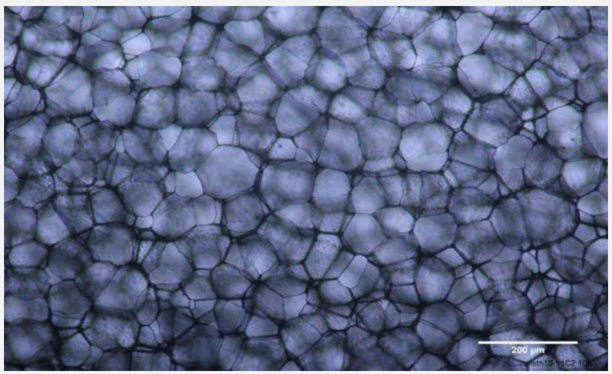
A New Generation of Building Insulation by Foaming Polymer Blend Materials with CO_2

2014 Building Technologies Office Peer Review



Cross-section of ISTN XPS board

ISTN XPS board produced in factory demonstration

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

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Project Summary

Timeline:

Start date: January 1, 2014

Planned end date: December 31, 2015

Key Milestones

1. Insulation value of R-6 per inch, pore geometry and orientation created by the foam extrusion process with 97% porosity (30 kg/m^3 density) and full-scale manufacturing costs of < \$0.40/ft^2; 12/31/14
2. Insulation value to R-9 to R-10 per inch with foaming density less than 30kg/m^3 and full-scale manufacturing costs of < \$0.70/ft^2; 12/31/15

Key Partners:

None	

Budget:

Total DOE $ to date: $50,000

Total future DOE $: $350,000

Project Goal:

Develop a new, environmentally clean building insulation with significantly superior performance but competitive costs on a per R-value basis. The key is to improve pore size, geometry, and orientation to maximize insulation value while keep using the most cost-effective foam extrusion production.

Target Market/Audience:

Residential/commercial buildings and new construction.

Previous work:

$2M DOE grant award to develop super building insulation via CO_2 foaming; fully-developed product prepared for commercialization stage

Purpose and Objectives

Problem Statement: The major technology gap in producing a superior, cost-effective building insulation is the production of submicron pores while maintaining a high porosity (>95%). In this project, our approach employs nanotechnology methods to gradually reduce pore size and implement morphology control so as to double R-value compared to state-of-the-art products, while maintaining the current cost per unit.

Target Market and Audience: The new technology will serve the residential/commercial building and new construction markets. The adoption of an advanced thermal insulation by these markets would provide annual U.S. energy savings of 0.361 Quads and $8 billion in annual economic savings.

Impact of Project: The goal of this project is to develop a super-thermal insulation with 100% greater insulation value (R-9 to R-10 per inch) and manufacturing costs that are equal on a per-R-value basis (< $0.70/ft^2$).

Achievement towards the goal will be measured by:

a. 1-year: Reaching R-6 per inch insulation (< $0.40/ft^2$) using composite materials and CO_2 foaming process in a pilot production scale, a critical building block for using further nanotechnology to improve R-6 to R-9/R-10.
b. 2-year: R-9 to R-10 per inch (< $0.70/ft^2$) at a laboratory scale.
c. 3 years: Commercialize the product via a venture capital-backed manufacturing company or strategic partnership.

Approach

Approach:

(1) Developing and commercializing HFC-free building insulation with R-value increased above R-5/inch

(2) Producing advanced foam insulation with pore morphology control and CO_2 foaming so that R-6/inch foam building insulation can be manufactured with a competitive cost

(3) Incorporating material nanotechnology to improve foam insulation value to R-7~10/inch at laboratory scale in two years, and subsequently commercializing this new product in the building materials market with a venture-capital supported project from years 3 to 5.

Key Issues:

(1) Increasing insulation (R/inch) value while reducing the total cost on a per-R-value installed basis

(2) Directly implementing technologies in most cost-effective foam extrusion product process

(3) Significantly reduce pore size and control pore geometry in a fast foaming process

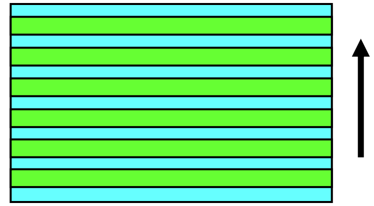
Distinctive Characteristics:

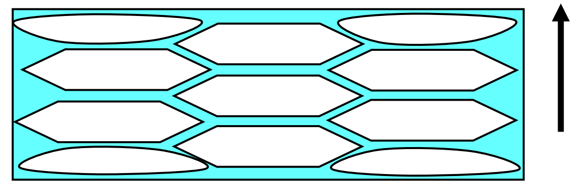
(1) If technology development is successful, the impacts to market and energy savings are immediately accomplishable

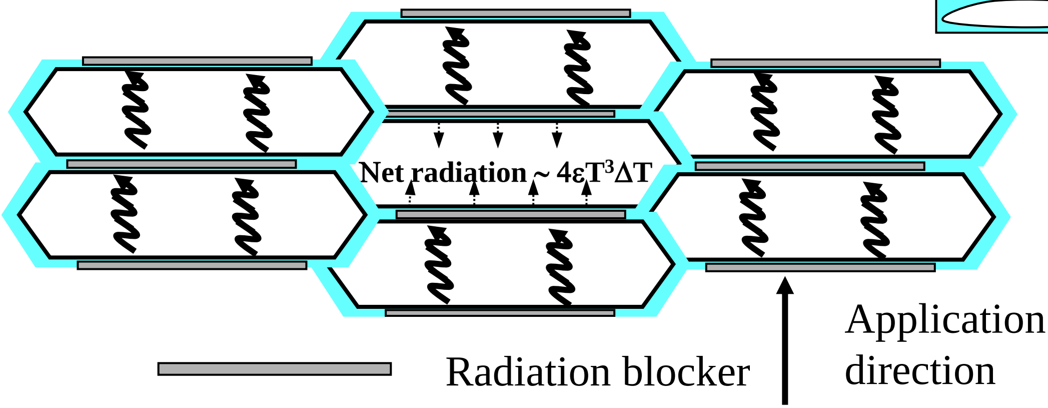
(2) The technology will lead to an advanced insulation with the least material consumption and lowest processing cost

ISTN Technology Innovations

(1) Aligning oblate (disk-shape) pores against heat flow direction to reduce thermal conductivity in application direction – increasing R ***from R-4.2/inch to R-5.5/inch***.

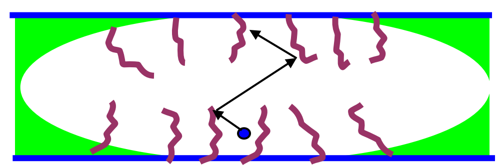




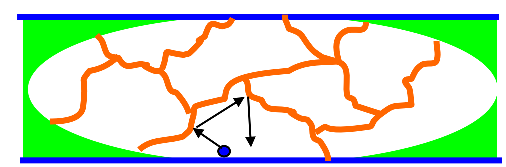


(2) Adding reflective or absorptive radiation blockers in a layered structure can minimize radiation loss – increasing R ***from R-5.5/inch to R-7/inch***.

(3) Secondary nanostructure (< **100 nm**) to enhance collisions with air molecules – increasing R ***from R-7/inch to R-10/inch***.



Surface incorporated structure



Intertwined structure within a pore

Progress and Accomplishments

Lessons Learned:

Factory trial – Die modification is substantially more difficult at larger scales due to the very high throughput

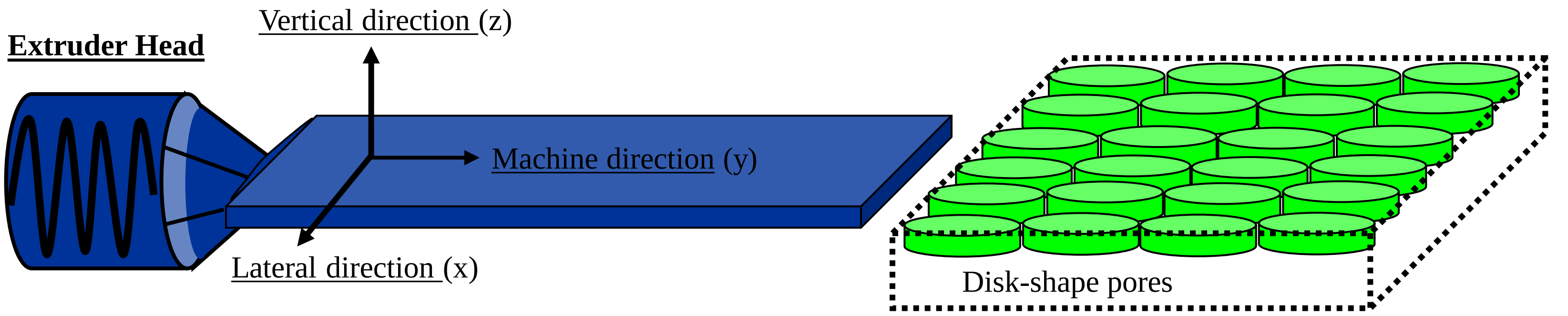
Accomplishments:

Previous project – Developed a cost-effective, commercial-stage R-5 per inch building insulation produced via environmentally clean CO_2 foaming process.
Current project – Achieved lower foam density of 40 kg/m^3 at pilot scale compared to Q1 milestone of 50 kg/m^3.

Market Impact:

Previous project – Extensive factory trial and performance testing data demonstrating R-5 per inch insulation value, and market-competitive production costs of ~$0.30/ft^2. These milestones make the product commercialization-ready by being equivalent to state-of-the-art product, but manufactured using CO_2 rather than environmentally harmful HCFCs.

Program Status and Following Progress



- Full-capacity factory trial was successfully carried out on October 20-23, 2012 at Hoswell Shanghai insulation plant
- Commercial size insulation boards were produced without using any HFC and the products demonstrated exceptional insulation compared to any samples made by CO_2 blowing in previous experiments
- Aging studies of thermal conductivity and dimensional stability are still in progress in collaboration with Oak Ridge National Lab and Hoswell

Project Integration and Collaboration

Project Integration:

(1) Collaborating with a major manufacturer in China to conduct trials at a factory production line

(2) Closely working with a world renowned foam extrusion equipment supplier on testing die design configurations and alterations

(3) Potential commercialization agreements with several large insulation and chemicals companies to accelerate market adoption

Communications:
ET/BA workshop

Next Steps and Future Plans

Next Steps and Future Plans:

- Project period:
  - Optimize polymer blend composites and foaming production process to create R-6 per inch product at most effective cost
  - Incorporate nanotechnology structures into material and production process to increase R-value (R-9 to R-10) and maintain cost efficiency
  - Identify commercial partner to expedite time-to-market
- Longer-term:
  - Produce the new technology at a large-scale and make it the primary building insulation in the US and other markets
  - Significant U.S. energy and economic savings of 0.361 Quads and $8 billion on an annual basis
  - Apply the technology platform created in this proposal to other insulation applications, such as refrigeration and high-temperature, which are also extremely important markets for energy conservation

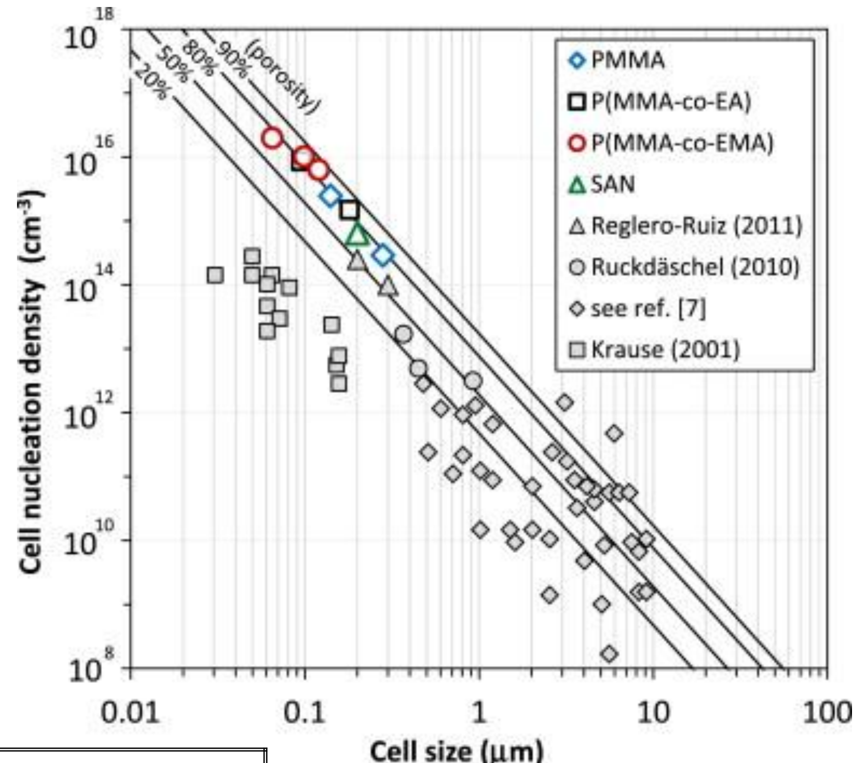
Homogeneous Nucleation is the Challenge

$$P_{in} - P_{out} = \Delta P = \frac{2\sigma}{r}$$

$$\Delta G_a = \frac{4\pi r^2 \sigma}{3} \qquad \Delta G_a = \frac{16\pi\sigma^3}{3(\Delta P)^2}$$

1st stage – Nucleation and Growth,
110 to 50 bar (as rapid as possible)

2nd stage – Expansion
50 to 1 bar (within 5 second)



σ (dyne/cm)	Nucleus radius (Δp = 2σ/r = 60 bars)	Nuclei density (/cc) (Estimated)	Pore size after growth stage	Pore size after expansion
20	6.67 nm	6×10^8	8 micron	25 micron
15	5 nm	5×10^{15}	32 nm	100 nm

<u>Reducing pore size to submicron while keep porosity high (>95%) is extremely difficult.</u>

"Low density thermoplastic nanofoams nucleated by nanoparticles", Stephaney Costeux , Lingbo Zhu, Polymer, Volume 54, Issue 11, 2013, 2785 - 2795