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 ≤ 0.012 W/m.K (R12/in) with a manufacturing cost of < $1.0/sf. 1.0-in. (09/30/2020)

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.

Budget:
Total Project $ to Date:
• DOE: $173,000
• Cost Share: $0
Total Project:
• DOE: $750,000
• Cost Share: $0

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.

ORNRL will develop and test the material while engaging with potential partners for scale up and material property improvements.
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 \approx 14$/in) but at a lower cost ($<1.0/sf \times 1.0$-in. or $\approx 5-7$/R) is required, especially, for retrofitting existing buildings without significantly affecting the wall thickness.

[Image showing Energy Usage in the U.S. Residential Sector in 2015]

[Graph comparing Conventional insulation, Aerogels, and Proposed material (VIPs)]
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

![Diagram showing particles, linkers, and increased air volume](image_url)
Approach

Enhanced phonon scattering/contact resistance

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

+ Large air volume
  - Interstitial space

No contact resistance

High contact resistance

\[ Q = \frac{\Delta T}{R} = G\Delta T \]

Where, \( Q \) - applied thermal flux, \( \Delta T \) - observed temperature drop
\( R \) - thermal boundary resistance, \( G \) - thermal boundary conductance

Diglycidyl ether
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
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

Hydrophobic chain
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
- Small sized linkers made from wood pulp

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

Building blocks have been synthesized and chemistries have been selected

- Diglycidyl ether
- Bisphenol A diglycidyl ether
- n-Butyl glycidyl ether
Progress

Composite made of particles and linkers

Particles used as building blocks

linker

Drying

Slab made by crosslinking particles ($k \approx 0.018 \text{ W/m.K}$)

TPS sensor sandwiched between two sample slabs

- 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

Sample prepared by aggregating the particles
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

<table>
<thead>
<tr>
<th>Material</th>
<th>Estimated cost or from online vendors ($)</th>
<th>Cost /sf.inch ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particles</td>
<td>≈0.5/sf.inch</td>
<td>≤0.5</td>
</tr>
<tr>
<td>Linkers</td>
<td>≈3.0/kg</td>
<td>&lt;0.01</td>
</tr>
<tr>
<td>Carbon black</td>
<td>≈0.22/lb</td>
<td>&lt;0.0005</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td></td>
<td>≈0.40</td>
</tr>
<tr>
<td></td>
<td>electricity, water, waste disposal,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>labor, fire-retardants, etc.</td>
<td></td>
</tr>
<tr>
<td>Total manufacturing cost</td>
<td></td>
<td>$0.91/sf.inch</td>
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<tr>
<td>Total manufacturing cost</td>
<td></td>
<td>$0.50/sf.inch</td>
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<tr>
<td>(1000,0000 sf. Scale)</td>
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Project Budget

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

<table>
<thead>
<tr>
<th>Budget History</th>
<th>FY 2018</th>
<th>FY 2019 (current)</th>
<th>FY 2020 – FY 2021 (planned)</th>
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<tbody>
<tr>
<td>DOE</td>
<td>Cost-share</td>
<td>DOE</td>
<td>Cost-share</td>
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<tr>
<td>$93K</td>
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# Project Plan and Schedule

<table>
<thead>
<tr>
<th>Project Schedule</th>
<th>Completed Work</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Start: 10/01/2019</td>
<td>Active Task (in progress work)</td>
</tr>
<tr>
<td>Project End: 09/30/2021</td>
<td>Milestone/Deliverable (originally planned) use for</td>
</tr>
<tr>
<td></td>
<td>Milestone/Deliverable (actual) use after met on time</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Task</th>
<th>FY 2013</th>
<th>FY 2014</th>
<th>FY 2015</th>
<th>FY 2016</th>
<th>FY 2017</th>
<th>FY 2018</th>
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<tbody>
<tr>
<td>Past Work</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Q1 Milestone: Selected candidate strategies for making particle-based insulation material based on literature review</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Q2 Milestone: Selected a drying strategy that can produce a material with targeted cost ($3.65/ft², installed cost) and thermal conductivity ≤ 0.03 W/m·K (R14.4/in) at the end of the project</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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</tr>
<tr>
<td>Current/Future Work</td>
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<tr>
<td>Q3 Milestone: Achieved a particle-based material with thermal conductivity ≤ 0.018 W/m·K (R8.6/in)</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<td>✔️</td>
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<tr>
<td>Q4 Milestone: Reported estimate of the potential cost of 1 ft² x 1 ft x 0.5 in. material when produced at an industry scale (e.g., million ft²/year)</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<tr>
<td>Q4 Go/No-Go Decision: Achieved a particle-based material with thermal conductivity ≤ 0.016 W/m·K (R8.5/in)</td>
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<td>✔️</td>
<td>✔️</td>
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<tr>
<td>Q1 Milestone: Achieved a thermal conductivity ≤ 0.015 W/m·K (R9.6/in)</td>
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<tr>
<td>Q2 Milestone: Achieved thermal conductivity ≤ 0.014 W/m·K (R10.3/in)</td>
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<tr>
<td>Q2 Milestone: Achieved a material with tensile strength ≥ 50 kPa</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Q3 Milestone: Material retained 85% of its thermal resistance after being exposed to 60% relative humidity for two weeks</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<td>✔️</td>
</tr>
<tr>
<td>Q4 Milestone: Material passes ASTM E1321 flame spread test</td>
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<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<td>✔️</td>
</tr>
<tr>
<td>Q4 Go/No-Go Decision: Achieved a particle-based material with thermal conductivity ≤ 0.012 W/m·K (R12/in)</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Q1 Milestone: Made a 4-in. x 4-in. x 0.5-in. slab of the material</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
</tr>
<tr>
<td>Q2 Milestone: Retained the thermal conductivity ≤ 0.011 W/m·K (R14.4/in), mechanical strength ≥ 50 kPa, and passed the 60% humidity treatment test</td>
<td>✔️</td>
<td>✔️</td>
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<td>✔️</td>
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<tr>
<td>Q3 Milestone: Calculated the energy savings and payback period</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<tr>
<td>Q4 Milestone: Reported findings from interaction with industry that can manufacture the material at scale</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
<td>✔️</td>
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<td>✔️</td>
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<tr>
<td>Q4 Deliverable: A material with R16/ft² with a manufacturing cost ≤ $1/sq ft. X 1 in.</td>
<td>✔️</td>
<td>✔️</td>
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