R25 Polyisocyanurate Composite Insulation Material

Modified Atmosphere Insulation (MAI) panels on high-density (HD) foam substrate

Foam application on manufacturing line

Finished composite insulation boards

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Project Summary

Timeline:
Start date: Oct 1, 2014
Planned end date: Sep 30, 2017
Key Milestones
1. First full-scale MAI-polyiso composite measured to be R-10/inch; 9/30/15
2. Verify R-value of improved MAI-polyiso composite produced on the production line to be R-12/inch; 9/30/2016
3. Optimized cost of commercial composite panels with R-12/inch; 6/30/2017

Budget:
Total Project $ to Date:
- DOE: $1,101,756
- Cost Share: $177,812

Total Project $:
- DOE: $1,237,500
- Cost Share: $310,000

Key Partners:
Firestone Building Products Company
NanoPore, Inc.

Project Outcome:
Develop a 2-inch thick composite foam insulation board with R25 (hr-ft²-F/Btu), with a cost premium of $0.30/ft². This addresses the MYPP goal of creating low-cost, advanced insulation materials.
Problem Statement: Address the EERE BTO’s mission to develop low-cost, high-performance advanced insulation materials for building envelopes (Table 8 under section 2.3 of BTO’s Multi-Year Program Plan or MYPP).

- Per BTO’s 2014 Roadmap, adding R24 to existing walls has a 2030 technical potential of 1,101 TBTUs.
- Need 4 inches or more of current insulation materials vs. 2 inches of the new composite insulation.
Purpose and Objectives

Target Market and Audience: The target market is residential walls and low-slope commercial roofs, both retrofit and new construction.

- In 2010, the primary energy consumption attributable to commercial roofs and residential walls was 2,810 TBTUs (per 2014 BTO Roadmap).

Impact of Project:
1. **Major output:** Development of R12/inch composite insulation with MAI cores encapsulated by polyiso foam, produced on a manufacturing line.
2. **Near-term outcomes (end of project):**
   a. Verified thermal performance (R12/inch) of the insulation boards.
   b. Techno-economic analysis evaluating $0.30/ft^2 cost premium target.
3. **Mid-term:** Field-demonstration and evaluation of long-term performance.
4. **Long-term:** Incorporation of the new composite insulation into regular production by foam manufacturer(s) and market adoption.
Approach

**Key Issues:**

- Damage to MAI panels by exothermic foam expansion during encapsulation.
- Complete foam encapsulation of the MAI panels (without air pockets).
- Moisture-related issues arising due to addition of the composite insulation.
  - Barrier films of the MAI panels act as additional air/vapor barriers for building envelopes.
Approach

Distinctive Characteristics:

- Use of MAI (40% lower cost than regular vacuum insulation panels or VIPs).
- Polyiso (PIR): Highest R/inch of all commercial insulation materials, with demonstrated toughness and durability in construction environments.
- New composite insulation: Combining the features of MAI panels (very high R-value) and polyiso (high R-value and durability).
- Encapsulation of MAI panels in polyiso foam protects them during transportation and handling, installation, and use.
Progress and Accomplishments

Laboratory-scale experiments: Foam encapsulation of MAI panels

• MAI panels with metallized and all-polymer barrier films were tested.
  – Polymer barriers significantly reduce thermal bridging around MAI panels.
• The foam encapsulation of MAI panels was satisfactory, except one test.
  – Caused by lab foaming conditions; not expected in plant production.
• MAI panels withstood the exothermic foam expansion.
  – No measurable dimensional changes to MAI panels.
  – Barrier surface temperature rise (<90°C) less than damage threshold (110°C).
Progress and Accomplishments

Laboratory-scale experiments: Foam adherence to MAI barrier films

- Metal plates attached to foam surface and cured for 3 days.
- Foam cut around the metal plates and pulled until adhesive (foam-MAI barrier) or cohesive (foam) failure.
- All barriers passed the minimum required adhesion force of 4 psi.

<table>
<thead>
<tr>
<th>MAI barrier ID</th>
<th>Adhesion (psi)</th>
<th>Failure mode</th>
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</thead>
<tbody>
<tr>
<td>T1-1 (PE)</td>
<td>6.8</td>
<td>Adhesive</td>
</tr>
<tr>
<td>T1-2 (PET)</td>
<td>31.2</td>
<td>Cohesive</td>
</tr>
<tr>
<td>T1-3 (BOPP)</td>
<td>5.1</td>
<td>Adhesive</td>
</tr>
<tr>
<td>T1-4 (nylon)</td>
<td>17.9</td>
<td>Partial cohesive</td>
</tr>
</tbody>
</table>
Progress and Accomplishments

Design of MAI-Polyiso Composite Boards Based on Thermal Modeling

• First-generation 4’ x 8’ composite design
• 4x3 array of MAI panels (22.75” x 14.7”)
  – 1 inch gaps for mechanical fasteners
  – 86.9% MAI coverage
• Estimated R-value of the 2-inch board: 25.5 hr-ft²-°F/Btu (R12.7/inch)

Simulated heat flows through a MAI-foam composite board.
Progress and Accomplishments

  - *No major changes needed to the assembly line; critical consideration with respect to cost premium of the new composite insulation.*
Progress and Accomplishments

- September 2015: Guarded hot box tests (ASTM C1363) yielded R21.6 for the 2-inch composites ($R10.8/\text{inch}$).
  - Year 1 Go/No-Go target: R10/inch
- Autopsy of one board performed after the hot box test.
  - No discernible changes in MAI shape and dimensions.
  - One area had poor foam fill, with implications on measured R-value.
Progress and Accomplishments

• Second generation composites: Higher MAI coverage to achieve R12/inch.
  – 89.8 - 91.3% vs. 86.9% in FY15

• Modeling indicates increases in overall R-values of 1.3 – 2.1 hr-ft²-°F/Btu
  – ΔR/inch of 0.7-1.1
Progress and Accomplishments

Second-generation composite production (March 3, 2016)

- Potential online quality control using IR imaging
- Thermal diffusivity ($k/\rho c_p$): Damaged MAI $\gg$ Intact MAI
  - Cools the ‘warm’ spray-applied foam faster.
Progress and Accomplishments

Techno-economic Analysis

- September 2015: Interim report detailing methodology and strategy.
- Identifying external factors impacting demand for new composite insulation.
  - e.g. competitive products, energy cost, building codes, etc.
- Evaluation of production efficiencies and material cost reductions needed to achieve the desired $0.30/ft\(^2\) cost premium.
- Initial analysis report due in April 2016 (based on Year 1 project results).
  - Phase 2 analysis report: December 2016.
  - Final analysis report: June 2017.

Hygrothermal Analysis

- Hygrothermal modeling indicated no adverse moisture-related effects due to addition of MAI panels.
**Progress and Accomplishments**

**Market Impact:** Potential market impact is listed as the project is still in R&D stage.

- Based on numerical simulations of standard residential and commercial building models, the new R25 insulation board has a 2030 primary energy savings potential of 1319 TBTUs.
- The techno-economic analysis, due by June 2017, will determine cost premium and/or pathways to desired cost premium and the market demand.

**Awards/Recognition:** N/A

**Lessons Learned:**

- Handling of MAI-HD boards (before the foaming process) – Improper handling can lead to detachment of MAI panels from the HD substrate.
- One composite produced during July 2015 contained 2 failed MAI panels (out of 12); Quality control process is needed during eventual mass production.
  - Simulations indicate 15% reduction in R-value due to 2 failed MAI panels.
**Project Integration and Collaboration**

**Project Integration**: The project is a collaboration between ORNL, Firestone Building Products Company and NanoPore, Inc. Dr. Jim Hoff of Tegnos Research Inc. is performing the techno-economic analysis.

- Firestone has been in the polyisocyanurate industry for 25 years and is the largest manufacturer of commercial roofing materials in the world.
- NanoPore has been developing nanoporous materials and advanced insulation (including VIPs) since 1993 and has more than 100 patents.
- Dr. Jim Hoff has 30+ years of executive experience in the building materials industry and is a former Vice President at Firestone Building Products.

**Communications**:

Next Steps and Future Plans

• Develop accelerated aging test protocol for MAI panels (June 2016)
• Verify improved composite boards to be R12/inch by testing in ORNL’s guarded hot box (Sept. 2016)
• Detailed techno-economic analysis and cost optimization (June 2017)

Additional Tasks (beyond current scope):
• Demonstration of new composite insulation in actual or simulated retrofit applications.
  – Identify installation challenges, design changes required, etc.
• Long-term testing in actual buildings to ascertain lifetime thermal performance of the composite insulation.
REFERENCE SLIDES
Project Budget

Variances: N/A
Cost to Date: 89% of the budget (including cost to date and encumbered costs)
Additional Funding: N/A

<table>
<thead>
<tr>
<th>Budget History</th>
<th>FY 2015 (past)</th>
<th>FY 2016 (current)</th>
<th>FY 2017 (planned)</th>
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<tbody>
<tr>
<td>DOE</td>
<td>$542,961</td>
<td>DOE $431,006</td>
<td>DOE $264,032</td>
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<td>Cost-share</td>
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</table>
• Changes in ORNL’s subcontracting process resulted in delays at the beginning of the project in providing funds to the industry partners, causing the initial milestones to slip.

• There are Go/No-Go decision points at the end of each Fiscal Year:
  - FY15 - First full-scale MAI-polyiso composites measured to be R10/inch (9/30/2015)
  - FY16 - Improved MAI-polyiso composites measured to be R12/inch (9/30/2016)

### Project Schedule

<table>
<thead>
<tr>
<th>Task</th>
<th>FY2015</th>
<th>FY2016</th>
<th>FY2017</th>
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<tbody>
<tr>
<td>Past Work</td>
<td>Q1 (Oct-Dec)</td>
<td>Q2 (Jan-Mar)</td>
<td>Q3 (Apr-Jun)</td>
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<tr>
<td>Bench-top prototype with MAI panel encapsulated with foam</td>
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<td>Methodology and strategy for techno-economic analysis</td>
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<td>First full-scale MAI-polyiso composites measured to be R-10/inch</td>
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<td>Hygrothermal analysis of envelope assemblies with MAI panels</td>
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<tr>
<td>Design for improved MAI-polyiso composite (using modeling)</td>
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<td>Current/Future Work</td>
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<tr>
<td>Accelerated aging test protocol for MAI panels</td>
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<td>Improved MAI-polyiso composites measured to be R-12/inch</td>
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Completed Work:

- Active Task (in progress work)
- Milestone/Deliverable (Originally Planned)
- Milestone/Deliverable (Actual)