U.S. DEPARTMENT OF ENERGY
Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

An Ultralow Thermal Conductivity Material

Oak Ridge National Laboratory
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Project Summary

Timeline:

Start date: 10/01/2018

Planned end date: 09/30/2021

Key Milestones

Milestone 1: Achieve a particle based material with thermal conductivity ≤ 0.016 W/m.K (09/30/2019)

Milestone 2: Achieve thermal conductivity of the material ≤ 0.012W/m.K (R12/in) with a manufacturing cost of < $1.0/sf. 1.0-in. (09/30/2020)

Budget:

Total Project $ to Date:

- DOE: $173,000
- Cost Share: $0

Total Project:

- DOE: $750,000
- Cost Share: $0

Key Partners:

The team has found potential partners and is in the process of talking with these partners who can guide and help in the material development and scale up.

Project Outcome:

The project aims to make a material with very high thermal insulation (R≈14/in.) by using particles. The targeted material will have a manufacturing cost <$1/sf. x 1.0-in. and stable to humidity and fire.

ORNL will develop and test the material while engaging with potential partners for scale up and material property improvements.

Team

Material synthesis → Material stabilization → Material characterization → Modelling & Calculations → Commercialization

Jaswinder Sharma, PhD

Georgios Polyzos, PhD

Diana Hun, PhD

André Desjarlais, PhD

Srikanth Allu, PhD

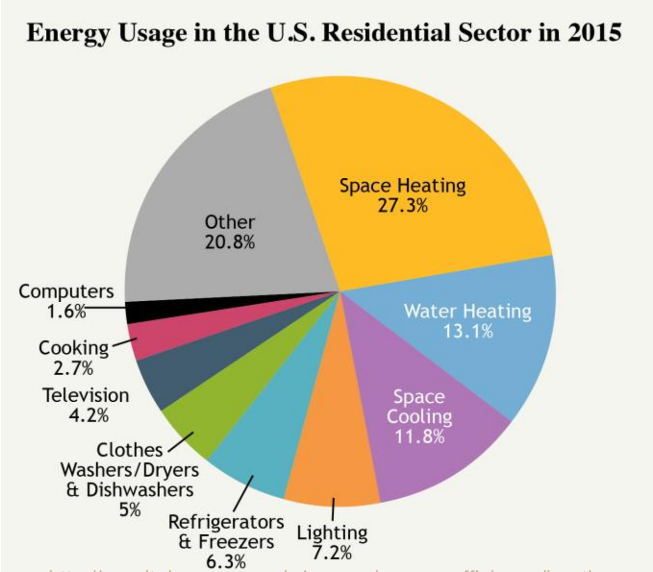
David Sims

Team expertise

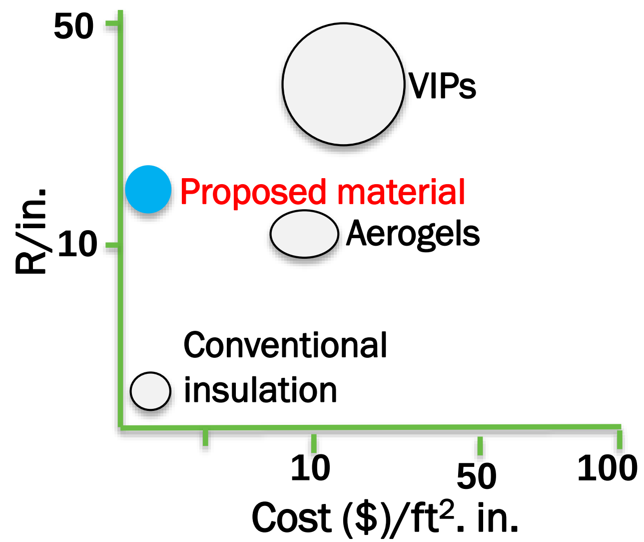
- Building envelopes
- Insulation materials
- Heat transport calculations and modelling
- Silica chemistry
- Polymer chemistry
- Superhydrophobic coatings
- Technology to market

Challenge

- 45 million (14.5% of population) US households make less than $23,500 per year, and upgrading house insulation is expensive for these families
- Conventional insulation needs more space and won't be able to meet future regulations without compromising with the living space
- Aerogels and vacuum insulated panels (VIPs) are good candidates, however, high cost and durability is hindering their use in buildings
- A new material with very high insulation (R≈ 14/in) but at a lower cost (<$1.0/sf. X 1.0-in. or ≈5-7¢/R) is required, especially, for retrofitting existing buildings without significantly affecting the wall thickness



http://needtoknow.nas.edu/energy/energy-efficiency/heating-cooling/

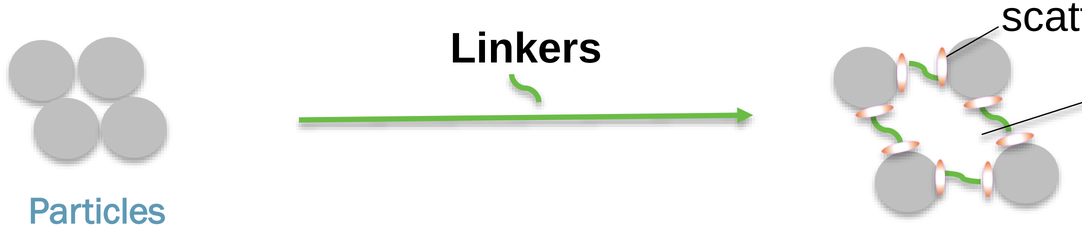


Approach

Combination of multiple factors in one material

Current research efforts focus on making a thermal insulation material by increasing the gas/air volume fraction (reducing the solid fraction), e.g., aerogels and foams.

- Our approach focuses on making a thermal insulation material by combining several factors:
  - Increase the air volume
  - Maximize the phonon scattering at the interfaces
  - Minimize the radiative heat transfer

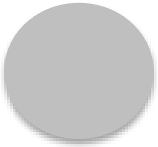


Approach

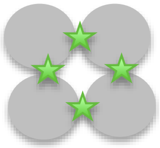
Enhanced phonon scattering/contact resistance

Phonon scattering

- Numerous interfaces
- Maximum heterogeneity
- Nano-components
- Maximum mismatch



No contact resistance

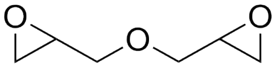


High contact resistance

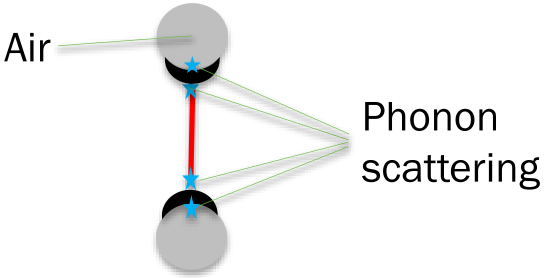
+

Large air volume

- Interstitial space



Diglycidyl ether



$$Q = \frac{\Delta T}{R} = G\Delta T$$

Where, Q-applied thermal flux, ΔT- observed temperature drop
R-thermal boundary resistance, G-thermal boundary conductance

Approach

Cost reduction

- Earth abundant materials
- Low cost drying – Fast freeze drying or ambient condition drying
- Minimal wastage of solvents
- No/less use of toxic materials
- Easy to handle

Silica

Soot/
carbon black

Wood
pulp/cotton

Approach

Key Risks and Mitigation

Risk 1. Moisture stability

- Minimal amount of moisture sensitive material
- Modify surface to make moisture repellant

Risk 2. Fire resistance

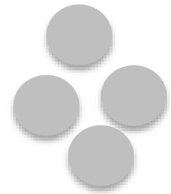
- Minimal amount of flammable materials
- Inclusion of fire-retardants

Risk 3. Particle aggregation

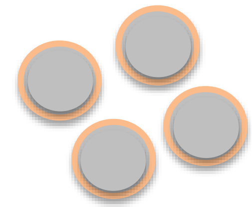
- Lower surface energy
- Minimize sintering
- Physical disaggregation

Risk 4. Market acceptance

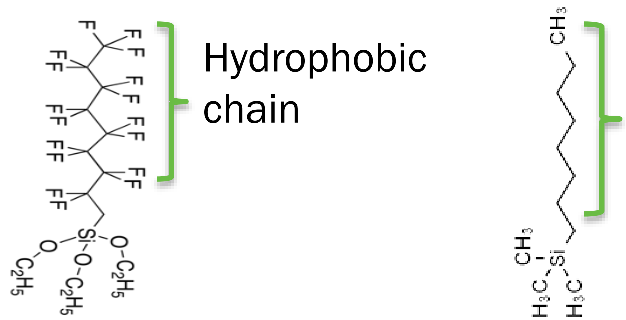
- Stakeholder outreach



Particles with minimal or without surface –OH groups



Particles with hydrophobic surface coating



Hydrophobicity rendering functional groups

Impact

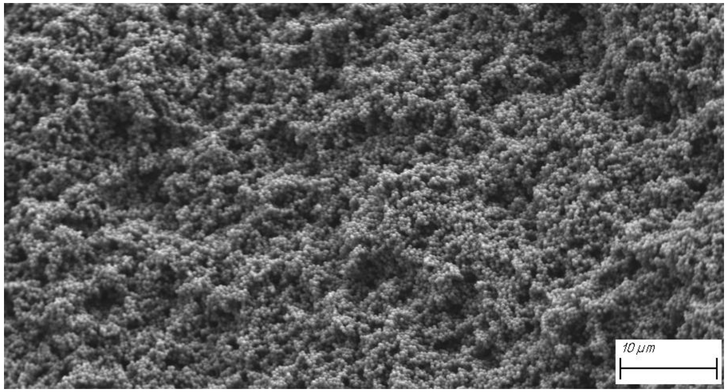
Multi-Year Program Plan Alignment

The project aligns excellently with BTO's Windows and Building Envelope Sub-program which focuses on developing and accelerating next-generation technologies & tools that reduce the amount of energy lost through building enclosures, contribute to improved occupant comfort, and have low product and installation cost.

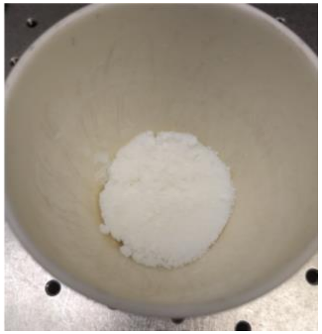
- If successful, the project outcome will provide a material with thermal insulation 2-3 times that of the conventional materials, and equal to or 1.5 times of the aerogels, while keeping the costs 50-60% lower than that of the aerogels
- The material will provide the same thermal performance but with a thinner layer—saving of occupant space
- Less transportation and disposal costs compared to the conventional insulation materials
- The high R-value (14/in.) material fits with long term goal of BTO— Energy savings by making the building envelop more insulating
- The project's market impact will be estimated by calculating the possible energy savings that can be achieved by replacing the current insulation materials

Progress

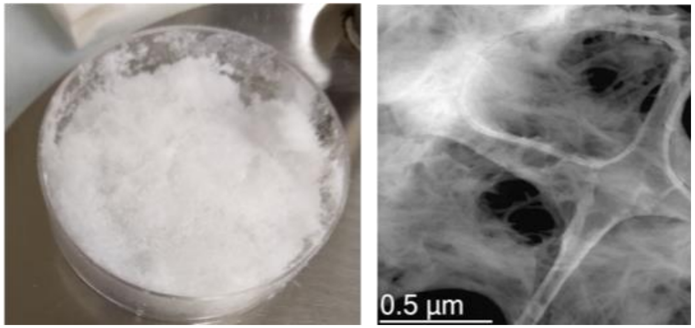
Particles and linkers used for making the material



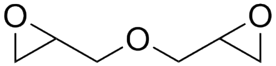
SEM image of particles (Diameter ≈ 300 nm)


Particle powder

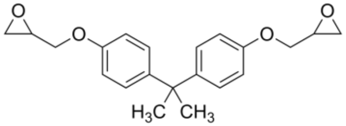
- Particle quality and diameter affect the thermal conductivity
- Synthesis process is scalable and low cost



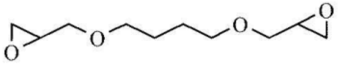
Small sized linkers made from wood pulp



Diglycidyl ether



Bisphenol A diglycidyl ether

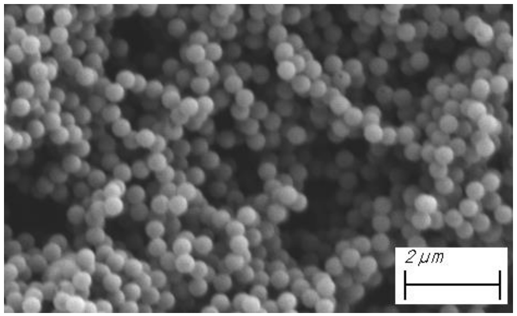


n-Butyl glycidyl ether

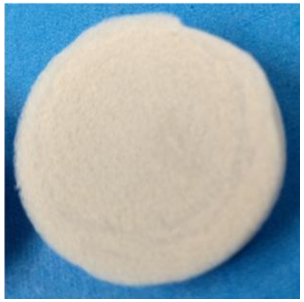
Building blocks have been synthesized and chemistries have been selected

Progress

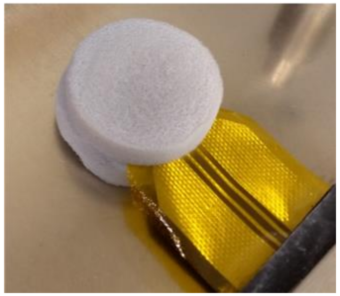
Composite made of particles and linkers



Particles used as building blocks



Slab made by crosslinking particles (***k* ≈ 0.018 W/m.K**)



TPS sensor sandwiched between two sample slabs

Sample prepared by aggregating the particles

- **Crosslinking particles with small linkers**
  - increases the total air-volume in the material
  - Increases contact resistance/phonon scattering in the system
  - Provides a robust material
- **Needs further optimization of particle/linker ratio**

Progress

Main Challenge: The particle aggregation

Aggregation

- Increases direct particle-to-particle heat transfer
- Decreases the number of heterogenous interfaces
- Lowers phonon scattering
- Lowers the stability of material
- Makes the material more vulnerable to moisture

Mitigated to certain extent:

- Sonication
- Avoiding sintering

Stakeholder Engagement

Project is in early stage, and thus we are in the initial steps to engage the stakeholders.

- Team has involved ORNL technology to market manager, David Sims for presenting the work at various platforms, e.g., TechConnect Conference

- Contacting industries who can guide us in product development and material scale up

- Contact with experts from other National Labs/Universities for further guidance for final product development

Remaining Project Work

- Address particle aggregation issue
- Further lower the thermal conductivity of the material
- Test and improve mechanical properties —— for easy handling
- Test and improve moisture stability and fire-resistance of the material —— enhanced durability and safety
- Engage with stakeholders

Thank You

Performing Organization: Oak Ridge National Laboratory (ORNL)
PI Name and Title: Dr. Jaswinder Sharma, Scientist
PI Tel and/or Email: 1-865-241-2333; sharmajk@ornl.gov

REFERENCE SLIDES

Initial Manufacturing Cost Estimates

Material	Estimated cost *or* from online vendors ($)	Cost /sf.inch ($)
Particles	≈0.5/sf.inch	≤0.5
Linkers	≈3.0/kg	<0.01
Carbon black	≈0.22/lb	<0.0005
Miscellaneous (electricity, water, waste disposal, labor, fire-retardants, etc.)		≈.0.40
Total manufacturing cost		**$0.91/sf.inch**
Total manufacturing cost (1000,0000 sf. Scale)		**$0.50/sf.inch**

Project Budget

Project Budget: $750,000
Variances: No.
Cost to Date: $145,000
Additional Funding: No.

Budget History					
FY 2018		FY 2019 (current)		FY 2020 – FY 2021 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$93K	$0	$157K	$0	$500K	$0

Project Plan and Schedule

Project Schedule		
Project Start: 10/01/2018	(light blue)	Completed Work
Projected End: 09/30/2021	(dark blue)	Active Task (in progress work)
	◆ (red)	Milestone/Deliverable (Originally Planned) use for
	◆ (black)	Milestone/Deliverable (Actual) use when met on time

	FY2019				FY2020				FY2021			
Task	Q1 (Oct-	Q2 (Jan-	Q3 (Apr-	Q4 (Jul-Sep)	Q1 (Oct-	Q2 (Jan-	Q3 (Apr-	Q4 (Jul-Sep)	Q1 (Oct-	Q2 (Jan-	Q3 (Apr-	Q4 (Jul-Sep)
Past Work												
Q1 Milestone: Selected candidate strategies for making particle-based insulation material based on literature review	Completed ◆ (black)											
Q2 Milestone: Selected a drying strategy that can produce a material with targeted cost ($3.6 sf.inch installed cost) and thermal conductivity ≈ 0.01 W/m.K (R14.4/in) at the end of the project		Completed ◆ (black)										
Current/Future Work												
Q3 Milestone: Achieved a particle/linkers based material with thermal conductivity ≤ 0.018 W/m.K (R8/in)		Completed	◆ (black)									
Q4 Milestone: Reported estimate of the potential cost of 1 ft x 1ft x 0.5 in. material when produced at an industry scale (>1 million ft2/year)			Active	Active ◆ (red)								
Q4 Go/No-Go Decision: Achieved a particle based material with thermal conductivity ≤ 0.016 W/m.K (R9/in)				◆ (red)								
Q1 Milestone: Achieved a thermal conductivity ≤0.015 W/m.K (R9.6/in.)					◆ (red)							
Q2 Milestone: Achieved thermal conductviity 0.014 W/m.K (R10.3/in.)						◆ (red)						
Q2 Milestone: Achieved a material with tensile strength ≥ 50 kPa						◆ (red)						
Q3 Milestone: Material retained 85% of its thermal resistance after being exposed to 60% relative humidity for two weeks							◆ (red)					
Q4 Milestone: Material passed ASTM E1321 flame spread test								◆ (red)				
Q4 Go/No-Go Decision: Achieved a particle based material with thermal conductivity ≤ 0.012 W/m.K (R12/in)								◆ (red)				
Q1 Milestone: Made a 4-in. X 4-in. X 0.5-in. slab of the material									◆ (red)			
Q2 Milestone: Retained the thermal conductivity ≤0.01 W/m.K (R14.4/in), mechanical strength ≥ 50 kPa, and passed the 60% humidity treatment test.										◆ (red)		
Q3 Milestone: Calculated the energy savings and payback period											◆ (red)	
Q4 Milestone: Report findings from interaction with industries that can manufacture the material at scale												◆ (red)
Q4 Deliverable: A material with R14/inch with a manufacturing cost ≤$1/sf. X in.												◆ (red)