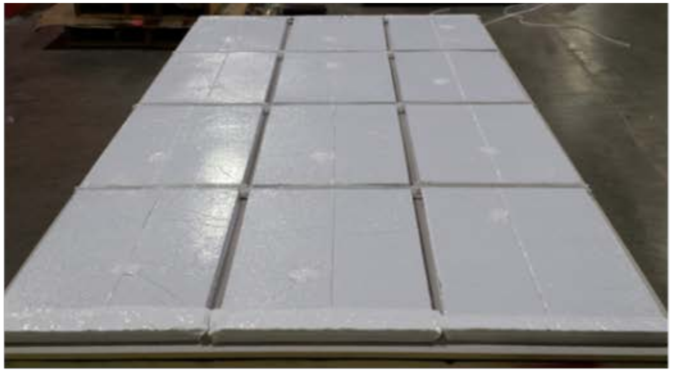
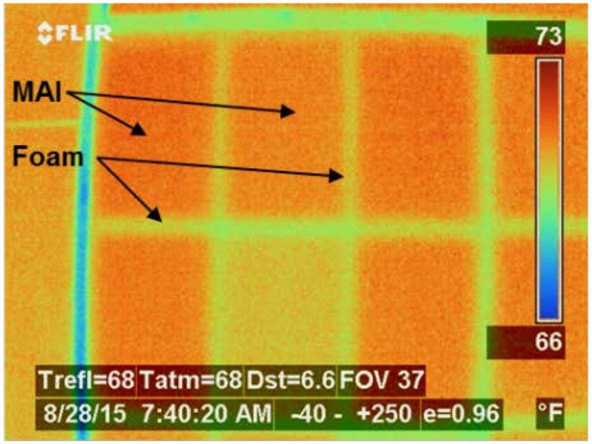
R25 Polyisocyanurate Composite Insulation Material

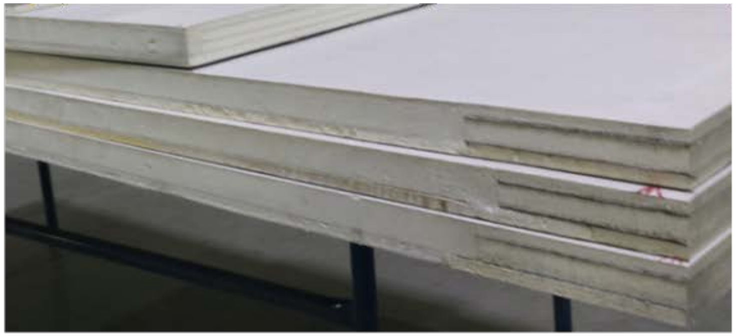
2017 Building Technologies Office Peer Review



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: Sept. 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. Techno-economic analysis with final optimized manufacturing operations and cost estimates; 9/30/17

Budget:

Total Project $ to Date:

- DOE: $1,438,000
- Cost Share: $310,000

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2014 BENEFIT FOA Award

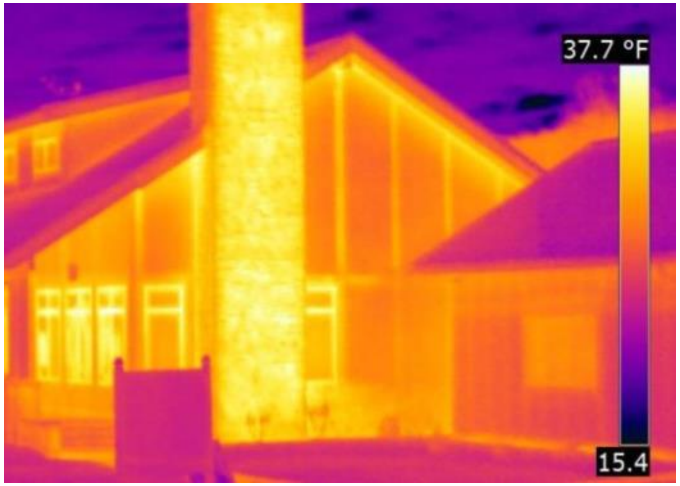
Key Partners:

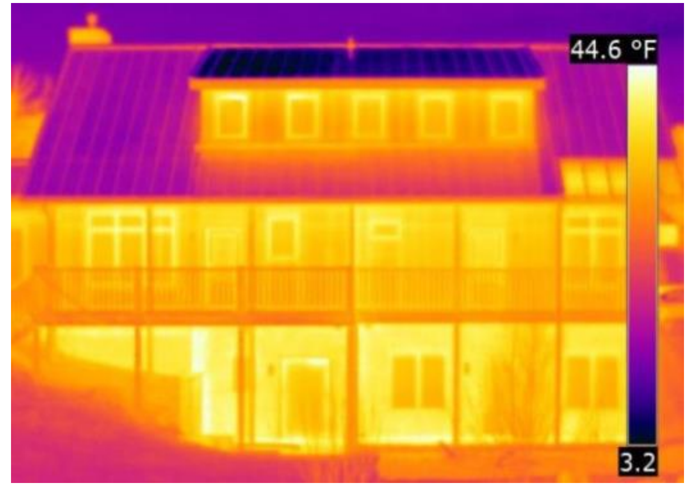
Firestone Building Products Company
NanoPore, Inc.

Project Outcome:

Develop a 2-inch thick composite foam insulation board with R25 (hr-ft^2-°F/Btu), with a cost premium of $0.30/ft^2 or lower. This addresses the DOE goal of creating low-cost, advanced insulation materials.

Purpose and Objectives





Problem Statement: Address EERE BTO's mission to develop low-cost, high-performance advanced insulation materials for building envelopes

Target Market and Audience: Low-slope commercial roofs; residential walls

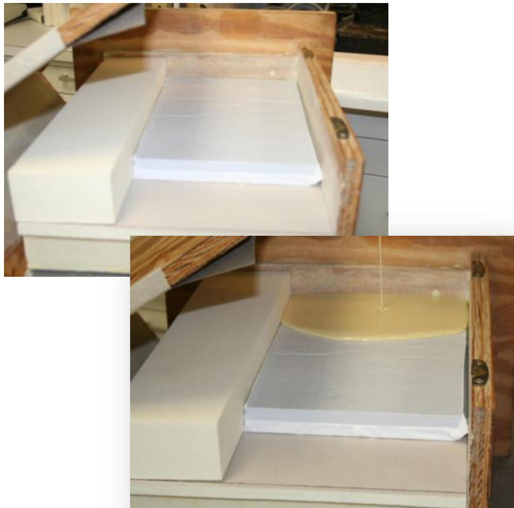
- Per Energy Information Administration, in 2010 the attributable primary energy consumption was 2,810 TBTUs
- In 2035, the projected primary energy consumption is 2,630 TBTUs

Purpose and Objectives

Impact of Project:

1. Major output: 2” thick R25 (R12/inch) composite insulation with modified atmosphere insulation (MAI) cores encapsulated by polyiso foam
2. Near-term outcomes (end of project):
   a. Verified thermal performance (R12/inch) of the insulation boards
   b. Detailed large-scale and automated manufacturing designs and integration plans, with estimates of capital and operating expenses
   c. Techno-economic analysis describing final optimized manufacturing operations and cost estimate of the composite insulation
3. Mid-term: Field-demonstration and evaluation of long-term performance
   a. Evaluation of aging of MAI panels due to diffusion of gases through barrier films and seals
4. Long-term: Incorporation of new composite insulation into regular production by foam manufacturer(s) and market adoption

Approach



Lab-scale foaming experiments

Plant production of composite boards

Thermal performance testing and economic analysis

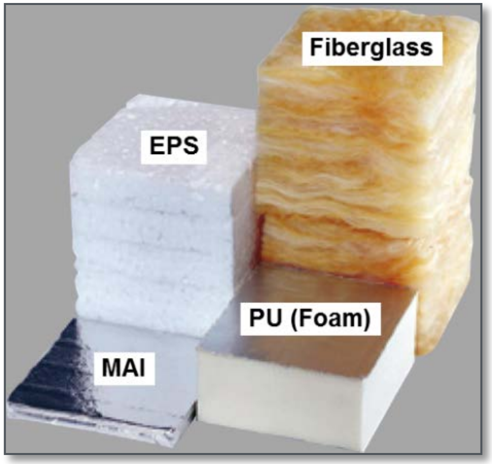
Key Issues:

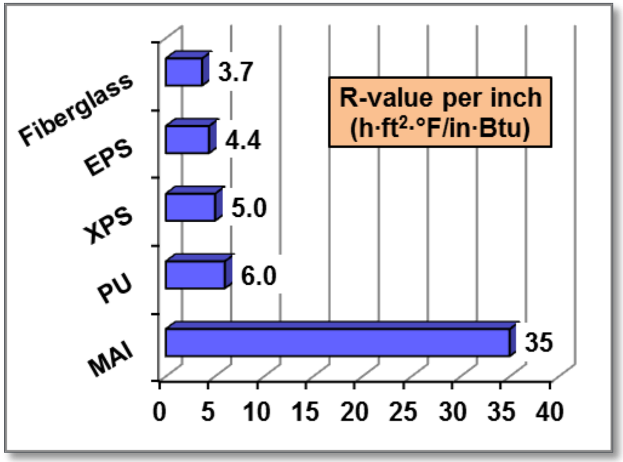
- Development of composite boards with required thermal performance
- Design of integration of MAI panels into an automated and large-scale manufacturing process
- Determination of a minimum viable product (valuable attributes) and the acceptable cost premium

Approach

Distinctive Characteristics:

- Use of MAI (~R35/inch and 50% lower cost than regular vacuum insulation)
- 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.
  - Reduced aging-related performance degradation of MAI panels



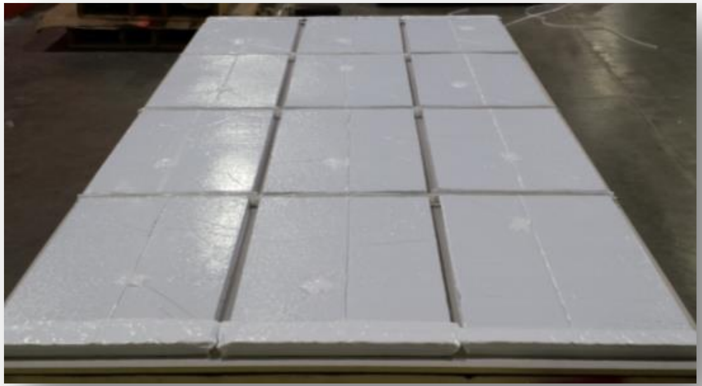


EPS	Expanded polystyrene
XPS	Extruded polystyrene
PU	Polyurethane
MAI	Modified atmosphere insulation

Progress and Accomplishments

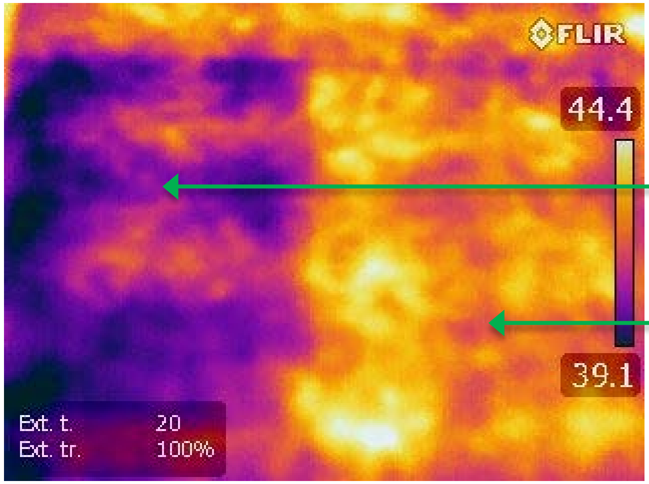
Manufacturing Trials:

- 1” MAI panels adhered to 0.5” high-density (HD) foam board and 0.5” regular density foam spray-applied on top
- First-generation boards created in FY15 with 86.9% MAI coverage
- Second-generation boards created in FY16, with 89.8, 91.3 and 93.8% MAI coverage
  - Infrared (IR) imaging used as an online quality control tool



MAI panels attached to HD foam board

MAI-HD board fed through foaming line



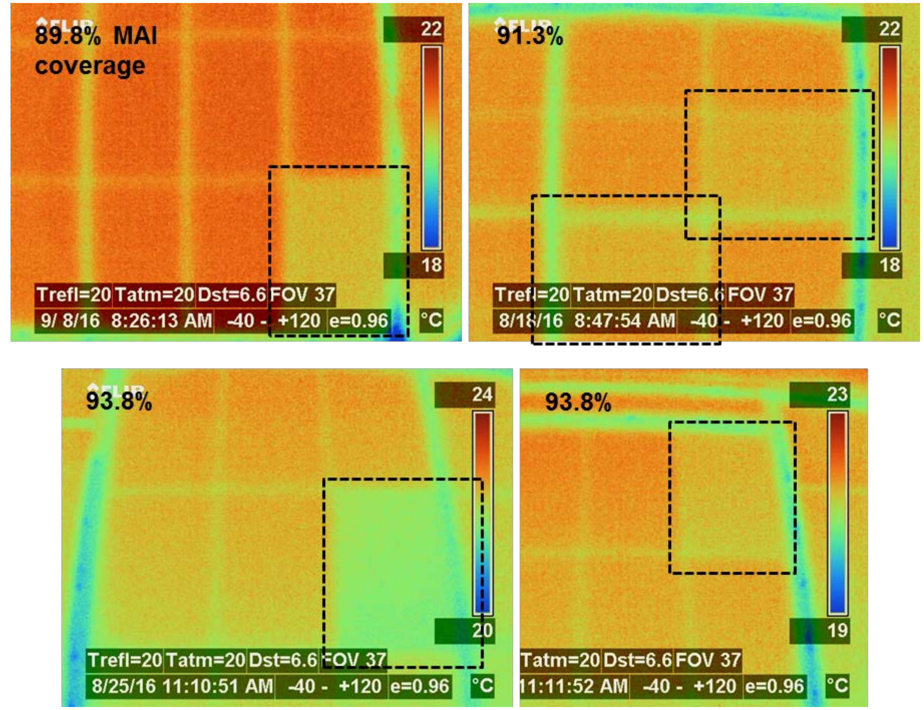
Damaged MAI panel

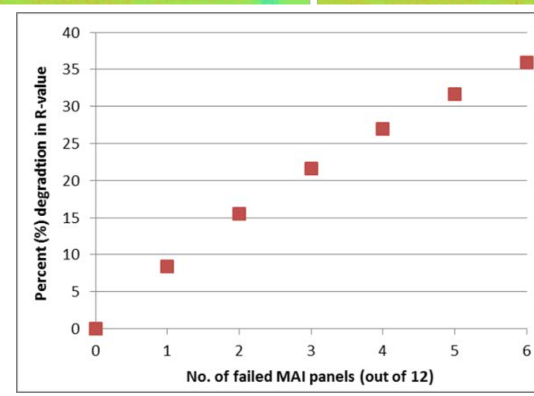
Intact MAI panel

Progress and Accomplishments

Thermal Performance Tests (ASTM C1363)

- First generation boards: R10.8/inch (*Go/No-go target: R10/inch*)
- Second generation boards: R11.4-R11.9/inch (*Go/No-go target: R12/inch*)
  - IR imaging revealed damaged MAI panels in several boards.
  - Not seen during manufacturing
- Previously, numerical modeling was performed to predict loss of R-value with damaged MAI panels
- Assuming 5% degradation, with all intact MAI panels, ***R-values of 12-12.5/inch can be expected***





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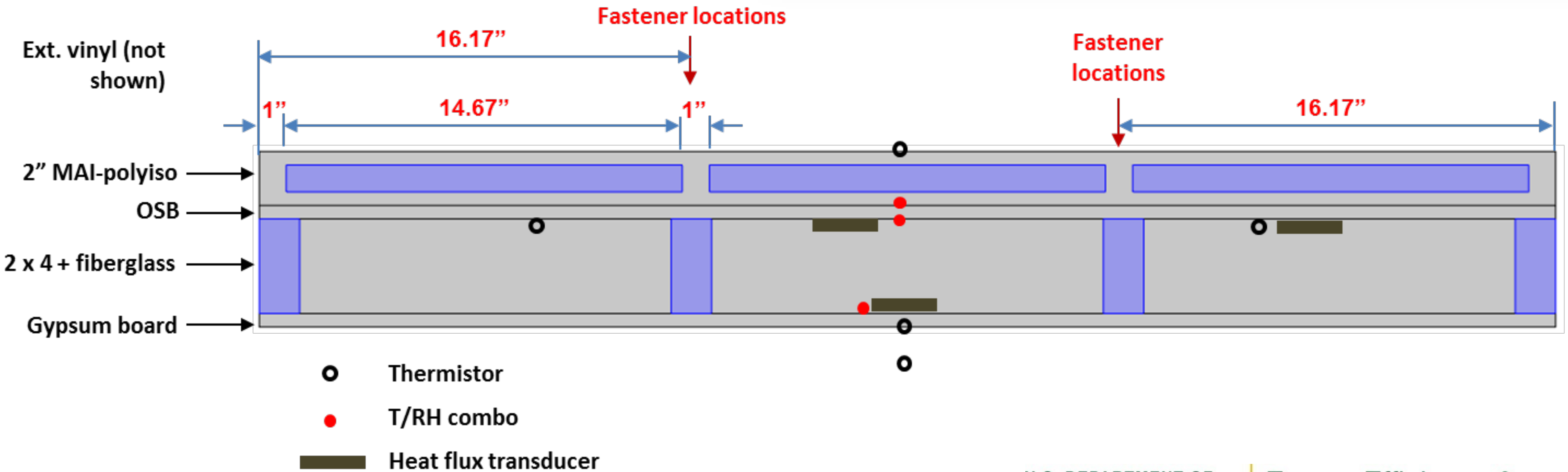
Progress and Accomplishments

Natural Weatherization Tests

- In Nov. 2016, two test walls were installed in ORNL's natural exposure test facility in Charleston, SC
- One wall with regular 2" polyiso as exterior insulation and another with the composite insulation board



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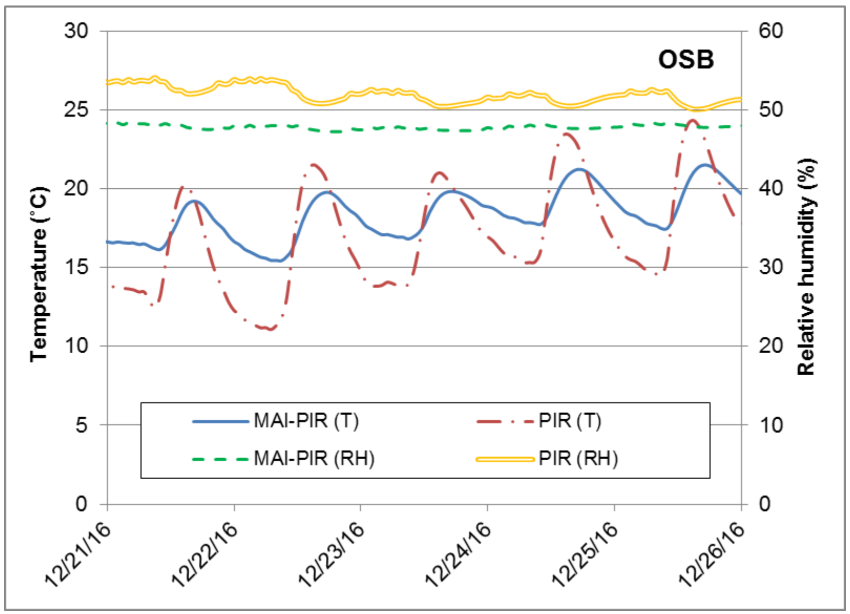
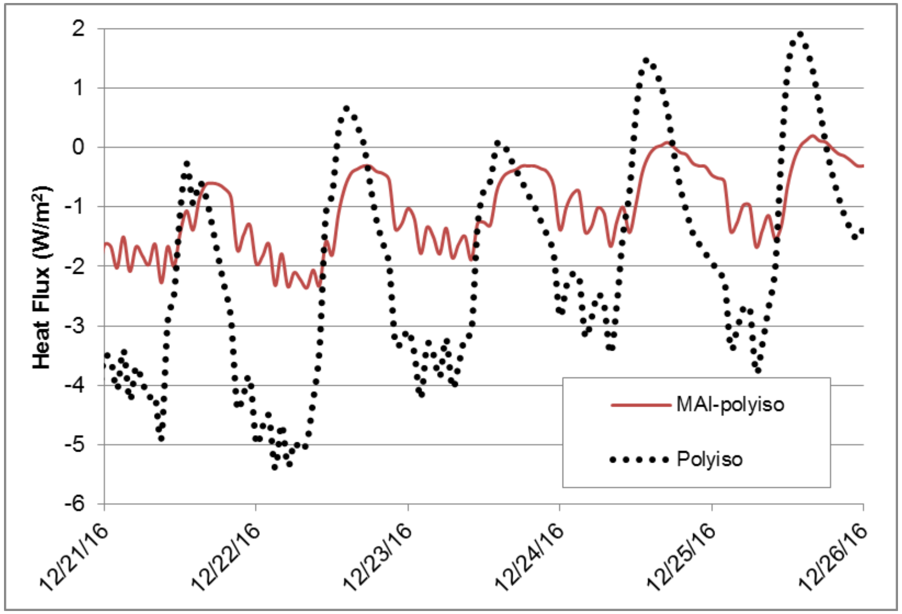
Progress and Accomplishments

Natural Weatherization Tests: Preliminary Data

- During winter, the OSB in the MAI-polyiso wall remained warmer, i.e. lower risk of moisture damage



Measured OSB temperature and RH



Measured exterior heat flows (Polyiso > MAI)

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Progress and Accomplishments

Techno-Economic Analysis

- Sept. 2015: Initial report outlining strategy
- Apr. 2016: Initial analysis report
- Dec. 2016: Phase 2 analysis report
  - Cost of equivalent 4’ x 8’ regular polyiso (4” thick): $51.00
  - Estimated cost offsets due to reduced materials, labor, transport, and handling (2” vs. 4” of regular polyiso): $2.40
  - Cost of 2” MAI-polyiso composite with $0.30/ft^2 premium: $63.00
    - Cost of polyiso portion (material, facers, etc.): $19.00
    - ***Desired cost of MAI panels: ≤ $1.40/ft^2***
  - FY14 scoping study – projected MAI cost for pilot-scale production (1.5M ft^2 per year): $4.20/ft^2

Progress and Accomplishments

Techno-Economic Analysis

- Sep 2017: Updated cost estimates to be based on 15-20M ft^2/year of MAI-polyiso composite production (1% of commercial low-slope roofing market)
  - MAI production of 12-18M ft^2/year
  - Incorporating economies of large-scale and automated production

Additional Economic Considerations

- Avoided cost of infrastructural changes - Recent study indicated savings of $200,000 in avoided construction costs by retrofitting a courthouse building roof using thin VIPs
  - R-50 Systems, LLC Saves $200,000 in Construction Costs on GSA Project (https://www.prlog.org/12600699-50-systems-llc-saves-200000-in-construction-costs-on-gsa-project.html)

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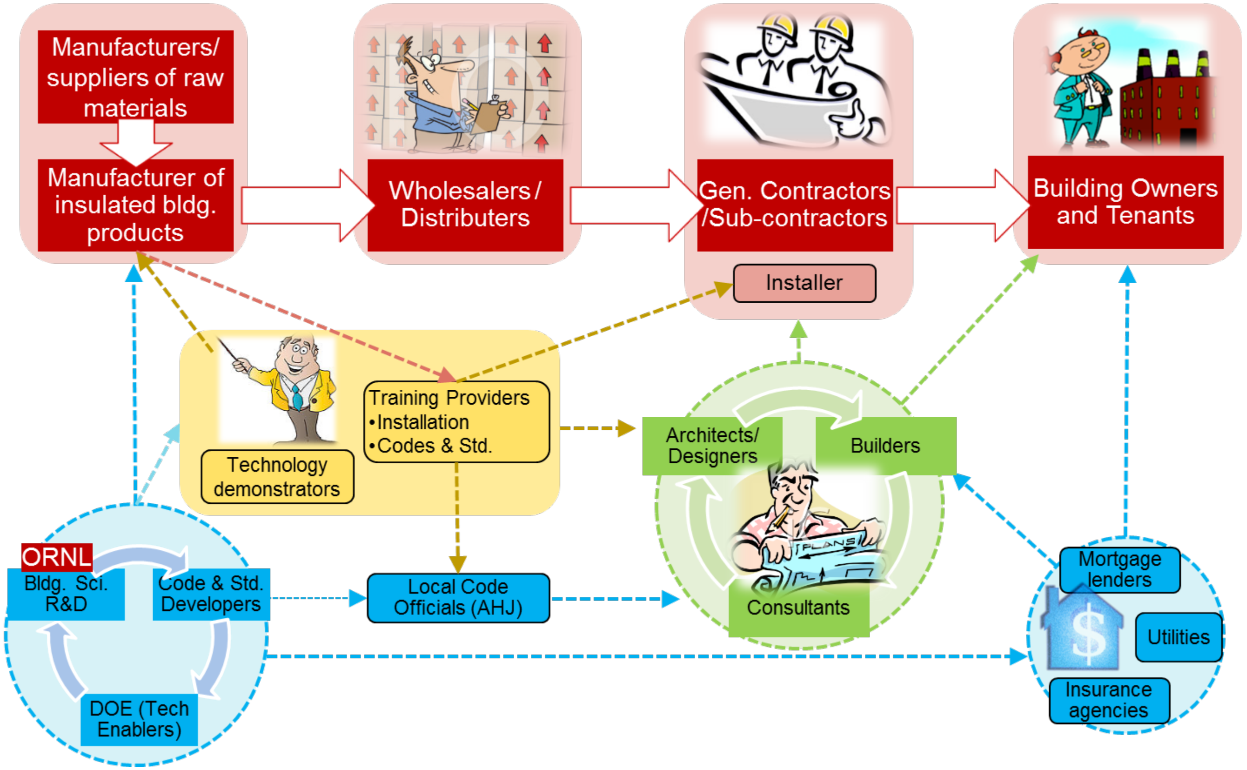
Progress and Accomplishments

Lab Corps

- In FY16, the PI participated in Lab Corps Cohort 3 and interviewed 75+ professionals related to buildings and construction
- Identifying participants and decision-makers in the insulation and building sectors



Progress and Accomplishments

Lab Corps – Key Takeaways

- Training, education and outreach are critical!
  - "Reckless roofers" – training the installers to properly handle vacuum insulation
  - "Adversarial relation between builders and code-officials" – educating contractors/builders and code-officials about new technologies

- Favorable Conditions
  - Code changes requiring increasingly higher insulation levels
  - Avoided construction costs with thinner insulation systems
    - Interview with a roofing contractor revealed costs of $50-100K in two cases

- Challenges/barriers
  - Cost!
  - Reluctance to change construction/installation practices

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 and design for manufacturing analyses will determine cost premium and/or pathways to desired cost premium and the market demand

Awards/Recognition: N/A

Lessons Learned:

- MAI panels in several insulation boards were revealed to be damaged after the March 2016 plant trials
  - IR imaging used during the trials did not show any damage, so we expect the damage to have occurred later
  - Plan is to design experiments that can reveal the cause of damage

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.

Producer of polyiso for 25 years; world's largest manufacturer of commercial roofing materials

Producer of nanoporous and *advanced* insulation materials since 1993, with >100 patents

Dr. Jim Hoff has 30+ years of experience in the buildings industry; former VP at Firestone

Communications:

- "Development of High Performance Composite Foam Insulation with Vacuum Insulation Cores," proceedings of the Thermal Performance of the Exterior Envelopes of Whole Buildings XIII International Conference, December 2016
- "Flipping the switch," R&D Magazine Article, February 2015 http://www.rdmag.com/news/2015/02/flipping-switch

Next Steps and Future Plans

Next Steps:

- Develop detailed large-scale and automated manufacturing plans for MAI and MAI-polyiso composite
  - Overall description and schematics of the production process
  - Capital and operating cost estimates; cost reductions from automated manufacturing processes
- Refined techno-economic analysis to estimate the optimized cost of the composite insulation

Future Plans:

- Detect and prevent damage to MAI panels during handling and transportation and during composite production
  - Design experiments to determine the causes and prevention measures
- Detailed aging studies, including accelerated aging tests, of MAI-foam composite to determine thermal performance over application lifetime
- Scaled-up manufacturing using the manufacturing plans developed in FY17

REFERENCE SLIDES

Project Budget

Variances: Additional $200K received from DOE in FY17 to develop large-scale manufacturing equipment configuration designs and production integration plans
Cost to Date: $1,133K
Additional Funding: N/A

Budget History					
FY2015 – FY 2016 (past)		FY 2017 (current)		FY 2018 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$1,238K	$310K	$200K	-	N/A	N/A

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Project Plan and Schedule

- Delays in modifications to subcontracts to industry partners caused a milestone to slip
- Go/no-go milestones were met at the end of FY15 and FY16:
  - o FY15 - First full-scale MAI-polyiso composites measured to be R10/inch (9/30/15)
  - o FY16 - Improved MAI-polyiso composites measured to be R12/inch (9/30/2016)

Project Schedule												
Project Start: 10/1/2014	Completed Work											
Projected End: 9/30/2017	Active Task (in progress work)											
	Milestone/Deliverable (Originally Planned)											
	Milestone/Deliverable (Actual)											
	FY2015				FY2016				FY2017			
Task	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Oct-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Past Work												
First full-scale MAI-polyiso composites measured to be R-10/inch												
Improved MAI-polyiso composites measured to be R-12/inch												
Phase 2 techno-economic analysis report												
Current/Future Work												
Internal business and market analyses justifying the investments related to automation and scaling-up the production												
Optimized cost of commercial composite insulation with R12/inch												
Refined techno-economic analysis report including final optimized manufacturing operations												
Thermal performance of composite insulation under field-testing												