Low-Cost Haziness-Free Transparent Insulation Based o Hierarchical Porous Silica Particles

2015 Building Technologies Office Peer Review

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

Jaswinder Sharma, sharmajk@ornl.gov; ORNL

Project Summary

Timeline:

Start date: 10/01/2014

Planned end date: 09/30/2016

Key Milestones:

1.Particles with 0.5% light scattering and air volume ≥80%; 09/30/2015

2.Insulation material with ≥ 80% visible transmittance (09/30/2016)

Budget:

Total Project $ to Date:

- DOE: $473,631
- Cost Share: $75,000

Total Project $:

- DOE: $473,631
- Cost Share: $75,000

Key Partners:

The main partner in the project is VELUX®

We have initiated communications with many other industry partners who can synthesize the material at large scale

Project Outcome:

A thermal insulation material with a:

- Visible transmittance ≥80%
- Haze ≤ 0.5%
- R-value ≥ 5
- Premium cost ≤ $6/ft^2$

Purpose and objectives: Problem Statement

Why window insulation?

- Buildings consume 40% of energy in USA
- Energy loss through windows makes 10-15% of that 40% energy

Current Insulation approaches

- Air/Argon/Krypton/Xenon filling
- Vacuum insulation
- Aerogels (emerging technology)

Challenges to current approaches

- Cost
- Durability
- Retrofitting
- Leakage
- Visible transmittance/Haze

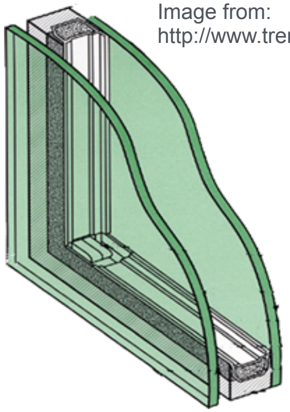


Image from: http://www.trendwindows.com/terminology.html

Double pane windows

VELUX®
SKYLIGHTS

Skylights

Image from: http://www.copelandroofing.com/images/velux-skylight.gif)

Purpose and objectives: Target market and audience

Heat loss through windows and skylights ≈ 5.2 quads of energy in USA

Assuming developed technology saves 10% of energy, 0.52 quads of energy will be saved

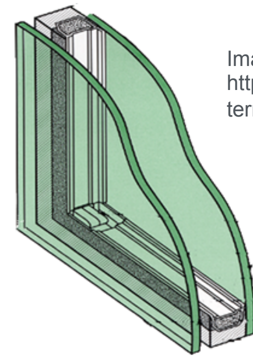
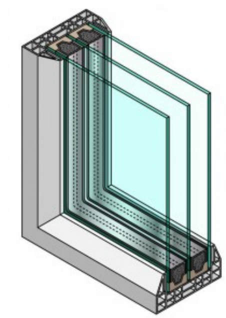


Image from: http://www.trendwindows.com/terminology.html

Double pane windows



Triple pane windows

Image from: https://modernize.com/windows/energy-efficient/ triple-pane-windows

The maximum number of sales units that could be achieved

Glazing type	Number of units
Residential glazing	20,500,000
Residential doors	6,486,000
Skylights	683,000
Commercial windows	43,355,000
Total	71,024,000
Triple glazed and similar high performance units make 1.4% of the total	2,151,500

Source: WDMA Window and Entry Door Industry, 2014 US Market Study

VELUX SKYLIGHTS

Skylights

Image from: http://www.copelandroofing.com/images/velux-skylight.gif)

Purpose and objectives: Project impact

Final product

At the end of the project, a thermal insulation material that can provide a R-value 5, but with a visible transmittance ≥ 80% and haze ≤ 0.5% is expected at a premium cost of $6/ft^2$

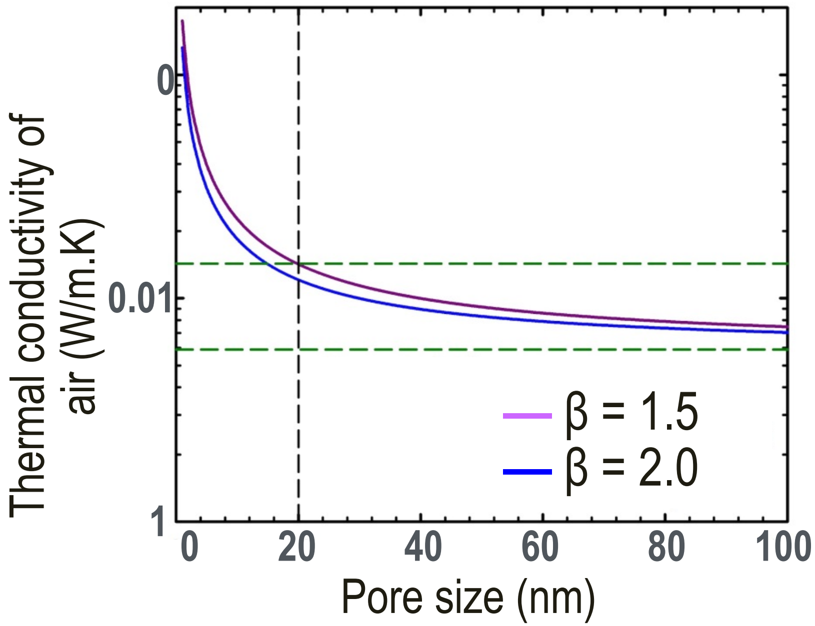
Outcome

— Near term outcome: Material scale up

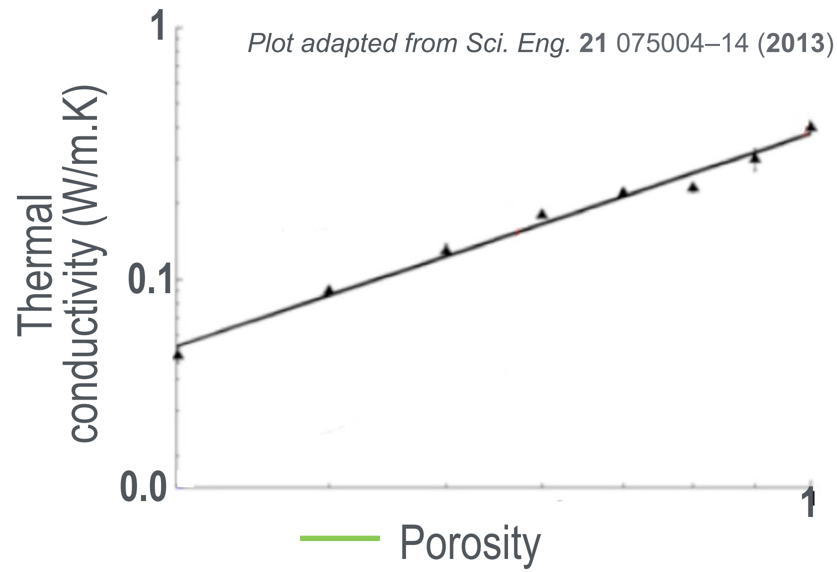
— Intermediate outcome: Inclusion of the technology in prototype units and their lab scale testing

— Long-term outcome: Market penetration – At a minimum, 2.1 million windows/skylights in commercial and residential buildings

Approach: Scientific principles



Effect of pore size on the air thermal conductivity *(Knudsen effect)*



Effect of porosity on thermal conductivity of porous silica

$$S \propto \frac{d^6}{\lambda^4}$$

*where '**S**' is Rayleigh scattering; '**d**' is the diameter of a particle or an interacting unit; and '**λ**' is the wavelength of interacting light*

Particle size and light scattering *(Rayleigh scattering)*

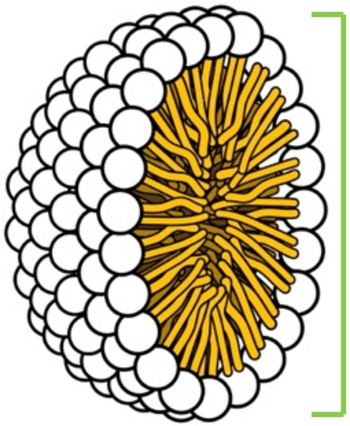
Approach: methodology

➢ Thermal insulation
- Pore size control by micelle size
- Particle size control by manipulating reaction parameters

➢ Visible transmittance and haze
- Keeping the particle and pore size very small compared to the visible light wavelength

➢ Cost and scalability
- Room/low temperature synthesis and processing
- Methods other than supercritical drying

From: https://en.wikipedia.org/wiki/Micelle#/media



Micelle size
≈ Pore size
≈ (2-7 nm)

Micelle

Nanoparticle solution

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

Key Issues and Distinctive Characteristics

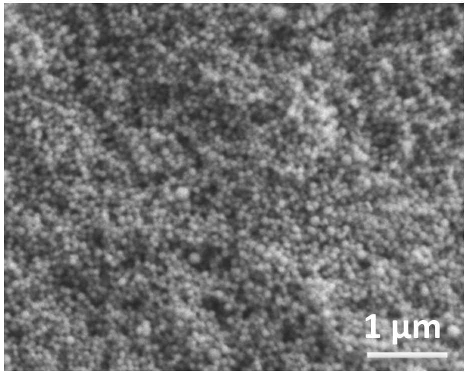
Key issues

- Solvent removal from the pores
- Pore collapsing

Distinctive Characteristics (compared to aerogels)

- **Low cost**— no costly drying step (supercritical drying) that is used for aerogel synthesis
- Minimal haze
- High visible transmittance
- Better mechanical properties

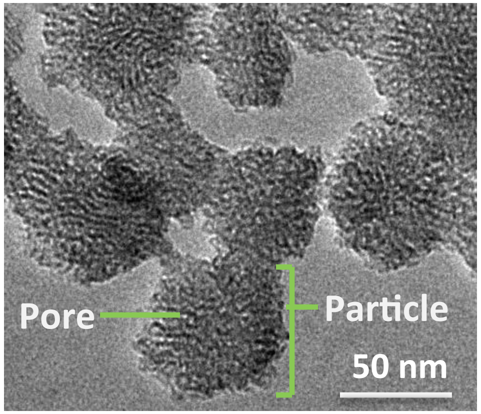
Progress and Accomplishments: Porous silica particles



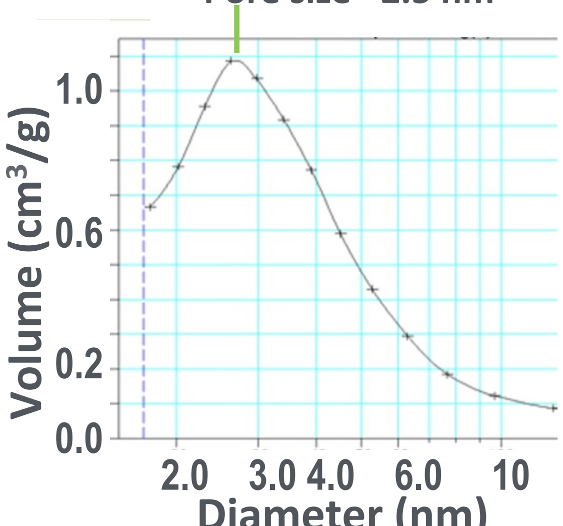
SEM image of particles with an average diameter ≈60 nm

Scaled up particles

Particles in insulated sample box



TEM image of particles



BJH analysis for pore size

Density = 0.3g/cm^3
Amorphous silica density = 2.2 g/cm^3

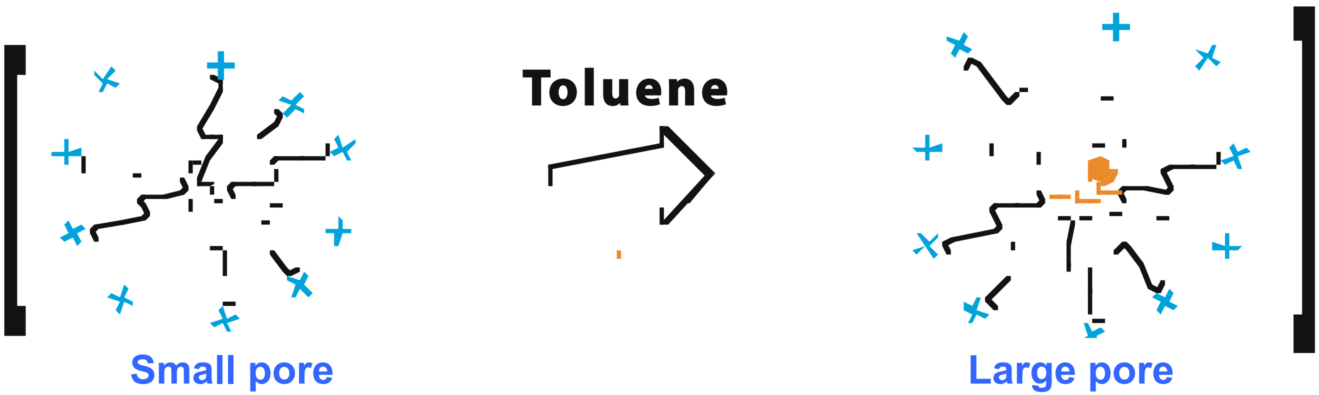
% of solid silica = 0.3/2.2 x 100 = 13.63

% of air volume = 100 – 13.63 = 86.37

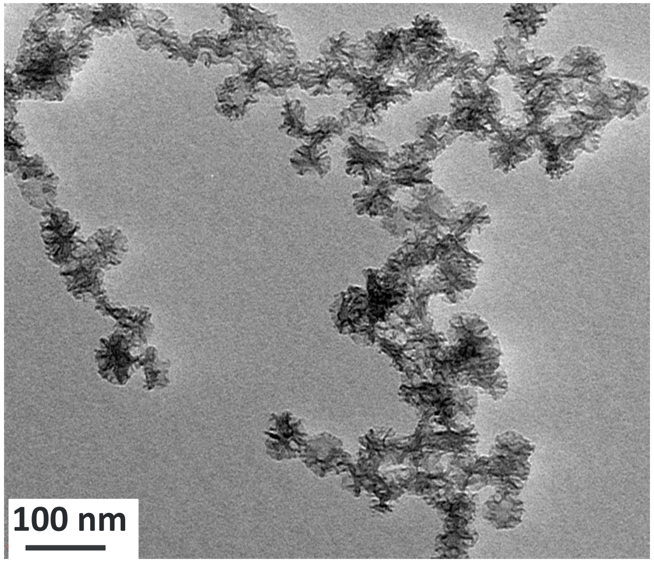
Thermal conductivity= 0.038 W/m.K

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

Progress and Accomplishments: Pore size tuning



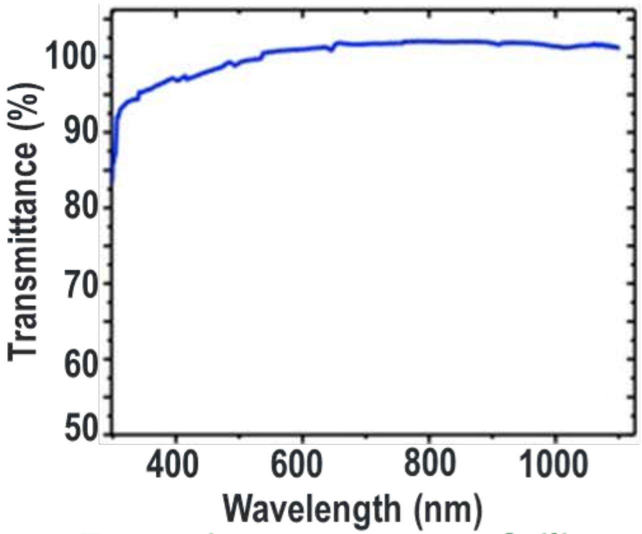
Toluene increases the micelle size (pore size≈ 4 nm)



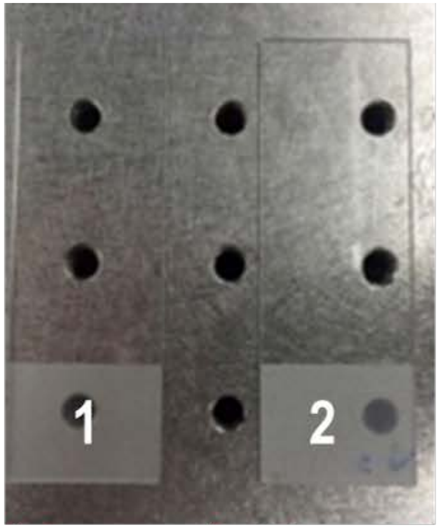
TEM image of porous silica particles with a pore size ≈ 4 nm

- Average particle size 60 nm
- Pore size ≈ 4 nm
- Thermal conductivity = 0.032 W/m.K
- By tuning the pore size thermal conductivity of the particles can be tuned

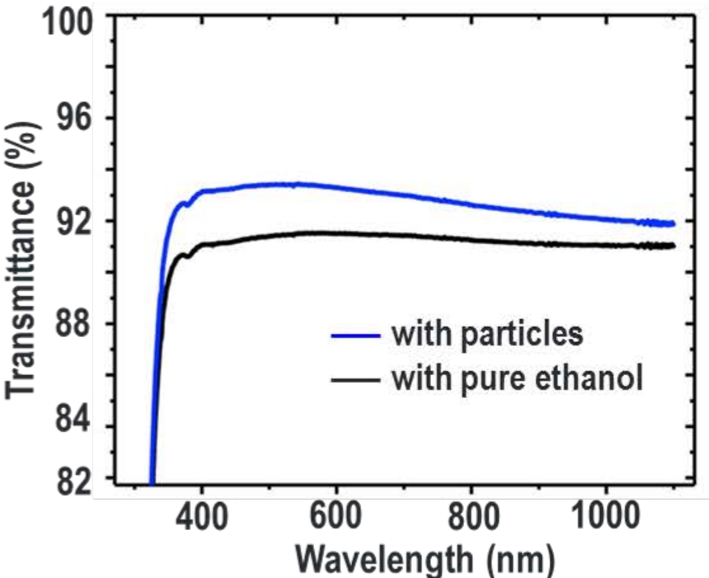
Progress and Accomplishments: Particles with ≤0.5% light scattering



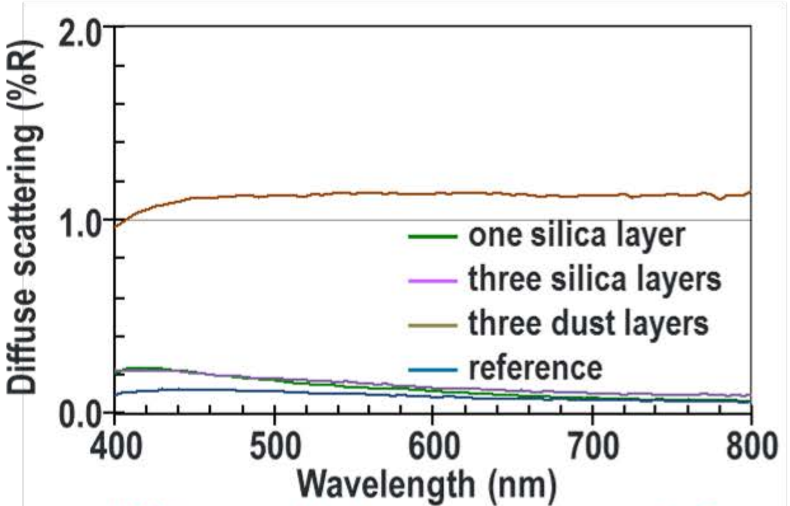
Transmittance spectra of silica particle solution in ethanol



Slides coated with particle solution (1) and pure ethanol (2)



Transmittance spectra of particle and ethanol coated slides



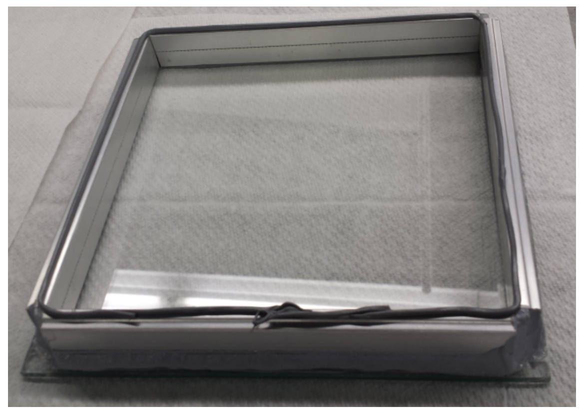
Diffuse scattering measurement of silica particles

- Unaggregated silica particles with size ≈ 60 nm don't scatter visible light significantly
- Thin layers show anti-reflection effect

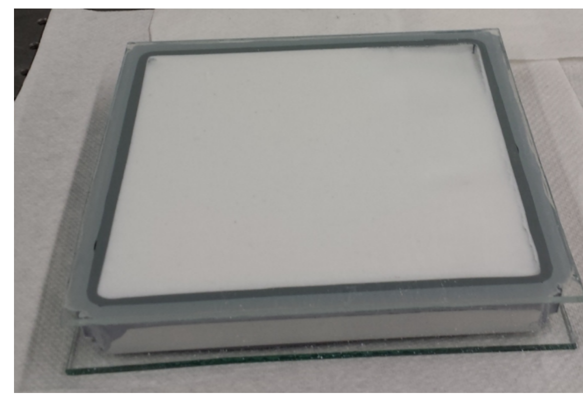
Progress and Accomplishments: Scale up

- Process is scalable
- Less costly
- Reproducible

Porous silica particles



Unsealed prototype without particles



Sealed prototype with particles

Challenges faced

- Particle filling
- Possible health hazards
- Particle aggregation (transparency)

Progress and Accomplishments: Hybrid silica gel (new focus)

Expected advantages compared to aerogels:

- Better mechanical strength
- Less pore collapsing
- Better pore size control
- Potential for scale up
- Less expensive
- High visible transmittance
- Less haze

Hybrid silica gel

Market impact

Market Impact

– The technology could result in an energy savings of 0.52 quad/yr ($1.51 billion/yr) and 26.78 billion kg of CO_2 emission reductions

– Other possible impacts of the technology are: incorporation of the developed material in insulation materials for refrigerators, cryogenic hydrogen storage, and coatings for windows

Efforts done to accelerate the impact

– Efforts are in progress to collaborate with new industry partners who can help in manufacturing the material at industry scale

- New collaborations with industry partners and universities are initiated to utilize the knowledge and materials obtained from this project for developing insulating, transparent, and retrofittable coatings and films for windows

Actual impact could be more than expected as the initial assessment did not include the use of developed material in single pane windows

Project Integration and Collaboration

Project Integration:

•Project team has already contacted potential industry partners that can help in industrial scale manufacturing and in bringing the technology to market quickly

•Based on results obtained from the current project, the team has already started collaboration with new industry partners

Partners, Subcontractors, and Collaborators:

The project includes a formal partner VELUX®

•Other partners that can help in the industrial scale manufacturing of the material (have been contacted)

•New collaborations with universities and many industry partners have been initiated to employ the developed technology for insulation products

Communications:

1. Colloidosome like structures: Self-assembly of silica microrods, RSC Adv., **6**, 26734 – 26737, 2016 (*impact factor 3.84*)
2. One manuscript is ready for submission in a high impact (≈*18*) journal.

Next Steps and Future Plans

- Select and optimize methods to remove the solvent from inside the pores of the newly developed material

- Measure the optical and thermal properties of the developed material

Funding

- Efforts to achieve funding from potential sponsors such as BTO (BENEFIT), ARPA-E (SHIELD), VTO (hydrogen storage), have been initiated

- One industry partner is interested in funding the next stage of work

REFERENCE SLIDES

Project Budget

Project Budget: $289,000 in FY 2015 and $184,631 in FY 2016
Variances: NA
Cost to Date: $90 K (50% of FY16)
Additional Funding: NA

Budget History			
10/01/2015– FY 2015 (past)		FY 2016- 09/30/2016 (current)	
DOE	Cost-share	DOE	Cost-share
$289,000	25,000	$184,631	$50,000

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

Project Plan and Schedule

Project Schedule	
Project Start: 10/01/2014	Completed Work
Projected End: 09/30/2016	Active Task (in progress work)
	Milestone/Deliverable (Originally Planned)
	Milestone/Deliverable (Actual)

Task	FY2015				FY2016				FY2017			
	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												
M1.1: Identify optimal particle size and air volume												
M1.2: Identify the pore size and porosity of particles												
D1.3.1: Present Inititial transition strategy for project												
M1.3.1: Create Input for BTO prioritization tool												
M1.2.1: Porous particles with air volume ≥70%												
M1.2.2: Porous particles with air volume ≥80%												
D1.3.1: Market strategy and commercialization plan												
M1.2.3: Particles with ≤0.5% visible light scattering and 80% air volume												
Go/No-Go decision												
1. Particles with ≤0.5% light scattering												
2. Particles with ≥ 80% air volume												
3. Particles with thermal conductivity ≤ 0.015 W/m.K						Project focus changed from achieving lower thermal conductivity of porous particles alone to achieving a high visible tranmittance, low haze, and lower thermal conductivity of final product						
4. Particles with a cost $3 for filling a 6x6x0.75 inch cavity												
5. Obtain a letter of interest from industry partner capable of manufacturing silica particles at scale												
M2.1: A 6x6 inch cavity filled with porous material												
D2.5.1: Updated strategy for securing next round of funding and coordination activities with industrial partner(s)												
Final Deliverable												
DQ8: A 2 x 2 inch hybrid gel made by incorporating porous silcia particles, with ≈ 80% visible transmittance and 0.032 W/m.K thermal cnductivity												

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