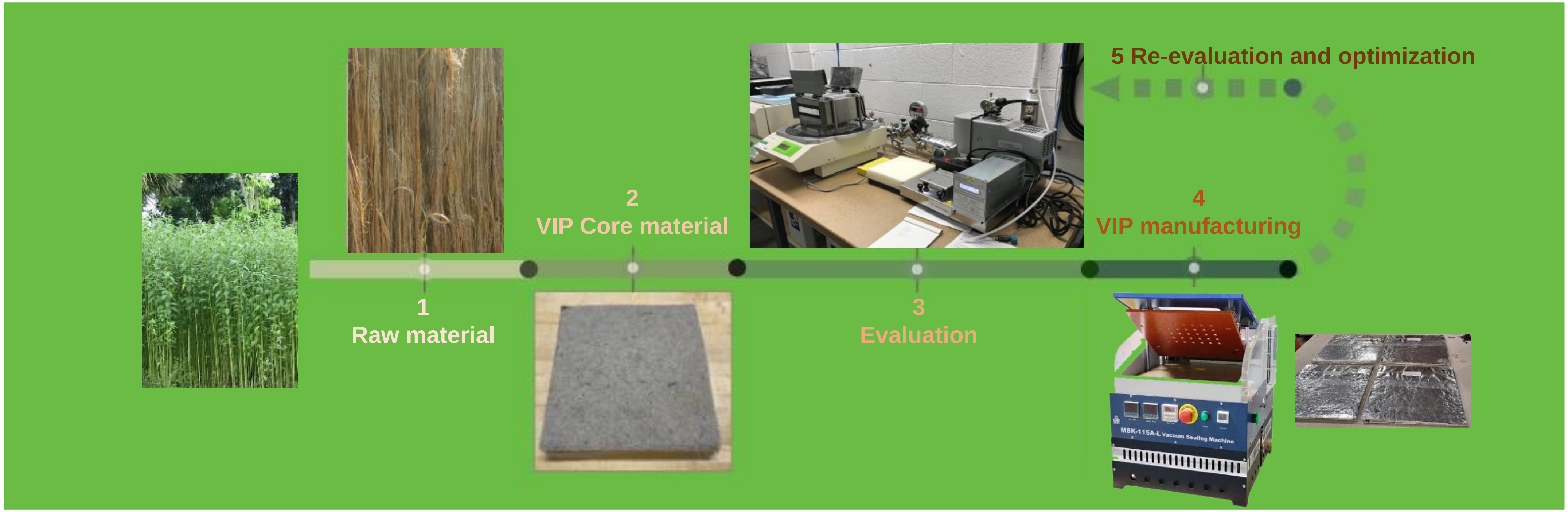
Development of low-cost VIP core materials



Oak Ridge National Laboratory
Som S Shrestha, Senior R&D Staff | Building Envelope Materials Research Group
865-241-8772. shresthass@ornl.gov
BTO-03.01.03.12, AOP

Project Summary

Objective: Reduce the cost of VIPs to increase their adoption in buildings.

Outcome: New VIP cores with 50 to 80% lower cost but similar thermal resistivity compared to fumed silica VIP cores.

Team and Partners

OAK RIDGE National Laboratory

RINCON CONSULTING LLC

Stats

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

DOE budget: $600k

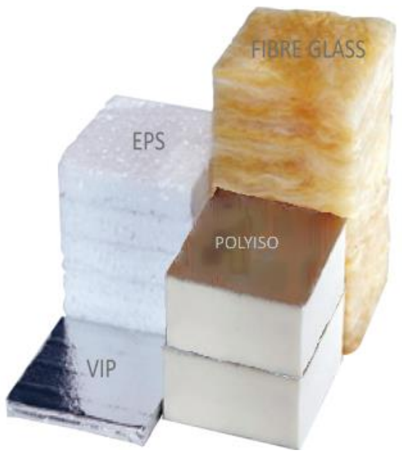
Milestone 1: Identify + evaluate materials

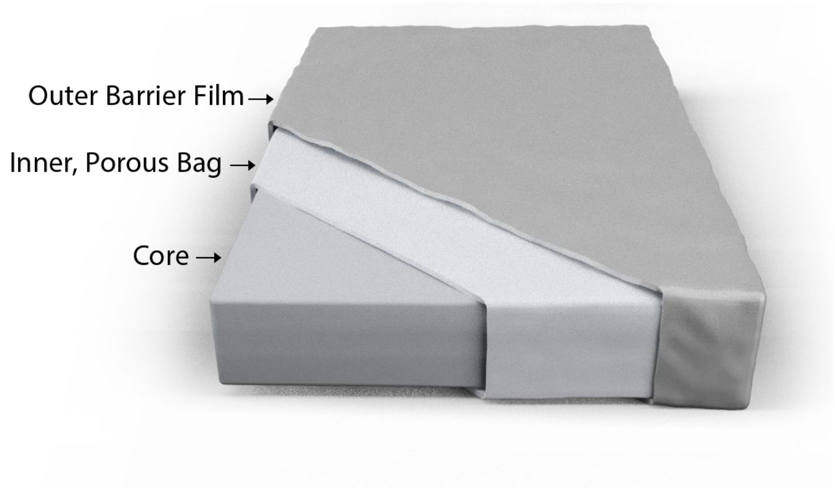
Milestone 2: Evaluate pressure and density-dependent thermal conductivity and cost analysis

Milestone 3: Fabricate VIPs and evaluate their performance

Problem

- ~ 25% of energy use in building is attributable to heat transfer through opaque envelope.*
- ~ 44% of US households spend > 8.6 % of their income on energy bills. * *
- High R/in. insulations can alleviate the issue, but current commercially used insulations limit their R-value to ~R6/in.
- Vacuum insulation panels (VIPs) can achieve > R35/in. but they are **costly** → not widely used in buildings.
- A main cost component of VIPs comes from their core materials.



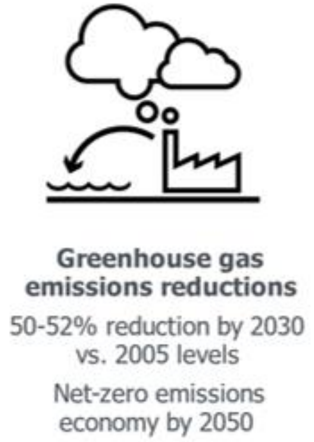


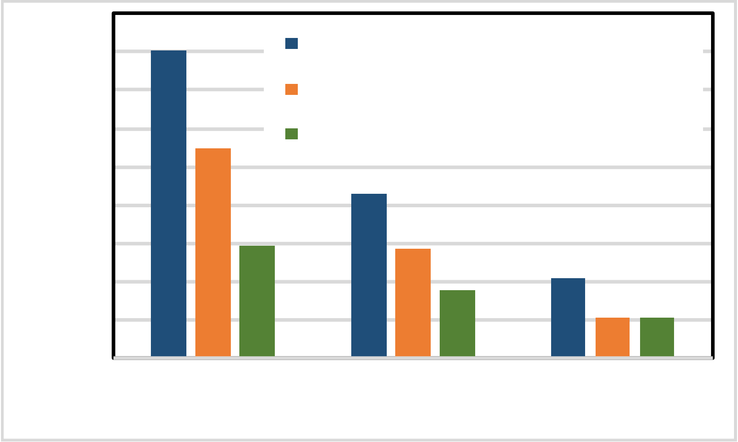
* DOE, Research and Development Opportunities Report for Opaque Building Envelopes
* * DOE LEAD Tool https://www.energy.gov/scep/slsc/lead-tool

Alignment and Impact

Low-cost VIPs

- ✓ Reduce the cost of core materials by 50 to 80% → boost adoption in buildings
- ✓ Eco-friendly natural fibers → reduce embodied energy and CO_2
- ✓ IEA estimates that VIPs can reduce building's operational CO_2 emissions by ~8%
- ✓ Allow meeting building code requirements in existing buildings with limited space of insulation





DOE Windows and Building Envelope Research and Development: Roadmap for Emerging Technologies

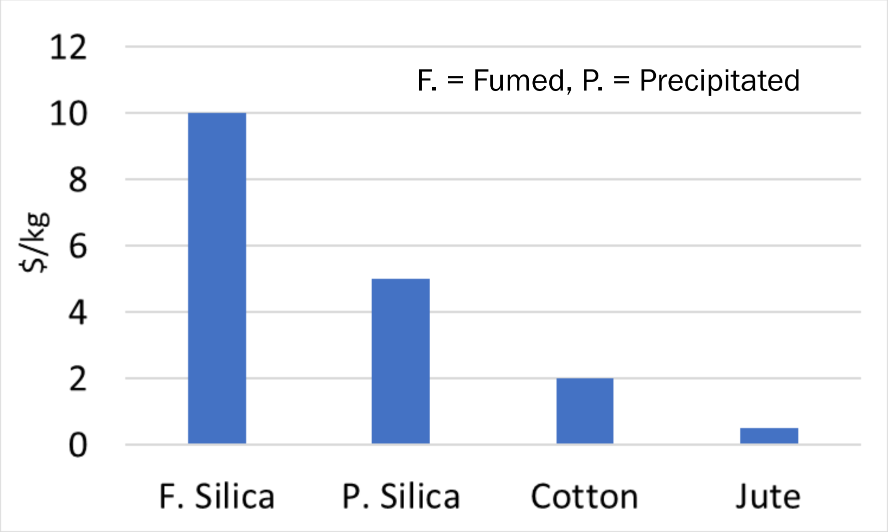
VIPs have great potential to save energy but they will have limited market adoption without a substantial reduction in cost

Approach: State of the art and alternatives

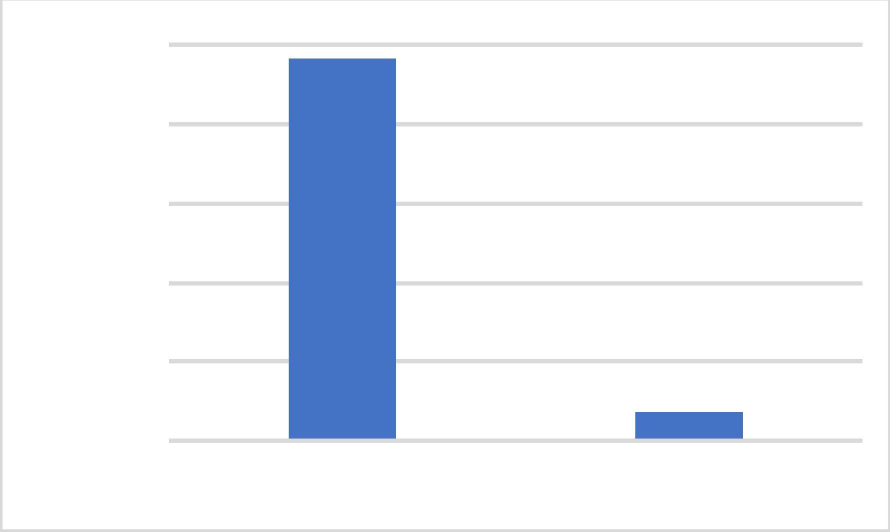
State of the art: Fumed silica	Lower cost alternatives
High materials cost	Lower materials cost by >50%
High embodied CO_2	Low embodied CO_2 or can be negative if carbon sequestration is accounted
Potential materials shortage if VIP use greatly expanded*	Abundant natural materials**

* World production: 250,000 tons/year

** World production
- Jute 2,500,000 tons/year
- Cotton 25,000,000 tons/year



Source: various literature



Shahaboddin Resalati, Christopher C. Kendrick & Callum Hill (2020). Embodied energy data implications for optimal specification of building envelopes, Building Research & Information, 48:4, 429-445, DOI: 10.1080/09613218.2019.1665980
A K Singh, M Kumar, and S Mitra. 2018. Carbon footprint and energy use in jute and allied fibre production. Indian Journal of Agricultural Sciences 88 (8): 1305–11, August 2018/Article

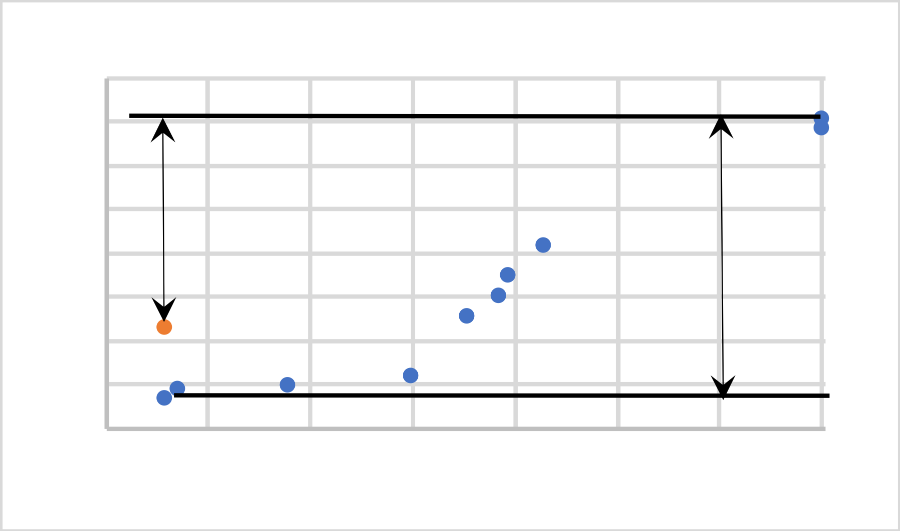
Approach: Identify candidate materials

Coupling effect on fibrous materials

$$K_{eff} = K_{solid} + K_{rad} + K_{air} + K_{coupling}$$

K-value at vacuum	
If there was no coupling effect	Measured
12 mW/mK (R12/in.)	4 mW/mK (R36/in.)

Coupling effect diminishes at vacuum



Selection based on

- Small fiber diameter
- K-value at ambient pressure < 50 mW/mK
- Availability

Identified several candidate materials

Approach: Evaluate properties

- Thermal properties using a heat flow meter apparatus (HFMA) with vacuum capability (ASTM C518)

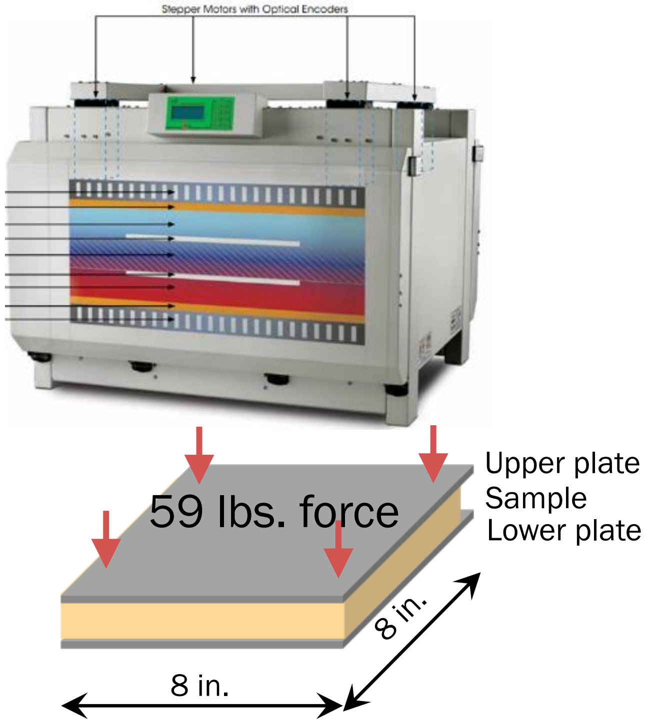
  HFMA limitation: compressive stress on the samples is only ~0.9 psi as compared to 14.7 psi when packaged in VIP barrier films. Density and K-value change at higher compression.

- Density as a function of compressive stress using a compression tester: Instron 3343 (ASTM C165)
- Fiber size analysis using scanning electron microscope

HFMA with vacuum

Instron 3343

Force exerted between upper and lower plate from stepper motors



Established test methods to evaluate pressure- and density-dependent K-value

Approach: Challenges, risks, mitigation, commercialization

Challenge: Losses R-value sharply as pressure increases
Plan: Explore mixing powders to fibers to reduce “effective pore size”

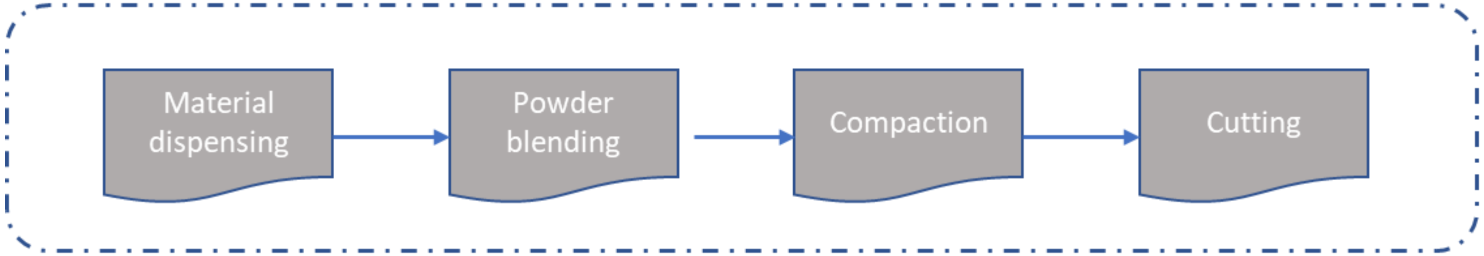
Challenge: Typically, industry is reluctant to change production lines
Plan: Develop processing method that requires minimum modifications to current manufacturing process

Challenge: Drying of some natural fibers may be energy intensive
Plan: Use of low-grade industrial waste heat

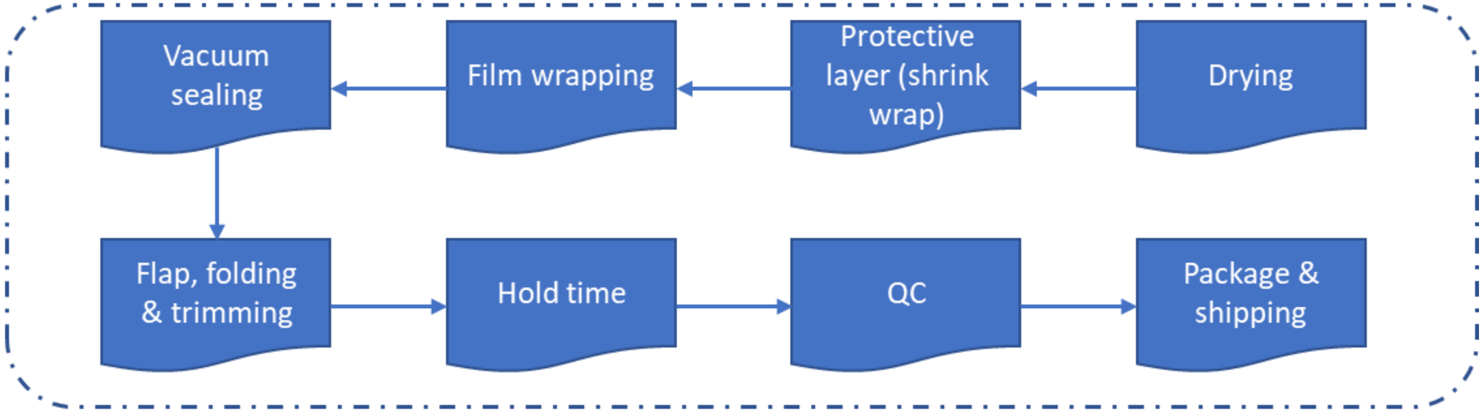
Commercialization: Engaged Mark Connell, a VIP industry expert, to ensure that the material and process developed through this project can be adapted by the VIP industry

Progress: Completed current VIP manufacturing cost analysis

Silica room processes

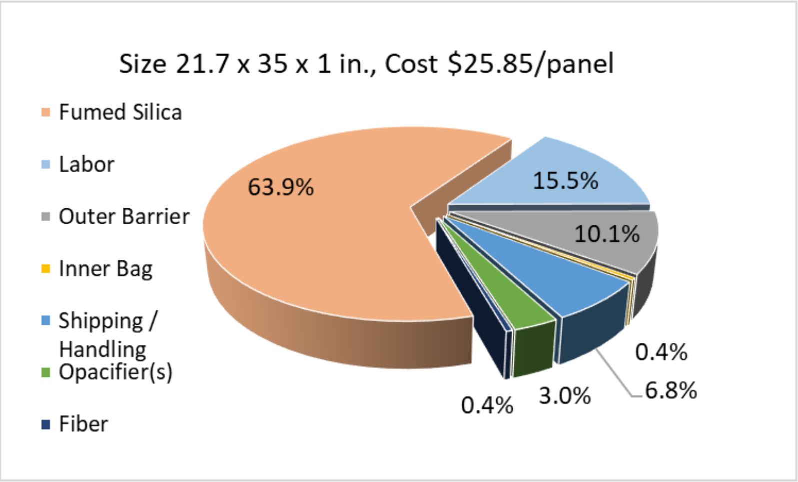


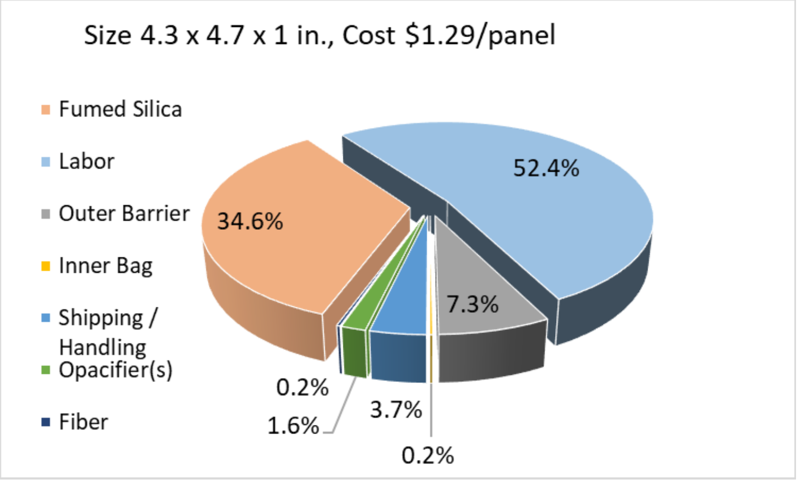
Packaging area processes



Cost of core material is a significant part of VIP cost

Cost breakdown depends on VIP size



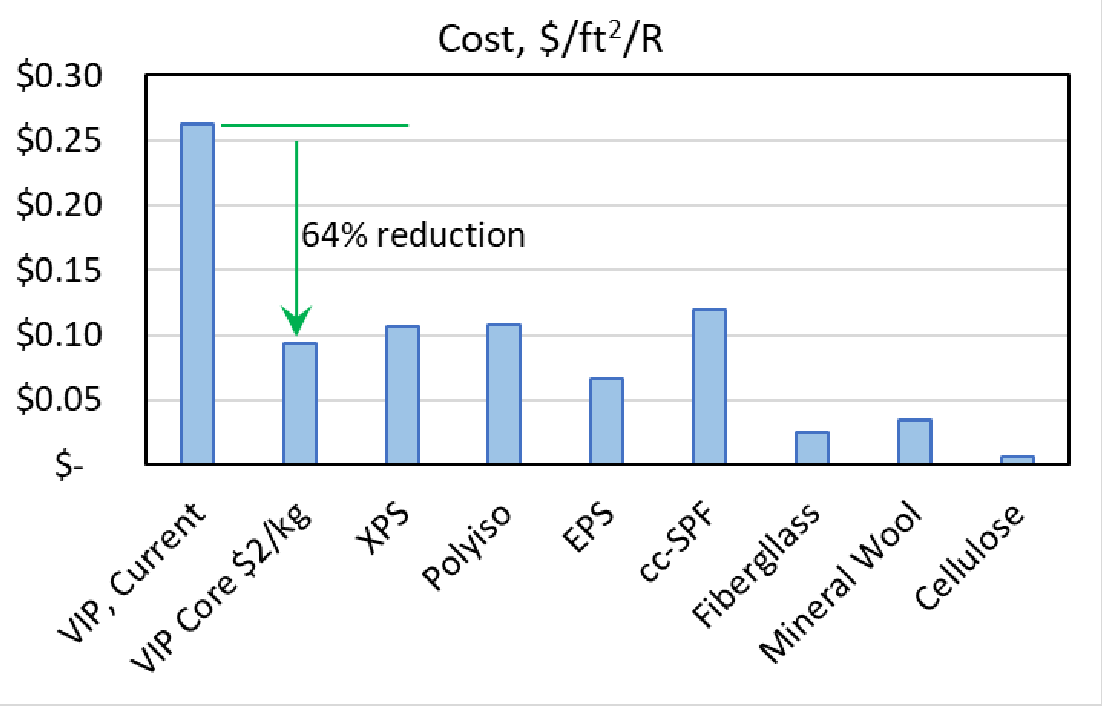


Based on a fumed silica VIP and a specific manufacturing environment, it can vary depending on capacity, equipment, labor costs, level of automation, etc.

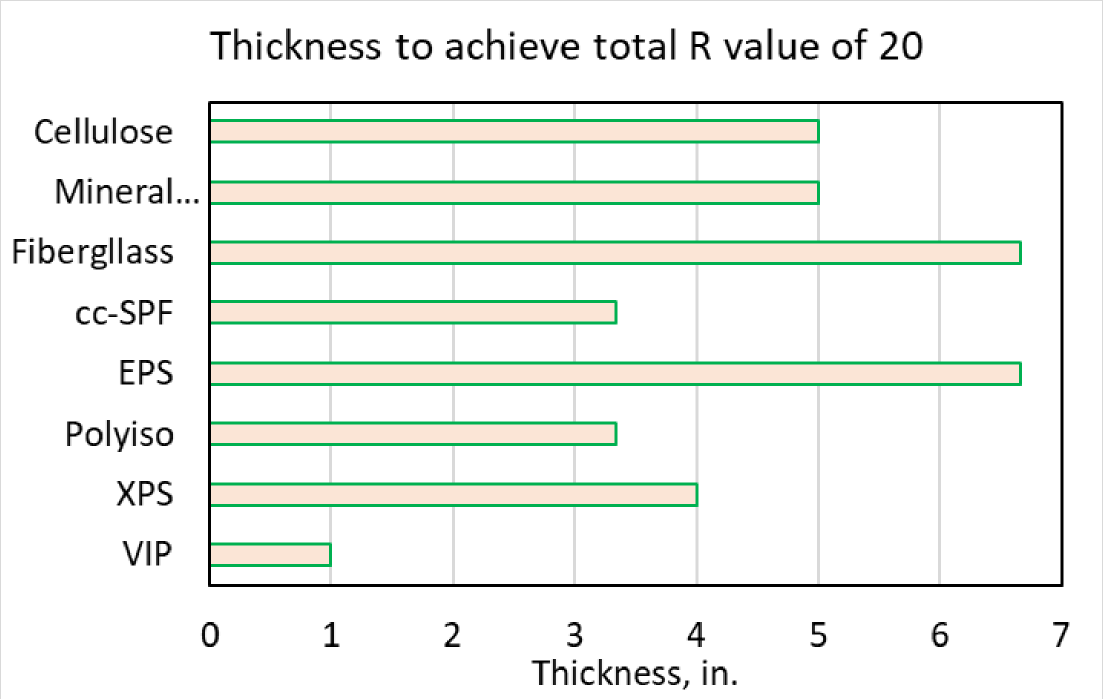
Progress: Cost and performance analysis

Assuming R20/in. for VIP and current pricing for commercial materials

Reducing the core cost to ~$2/kg can make VIPs competitive with conventional insulations



Current: fumed silica VIP



Reduced thickness offers additional benefits for VIPs, e.g., lower installation costs & reduced space requirements.

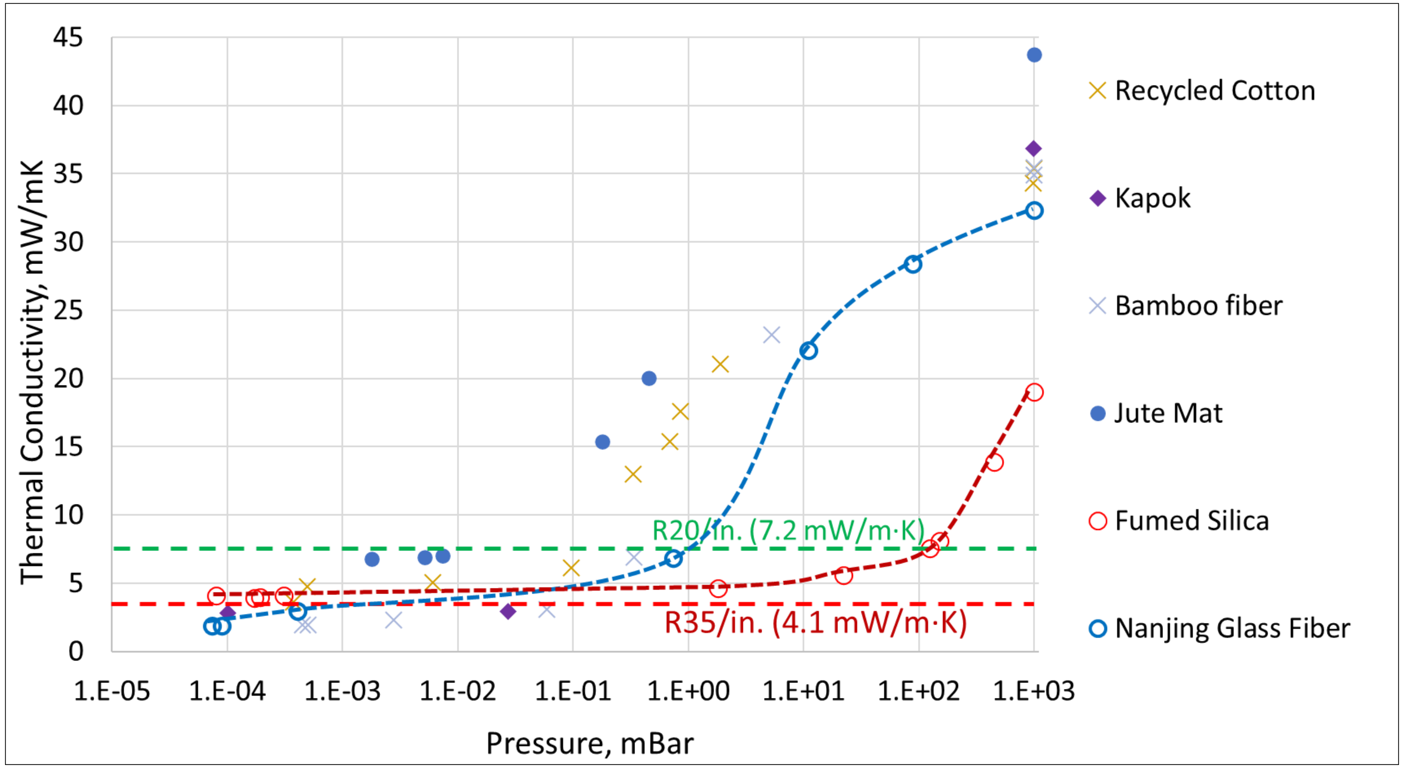
Reducing the cost of core material can make VIPs less costly than foam insulations

Progress: Measured pressure-dependent thermal conductivity

✓ Identified several candidate materials that can achieve R35/in.

Two issues:

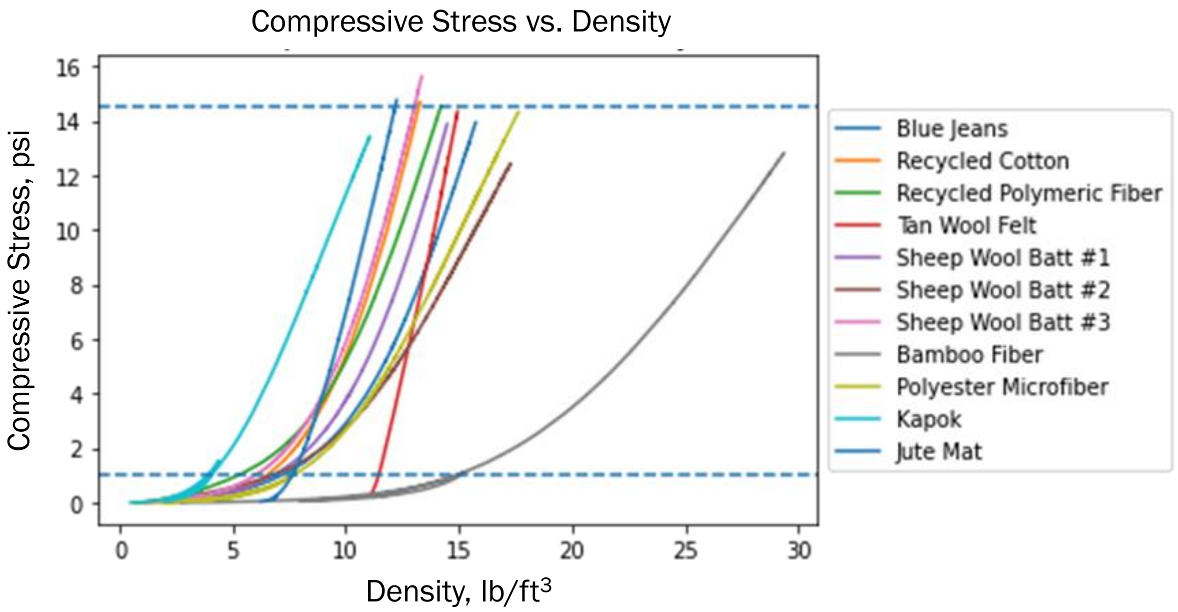
- Rapid increase in thermal conductivity as pressure increases
- Results may vary when compressive stress increases (when evacuated in barrier films)



Some promising candidates

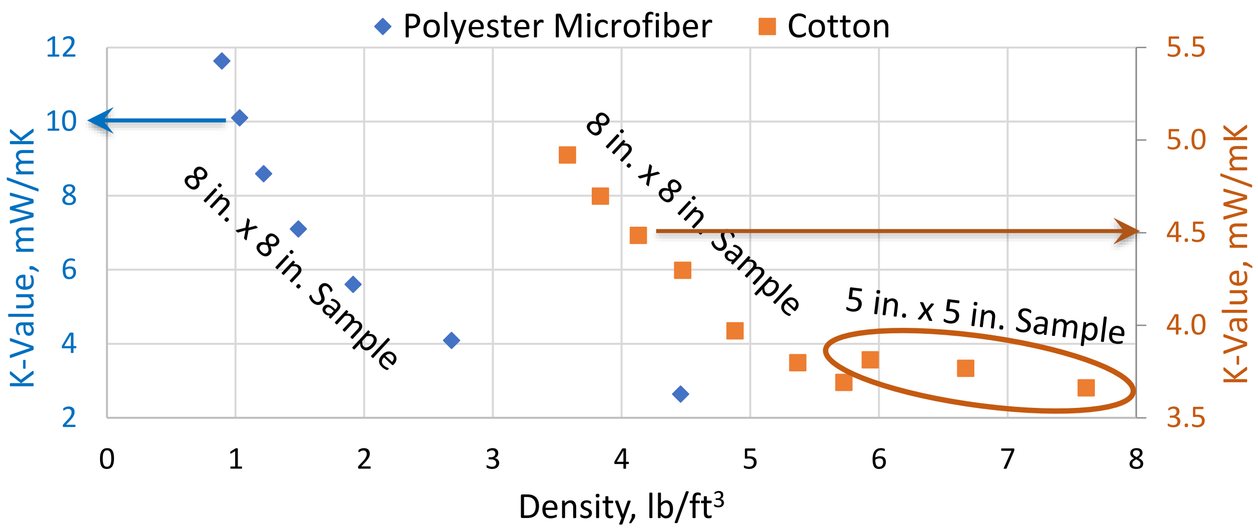
Some materials perform better than fumed silica at high vacuum

Progress: Measured density-dependent thermal conductivity



Conventional VIP core ~ 12 – 16 lb/ft^3

Density increases as the materials are compressed



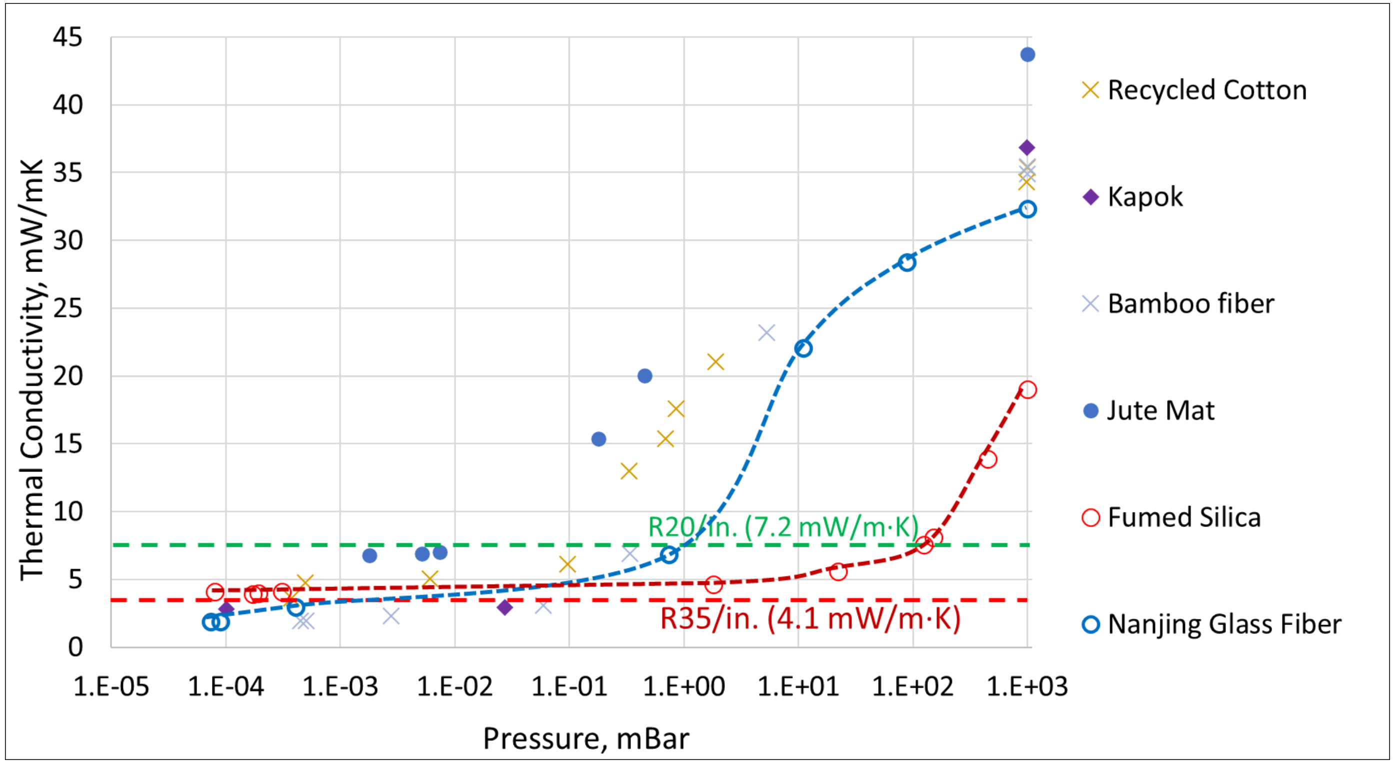
- K-value ↓ as density ↑ because decrease in radiation and conduction through gas dominated increase in solid conduction
- Yet to check if the trend continues up to density corresponding to 14.7 psi compressive stress

When core is compressed during evacuation, K-value might be different than when measured in HFMA.

Issue: Rapid increase in K-value as pressure increases
Future Work: Blend natural fibers with particles

Potential solution to retain R-value:

- Pre-process the core materials
- Blend natural fibers with small particle powder materials



There will be a tradeoff between R-value at high vacuum and retaining R-value at relatively higher pressure

Future work: Fabricate and evaluate VIPs

- Cost analysis
- Produce / optimize prototype VIPs using candidate core materials based on cost and performance
- Evaluate their thermal resistivity
- Aging test
- Life cycle analysis

Recently acquired vacuum sealing machine to produce prototype VIPs using different core materials

HFMA

Thank you

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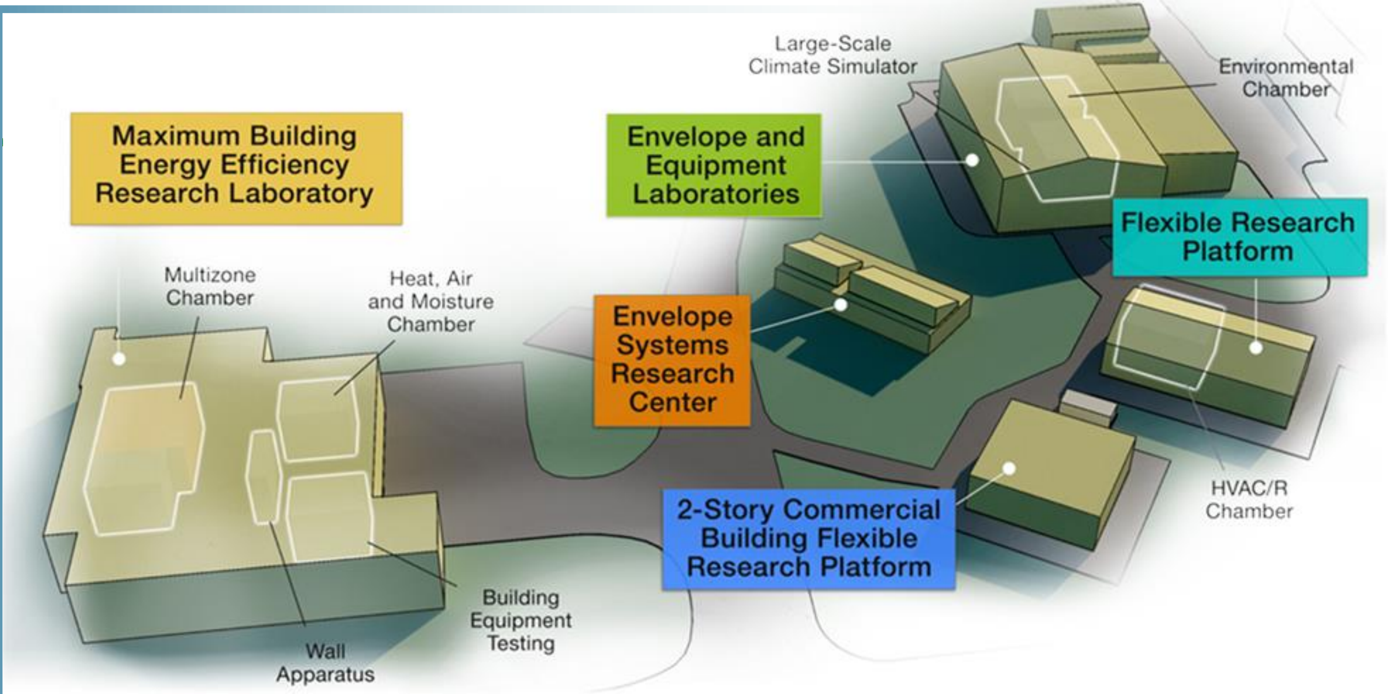
Som Shrestha, Senior R&D Staff
(865)-241-8772, shresthass@ornl.gov



ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 60,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results

236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution

No.	Deliverable/Milestones	Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1: Conduct analysis to breakdown the cost of core material, barrier film, getter, other additives, and processing cost													
D1.1	Completed the cost breakdown between core material, barrier film, getter, other additives, and processing cost. Determined how much of the overall cost could be decreased beyond the core material cost by reducing production time.	Go/No Go, Done	Go/No Go										
Task 2: Select and 10+ natural fibers and measure their thermal conductivity as a function of pressure													
D2.1	Measured pressure-dependent thermal conductivity on 3 materials.			Regular, Done									
D2.2	Measured pressure-dependent thermal conductivity on 3 additional materials.				Regular, Done								
D2.3	Measured pressure-dependent thermal conductivity on remaining materials.					Regular, Done							
G/NG	Measured effective thermal conductivity of at least one candidate material to be < 4 mW/mK (i.e., > R36/in.) at one-thousandth mbar range					Go/No Go, Done							
Task 3: Measure density as a function of pressure and thermal conductivity as a function of density													
D3.1	Measured change in thickness and density of materials for compressive stress up to 14.7 psi on 6 materials				Regular, Done								
D3.2	Measured change in thickness and density of materials for compressive stress up to 14.7 psi on remaining materials.					Regular, Done							
D3.3	Measured density-dependent effective thermal conductivity on at least two materials.					Regular, Done							
Task 4: Conduct the cost analysis of core materials													
D4.1	Cost analysis showed at least 50% reduction in core materials cost.						Regular						
Task 5:Develop a method to calculate heat flux through HFMA and compare it against the measured values													
D5.1	Identified and obtained 2 low-e foils with thermal emittance < 0.05. Measured their emissivity					Regular, Done							
D5.2	Conducted HFMA tests and compared calculated heat flux against measured values.						Regular						
Task 6: Design and evaluate structural elements to support low-density VIP core materials to withstand compressive stress													
D6.1	Developed finite element (FE) models of at least three the structural elements.					Regular							
D6.2	Evaluated compressive strength and effective thermal conductivity of the three structural elements using FE analysis. Selected one design for further evaluation.						Regular						
D6.3	3-D printed or procured the structural element selected from M5.2.							Regular					
D6.4	Measured R-value of structural element alone and with two types of core materials filled in the voids in structural element.								Regular				
G/NG	Measured effective thermal conductivity of at least one candidate material with structural element to be < 4 mW/mK (i.e., > R36/in.) at one-thousandth mbar range.								Go/No Go				
Task 7: Develop multi-scale models to predict the coupling between solid and gas conduction													
D7.1	Identified at least 9 EMA models from the literature and calculated the coupling thermal conductivity of the experimental materials..						Regular						
D7.2	Predicted the strength of solid/gas coupling thermal conductivity as functions of various parameters.							Regular					
D7.3	Conducted sensitivity analysis to predict the solid, gas, and solid-gas coupling thermal conductivities on the effective thermal conductivities on 4 different fibrous								Regular				
Task 8: Fabricate VIPs with the core material with or without structural element and evaluate their performance													
D8.1	Identified an industry partner to fabricate VIPs or developed capability at ORNL to fabricate VIPs.									Regular			
D8.2	Fabricated three VIPs each with two core materials and measured their R-values.										Regular		
Task 9: Final project report and recommendations													
D9.1	Submitted draft recommendations and project report.											Regular	
D9.2	Updated the report based on feedback from VIP industry experts and finalized the report.												Regular

Regular | Go/No Go | ★ Done

D4.1 → Delayed start

D6.1 → Ongoing

Task 7 (D7.1–D7.3) → **We may not need these tasks**

	Planned budget	Spent budget
FY22	$300K	$180K
FY23	$100K	$115K
FY24	$200K	0

Team

Som Shrestha
Rui Zhang
Oak Ridge National Laboratory

Experimental and Analytical Studies

Antonio Aldykiewicz Jr
Andre Desjarlais
Diana Hun
Oak Ridge National Laboratory

Cost Analysis, Advisory

Mark Connell
RINCON CONSULTING

Industry Guidance