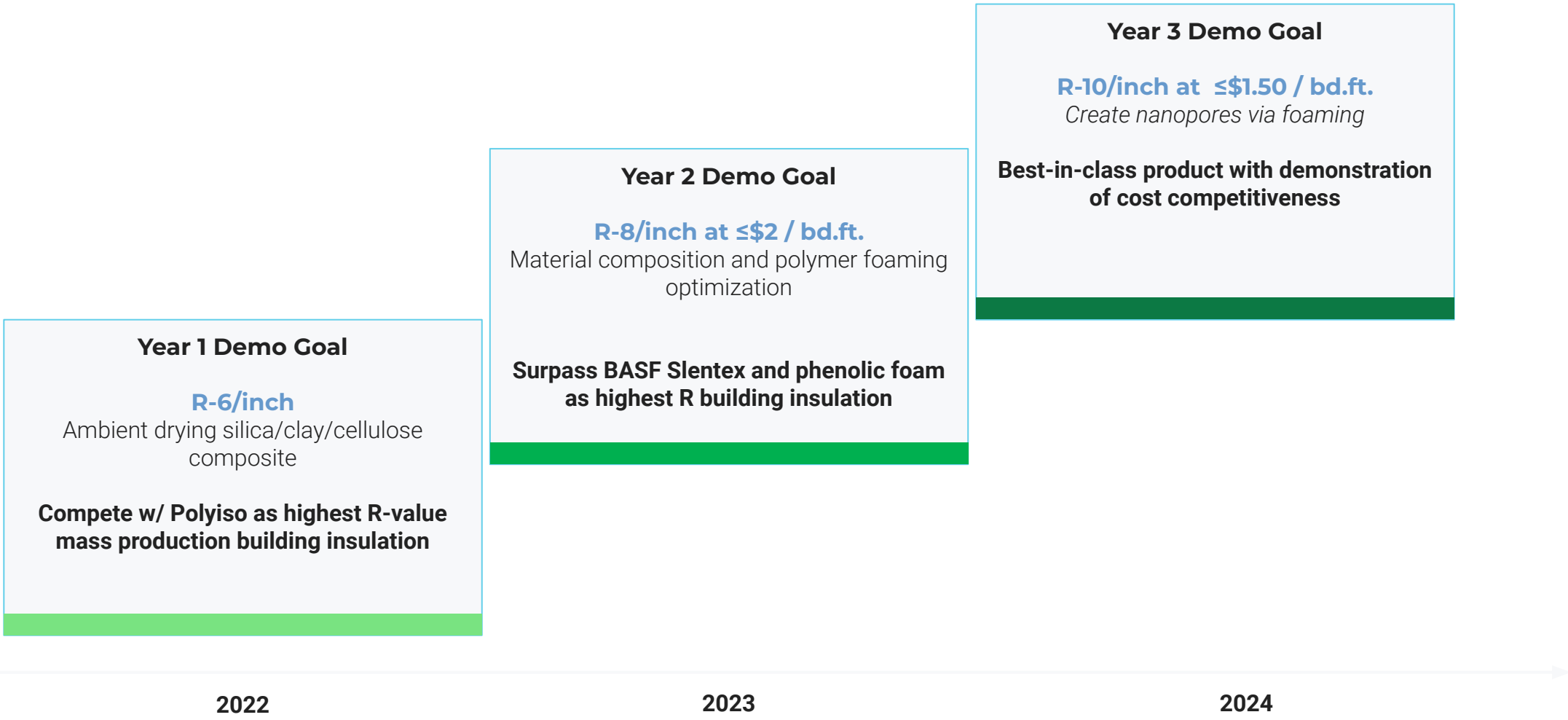
Stats

Performance Period: 10/1/2021 - 9/30/2024

Federal: $1,659,850; Cost Share: $555,000

- Milestone 1: Lab samples > R-6 / inch
- Milestone 2: 1 sq. ft. sample > R-8 / inch
- Milestone 3: >R-10/ Inch; $1.50 / bd. ft.

Project Roadmap



PROBLEM

Problem

Key opportunity to improve 70+ year old tech dominating >$50B global insulation industry:

- Low-income households spend ~17% of their income on heating and cooling annually, compared to only 3.5% for non-low-income
- Average age of residential US building stock is 39 years; ~90% of buildings in US are under-insulated
- Fiberglass & mineral wool difficult to install; higher performance insulation has high cost and/or high embodied carbon
- Liatris is developing a primarily inorganic composite super-insulation with competitive cost / R versus commodity products

Cost / Performance Comparison of Major Building Insulation Technologies									
	Spray-In	Foam-Based Boards				Fiberglass / Mineral Wool		Liatris (production scale)	
	Spray Foam	EPS	XPS	Polyiso	Phenolic	Fiberglass	Min Wool	Gen 1	Gen 2
$ / bd ft	$1.00	$0.38	$0.40	$0.70	$1.10	$0.45	$0.70	$0.50	$1.00
Nominal R-value/in	5.5	3.8	5.0	6.3	7.5	3.5	4.3	>5.0	>10.0
$ / R / bd ft	0.18	$0.10	$0.08	$0.11	$0.15	$0.13	$0.16	$0.10	$0.10
Fire / Smoke Protection									
Mechanical Strength									
Water Protection									
Health / Safety									

Customer Problem Statement from Market Discovery

"Right now ***our biggest focus is identifying nature based, non-flammable insulations*** to accompany our carbon negative building envelopes"

Hal Hinkle, CEO, BAMCORE (e-mail outreach to DOE ABC representative)

- **Ex. Goldman partner; >$40M VC raised for bamboo structural panels; ARPA-E HESTIA awardee**

BAMCORE®

ALIGNMENT & IMPACT

Impact and Outcomes

Insulation represents one of the fastest payback decarbonization opportunities:

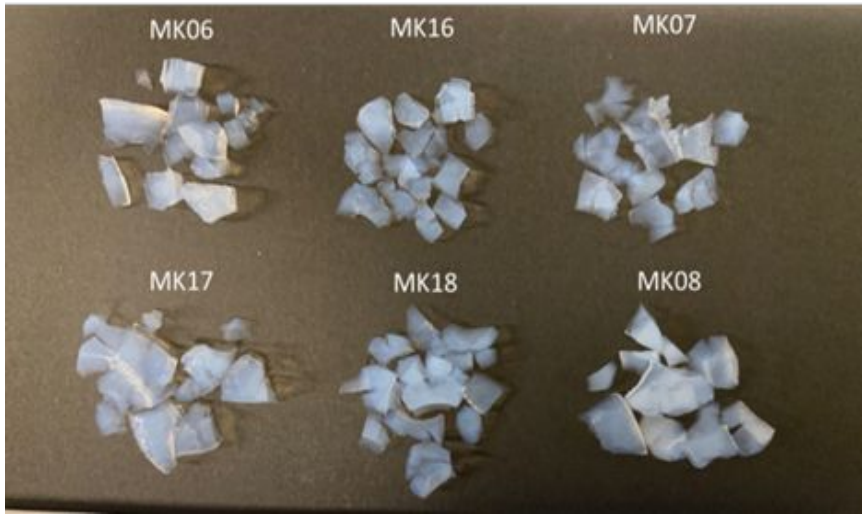
- R-10 / inch will allow higher total R-values in buildings with thickness constraints such as high-rise commercial and multi-family buildings (including in areas like NYC with foam insulation bans)
- Based on 2040 opportunity of 3.3 quads and 40% better performance vs. Polyiso, **the potential performance-based savings is 1.65 quads per year, reducing 8.7B metric tons of CO_2 per year**
- Simple payback period <2 years for both residential and commercial based on US gas / utility costs

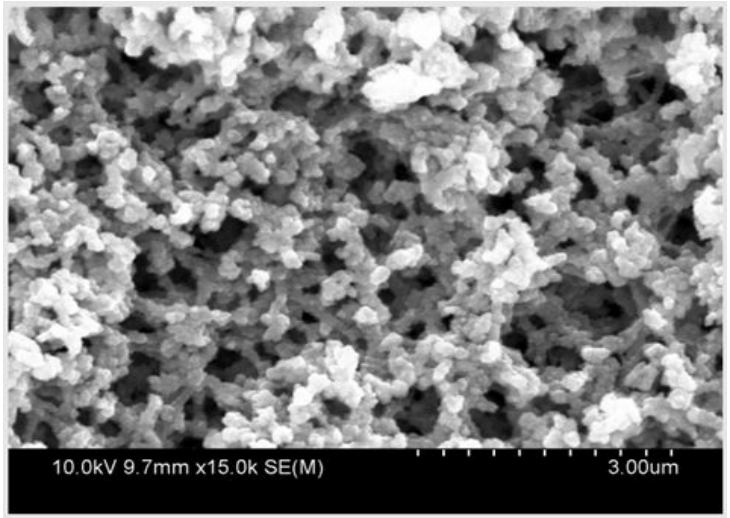
		Liatris (production targets)	
	Polyiso	**Gen 1**	**BENEFIT Initial**
Price / board ft	$0.80 - $1.00	$0.60 - $0.75	$1.60 - $1.80
Cost / board ft	$0.60 - $0.80	$0.50	$1.50
Nominal R-value/in	6	5.0	10.0
Price / R / bd ft	$0.16	$0.12 - 0.15	$0.16 - $0.18
Cost / R / bd ft	$0.10 - 0.15	$0.10	$0.15
Fire / Smoke Protection			
Mechanical Strength			
Water Protection			
EHS			

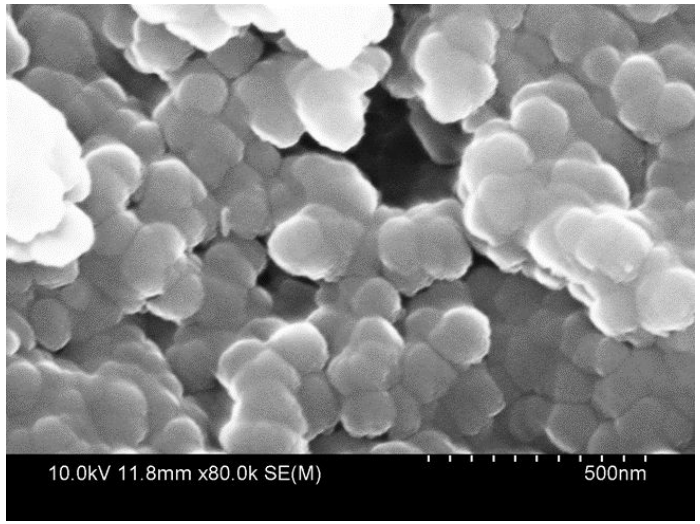
APPROACH

Ambient Dried Silica Aerogels Key to R&D Approach

- Liatris has **successfully produced ambient dried aerogels with R-values >7.5 / inch**
  - Started with MTMS & TEOS pre-cursors demonstrated in prior work; transitioning to even lower-cost commodity approaches (e.g. sodium silicate)
  - Proprietary surface hydrophobization process addresses prior shrinkage issues
  - Aerogel exhibits critical performance properties which show path toward R-10
    - >500 m2/g, pore size <20 nm, density below 0.10 g/cc, porosity @ 96%
  - Clay has been successfully added into the aerogel to reduce the cost while maintaining porosity >93%

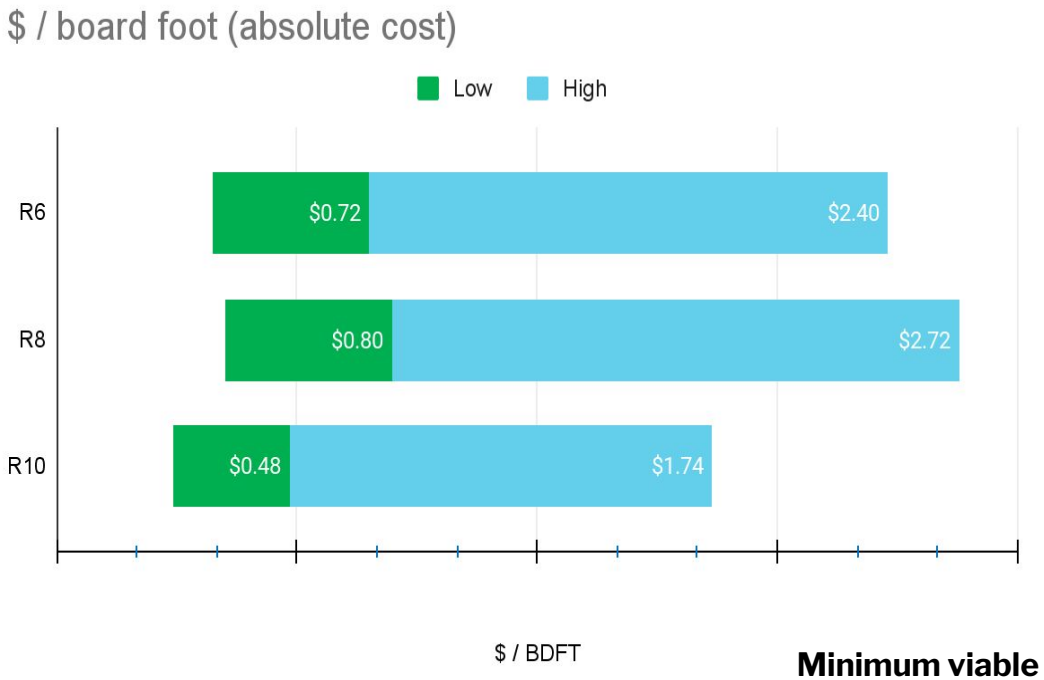


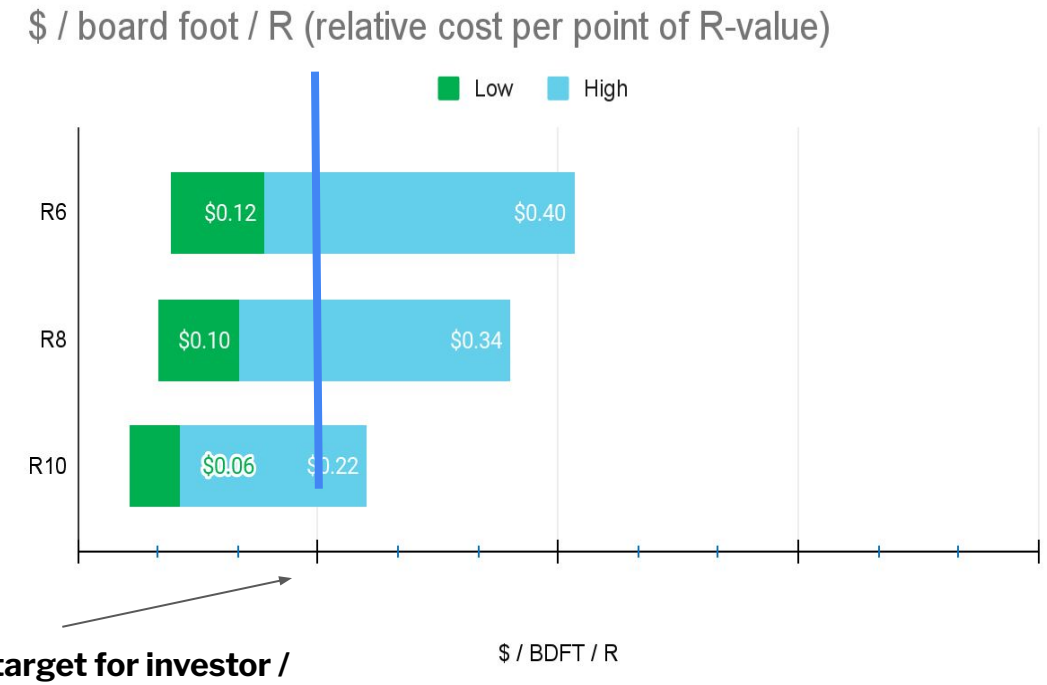




Cost Viability Validated Through Bottoms-up TEA

- Insulation manufacturing costs are heavily driven by direct materials; we have conservatively evaluated the current MTMS / TEOS approach for economic feasibility
  - Potential contribution margin (price - material cost) from manufacturing must be competitive on cost / R basis versus existing insulation
  - Small-scale processing must be compatible with scale-up on industry standard tools

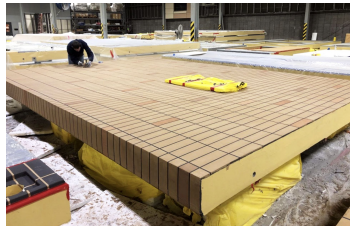




Minimum viable target for investor / strategic partner (contribution margin) interest in scale-up

Scale-up Approach Leverages Existing Platforms

- In two prior DOE awards @ ISTN (DE-EE0003983; DE-EE0006349), Dr. Arthur Yang & team (ISTN - technology licensed to Liatris) produced HFC-free XPS insulation with clay additives using CO2 foaming; our approach starts with controllable batch processes while leveraging lab-scale extrusion to build foundation for continuous, in-situ processing



Casting (exploratory concept)

Mechanically frothed aerogel composite could be poured into mold; casted mixture would cure within several hours (panel drying would take several days).

Hot Press Molding

Molding (EPS manufacturing process) allows for more controllable batch process which enables us to fine-tune process conditions more easily and reduce material waste.

Extrusion Foaming

Extrusion foaming (XPS manufacturing process) will provide highest automation / throughput and lowest cost of production.

Planned Commercialization / Partnering Approach

Partnering model utilized by largest manufacturers(e.g. Taiwan Semiconductor, Volkswagen) for private label start-up relationship; partner actively for both production and sales

LIATRIS

- Provides tech license; JDA to support mfg
- Market-specific mfg and sales rights
- May act as seller of and/or help co-brand in select niche markets, if needed

IP / know-how
Product forecast

Investment / license
Fixed price product

Product sales

Payment

Manufacturing & Sales Partner

- Provides capital and market reach
- Some product and region exclusivity
- Internal purchase at transfer price
- May sell to Liatris at fixed price

OEM Sales Partners

- Buys product; sells system into additional markets
- Case-by-case exclusivity / MFN
- Provides customer support

LIATRIS

Comprehensive Stakeholder Engagement Efforts

Through our DOE & NSF funded research work, as well as various state and local assistance programs (e.g. ExportMD, MD Global Consulting), our team has engaged >150 key industry stakeholders in the last 18 months to build a foundation for scale-up

***Goal**: continue to validate product demand & economics; proactively establish industry presence and thought leadership within limited resources, to lay groundwork for larger-scale growth discussions as scaling progresses*

***Key findings:** inbound investment interest and market discovery work continues to align with core value proposition; ramp up engagement with largest building developers / owners to increase market pull beyond OEMs*

Investors

khosla ventures

BLACKHORN VENTURES

Breakthrough Energy

ENERGY IMPACT PARTNERS

Baruch FUTURE VENTURES

Scale-up Partners

Georgia-Pacific

sto

Building with conscience.

Kingspan

Johns Manville

End Users

DVELE

VOLUMETRIC BUILDING COMPANIES

MIGHTY BUILDINGS

BOXABL welcome home

Academia

MIT ENERGY & CLIMATE CLUB

Harvard Business School

Stanford ENGINEERING
Building Decarbonization Learning Accelerator

UNIVERSITY OF MARYLAND 1856

State / Local

MONTGOMERY COUNTY ECONOMIC DEVELOPMENT CORPORATION MARYLAND

MARYLAND ENERGY INNOVATION ACCELERATOR

Maryland Project Restore

tech
Maryland Industrial Partnerships

MARYLAND TECHNOLOGY INTERNSHIP PROGRAM

Multiple Scale-up Paths in Discussion for 2024 Pilot

Liatris has potential scale-up paths via 1) non-combustible product for exterior insulation; 2) high-R product using EPS molding and 3) high-R product using XPS extrusion; we have created healthy interest among multiple partners to take this technology to market

	Exterior Wall Panel	Insulation / Other High Vol Bldg Materials	Emerging Construction	VCs
Existing Partner	sto Building with conscience.	GP Georgia-Pacific; BASF We create chemistry; ROCKWOOL	VOLUMETRIC BUILDING COMPANIES; BAMCORE; NEXII; MIGHTY BUILDINGS	khosla ventures; Breakthrough Energy; ENERGY IMPACT PARTNERS; G2 VENTURE PARTNERS
Probability	>80%	>60%	>70%	NA / TBD
Timing	~1 Year	>1 Year	<1 year	NA / TBD
Amount	$250K to $1-2M	$250K to $4-5M	$100K to $1M	NA / TBD
Comment	Sto is Liatris's first committed customer and a project sub-recipient; they are testing 1 sq ft prototypes and showing C-level strategic interest; other competitors interested as well	Several incumbent manufacturers have shown interest; we are negotiating a JDA with a major foam insulation manufacturer not shown here (NDA)	We are finalizing scale-up proposals to two large modular construction firms who want to place insulation manufacturing lines in their facility	Though we currently anticipate scaling up with strategic partners, two of the largest VC investors in climate & sustainability have made unsolicited investment offers

PROGRESS & FUTURE WORK

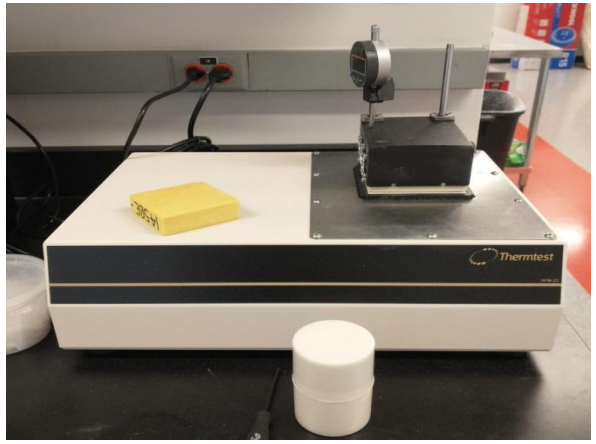
Project Progress On Track @ Halfway Point

	Budget Pd 1				Budget Pd 2				Budget Pd 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1.0 - Project Management	■	■	■	■	■	■	■	■	■	■	■	■
Task 2.0 - Ambient Drying												
Subtask 2.1 - Incorporate nano-cellulose w/ clay/silica	■	■	■									
Subtask 2.2 - PS-cellulose/clay/silica/silicone composite		■	■	■								
Subtask 2.3 - Ambient drying of cellulose-clay-nanogel		■	■	■								
Subtask 2.4 - Pressure vessel foaming of composite			■	■								
Task 3.0 - Integration with Supercritical Foaming												
Subtask 3.1 - Incorporate modified silica, siloxane				■	■	■	■	■				
Subtask 3.2 - Qualify pilot processes and equipment					■	■	■	■				
Task 4.0 - Increase Nanopore Content to Reach R-10 / In												
Subtask 4.1 - Preparation of foaming batches								■	■	■		
Subtask 4.2 - Design equipment retrofit for pilot							■	■	■			
Subtask 4.3 - Foaming pilot product w/ hot press mold									■	■	■	■

Barriers - Technical Challenges - Risks

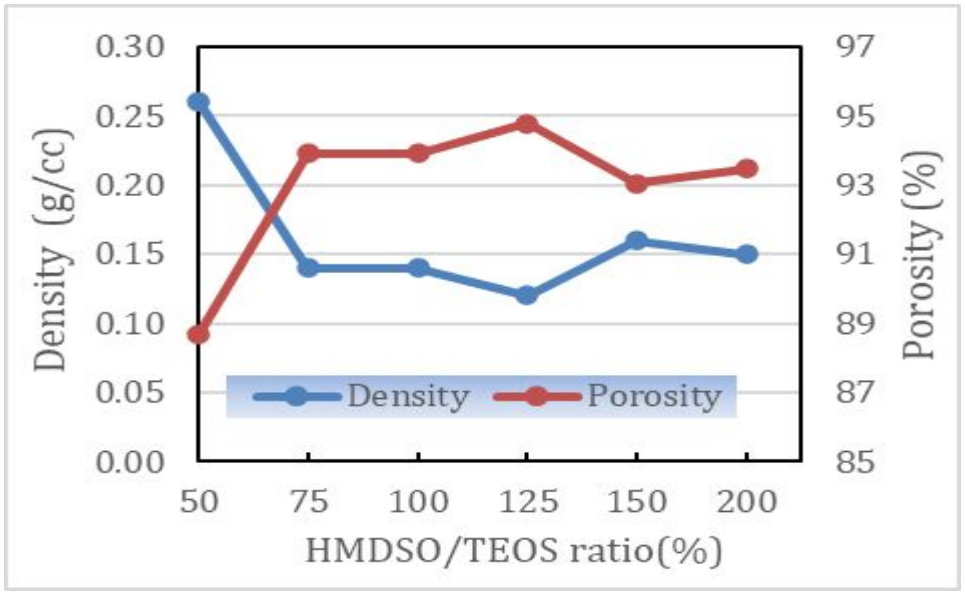
- Balancing the strong thermal performance of aerogels with cost and critical field validation properties of the material (mechanical strength, moisture, etc.) remains challenging despite some key first-in-kind advancements. Liatris has maximized internal cycles of learning by leasing a 5,000 SF dedicated lab facility and utilizing out-of-pocket (non-DOE) funding to buy key equipment such as thermal conductivity testing. We are starting to run a lab-scale extruder that is a key process validation tool but has been delayed significantly due to various COVID-19 related supply chain issues. We expect continued progress in the last 18 months and have been proactively engaging industrial partners to phase out the most critical scale-up risks.

Challenge / Risk	**Near-Term Impact**	**Mitigation Tactic**
Cost and time required for surface hydrophobization	Product is only cost-effective at very high R-values	New surface treatment processes (e.g. in-situ)
Limitations on clay and cellulose content	Limits embodied carbon and product cost reductions	In-house cellulose extrusion; vary clay types to increase loading
Oven drying of silica aerogels done in-house at lab scale	Restricts volume of internal sample production	Multiple industrial partner convos; increase non-aerogel content while maintaining high performance



Aerogel Property Improvement

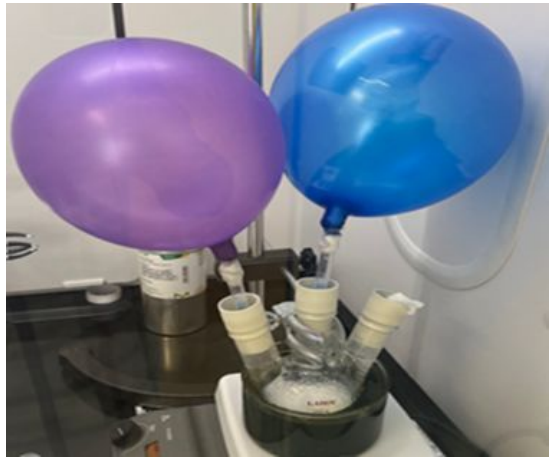
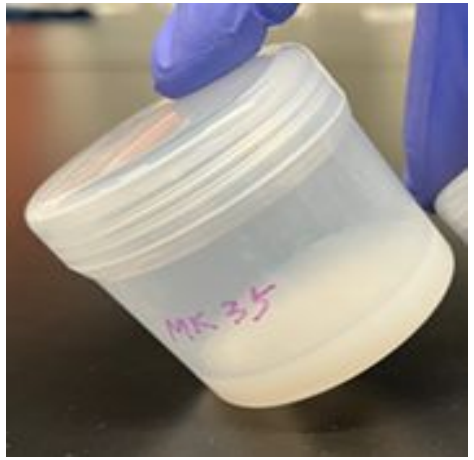
- Continue to optimize cost and performance of silica aerogels
  - Implement various formulation improvements including using optimum surface modification agent level, ammonia silicate, heat aging, etc.
  - Utilize in-situ surface hydrophobization process to allow for reduced number of process steps / usage of process fluids
  - Continue to increase ratio of clay filler in aerogel to reduce the cost while maintaining high porosities



Aerogels reinforced with clay

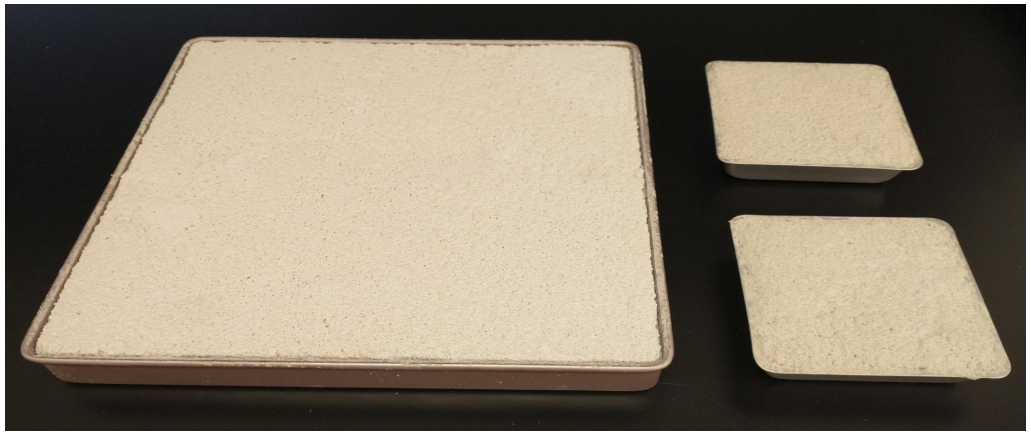
Aerogel Composites with Embedded Polystyrene

- Integration of a small ratio of embedded polystyrene (<20%) will be key for R-value improvements as well as compatibility with extrusion processing
- PS-aerogel composite via two step process
  - Polystyrene particles are produced to via emulsion polymerization
  - PS particles are added into the silica precursor solution
  - PS-aerogel composite is produced via gelation, aging, hydrophobization, and final ambient drying
- PS-aerogel composite via in-situ process
  - Styrene emulsion is produced in the silica precursors
  - Silica gelation of polymerization takes place simultaneously


Composite Prototype Scale-up

- We have successfully made 1 sq. ft. product prototypes which are being shipped to Sto and other customers / end-users for testing
  - Non-combustible insulation development with Sto funded prior to DOE BENEFIT has resulted in non-combustible composite insulation with density <10 lb/cu ft @ R-4 / inch with no aerogel; testing >R-5 / inch products for ASTM E136
  - Successfully produced composites with clay/cellulose <8 lb/cft @ R-6.2 / inch; key breakthrough for inorganic composite insulation
  - Utilizing in-house aerogels to produce higher R-value composites; leveraging both bench-top extruder in lab and toll producer relationships to explore super-insulation scale-up



Continue Following Disciplined / Staged GTM Plan

Commercialization: Three viable paths towards product scale-up

1. First product in exterior wall panel market with Sto or competitor, including manufacturing investment. Sto has affiliated operations in EPS insulation; mechanical foaming requires minimal initial capital investment and can be proven quickly; has throughput / volume limitations for larger scale ramp-up
2. Engage faster-moving industrialized construction (e.g. modular / prefab) players in highest growth market segments; alternative opportunity to combine demand + EPS insulation footprint (smaller scale / less centralized)
3. Build foundation for larger scale partnership with incumbent insulation producer that could best help Liatris reach true mass production scale with low or no customer acquisition cost; XPS partnership opportunity

Market Transformation: Gradual approach to supplementing existing insulation options

1. Capture initial market share as mineral wool alternative: First product in exterior wall market, R-4 / inch with ASTM E-136 fully non-combustible rating will be an attractive supplement to mineral wool products as is it easier to install, non-toxic, and non-combustible
2. Enter residential and commercial building applications where EPS and XPS is typically utilized: Through commercialization efforts of >R-6 / inch board insulation with low aerogel content, we can provide distinct differentiation vs. both XPS and EPS @ R-4 to R-5 / inch with higher embodied carbon.
3. Surpass polyiso (and phenolic / spray foam) benchmarks outlined in original FOA: Once commercialization of R-8 / inch and higher is achieved, we can target higher performance / lower cost sensitivity markets such as net-zero construction

Thank You

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Team

Liatris has a lean but experienced team led by insulation domain experts who have cradle-to-grave product development experience taking building and energy technologies from concept stage to field deployment. We have 4 Ph.D.'s and 2 M.S.'s, all with significant composite and polymer materials experience, on staff.

- Dr. Arthur Jing-Min Yang, Co-Founder & CTO (PI) – Dr. Yang is the full-time CTO of Liatris and founded ISTN (from which Liatris licensed its technology) in 1997. He served as Director of Insulation Research for Armstrong (later Armacell), where he managed a 15-person team and won the first federal grant for "super-insulation" (ATP - $4.5M – 1992).
- Frank Yang, Co-Founder & CEO - Frank has 15+ years' experience bringing new materials to market as a company operator, as well as leading technology scaling activities for DOE initiatives such as the ABC Collaborative and NREL's American Made Challenges through his role as a Partner at ADL Ventures
- Dr. Lida Lu, Director of R&D – Dr. Lu is an experienced polymer scientist and product development engineer with >25 years at Ardax, ISTN and Armstrong / Armacell developing composite building materials. He has expertise in novel insulation technologies as well as leading product development adhesives, ceiling, floor tile, etc.
- Shiao-Ying Fang, Director of Product Management – Shiao-Ying has been part of Liatris's founding team since 2018 assisting with various aspects of business development and product marketing. She previously led new product development efforts in the solar, water treatment, and semiconductor industries and has 20 years of work experience overall including helping found / launch 5 companies.




***All individuals working on the project are U.S. citizens**