Glass Performance Days 2025

10 – 12 JUNE 2025 | NOKIA ARENA - TAMPERE, FINLAND

GLASS PERFORMANCE DAYS 2025

Breakthroughs in Aerogel Technology: Opportunities and Challenges

AARON BASKERVILLE-BRIDGES | AEROSHIELD MATERIALS

AeroShield

The clear choice for window insulation

Elise Strobach, PhD
Founder & CEO
Strobach@aeroshield.tech

Aaron Baskerville-Bridges
Co-founder & VP of Operations
BaskervilleBridges@aeroshield.tech

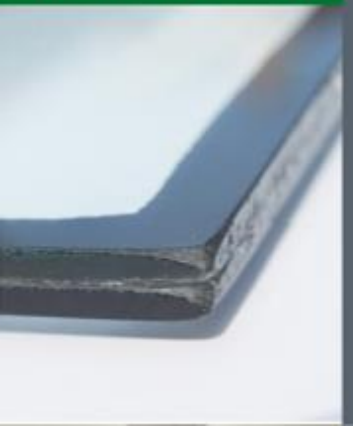
Kyle Wilke, PhD
Co-founder & CTO
Wilke@aeroshield.tech

Agenda

- ❑ The promise of aerogels
- ❑ Historic challenges with aerogels
- ❑ Recent advances in aerogel technologies
- ❑ Opportunities & challenges going forward

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY



Pathway to Zero Energy Windows

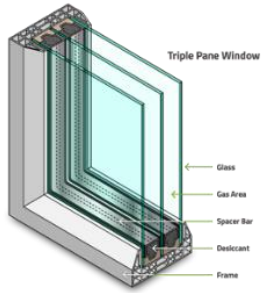
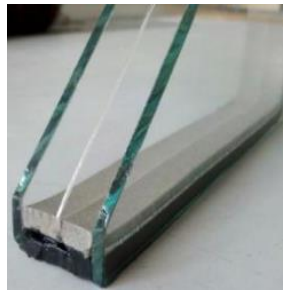
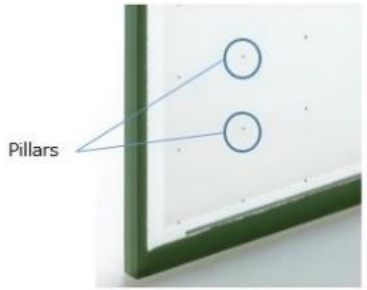
Advancing Technologies and Market Adoption

April 2022

Target whole-window U-Factors for DoE:

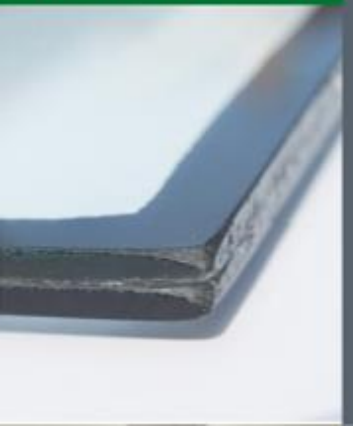
U < 0.17-0.077

<$2-$6/sqft premium to double

Established Technology	State of the Art		
Triple pane	**Aerogel double pane**	**Thin triple**	**Vacuum insulated glass**
Three panes of glass with two gas layers (typically argon)	Aerogel sealed inside a double pane IGU with gas layer	Third ultra-thin pane and two gas layers at double pane thickness	A vacuum between two panes separated by micro-pillars
			

U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY



Pathway to Zero Energy Windows

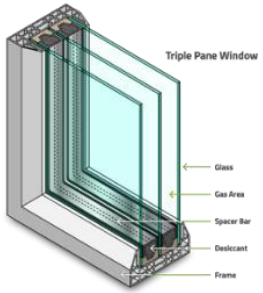
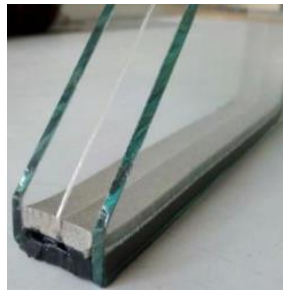
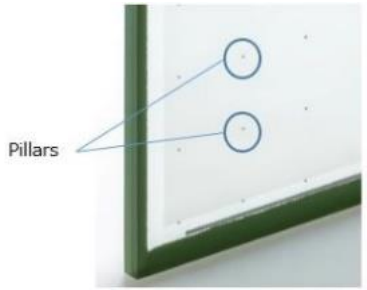
Advancing Technologies and Market Adoption

April 2022

Target whole-window U-Factors for DoE:

U < 0.17-0.077

<$2-$6/sqft premium to double

Established Technology		State of the Art	
Triple pane	**Aerogel double pane**	**Thin triple**	**Vacuum insulated glass**
Three panes of glass with two gas layers (typically argon)	Aerogel sealed inside a double pane IGU with gas layer	Third ultra-thin pane and two gas layers at double pane thickness	A vacuum between two panes separated by micro-pillars
	 **Focus today**		

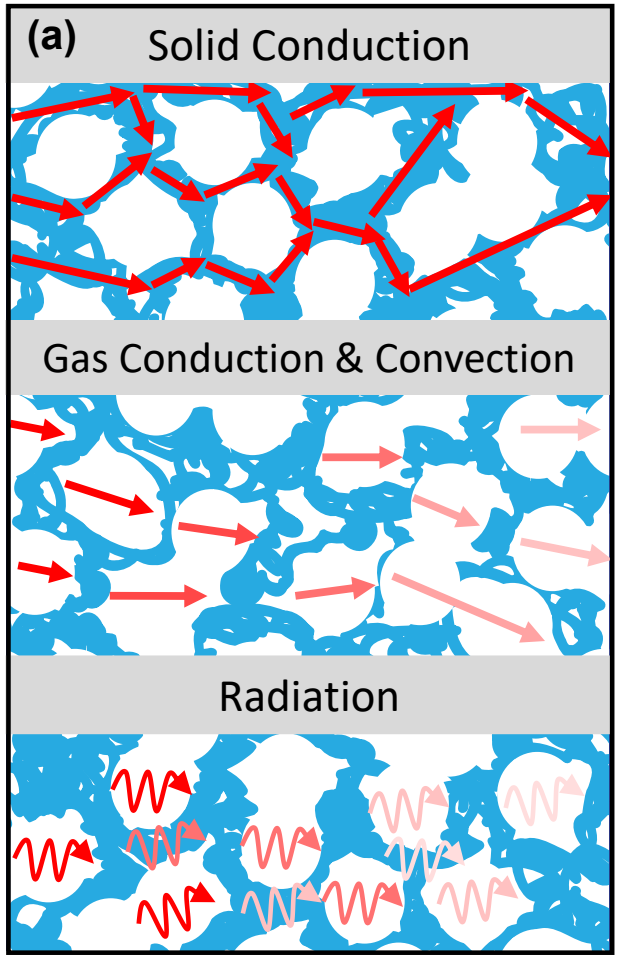
What Are Aerogels?

Aerogels are ultralight, highly porous materials known for their exceptional thermal insulation properties and low density.

NASA. (n.d.). Aerogel. NASA Stardust. Retrieved October 9, 2024, from https://curator.jsc.nasa.gov/stardust/aerogel.cfm

The Science Behind Superior Insulation

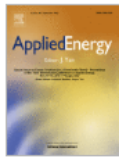
- Minimal Solid Conduction
  Material occupies only a small fraction of the volume, resulting in low density and therefore limited heat conduction.
- Restricted Gas Conduction/Convection
  Extremely tiny and complex network of pores traps air, significantly reducing gas conduction and convection.
- High Radiative Heat Transfer
  Ineffective at blocking infrared radiation, making them ideal for northern climates when combined with low emissivity coatings.



Additional Sustainability Benefits: Embodied Carbon

ELSEVIER

Applied Energy
Volume 97, September 2012, Pages 396-404



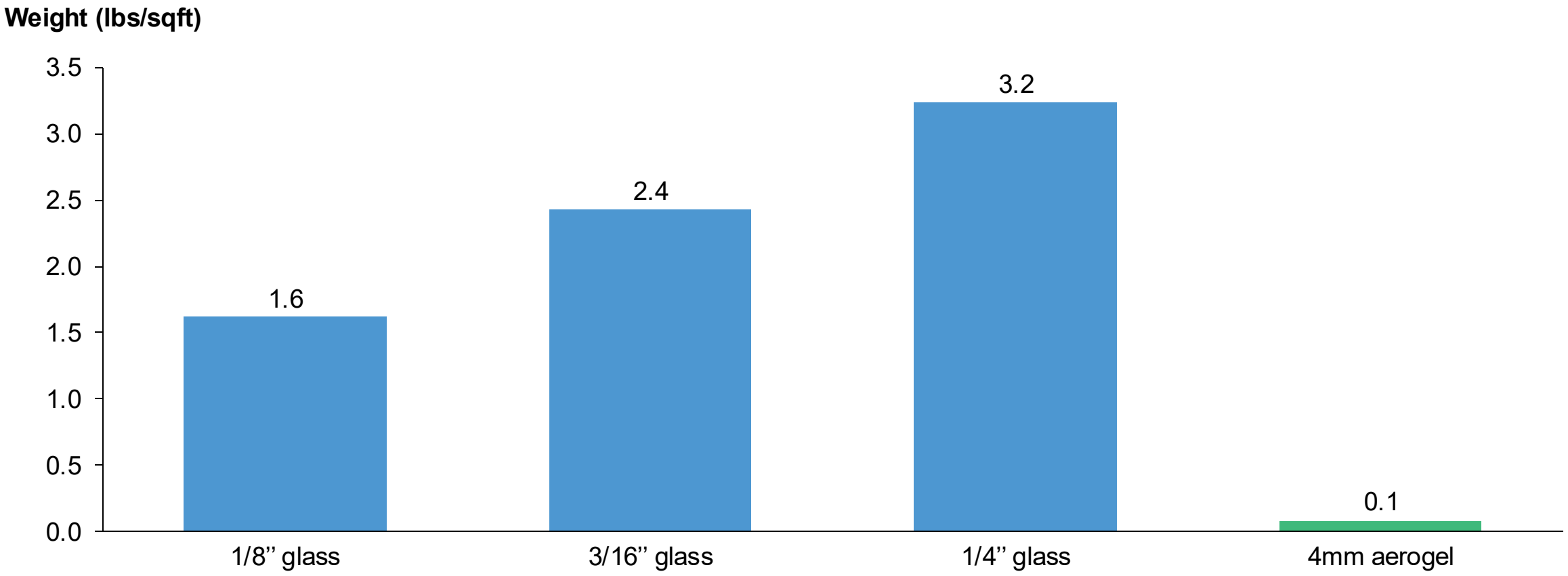
Streamlined life cycle assessment of transparent silica aerogel made by supercritical drying

"Parity between the CO2 burden and CO2 savings is achieved in less than 2 years, indicating that silica aerogel can provide a measurable environmental benefit."

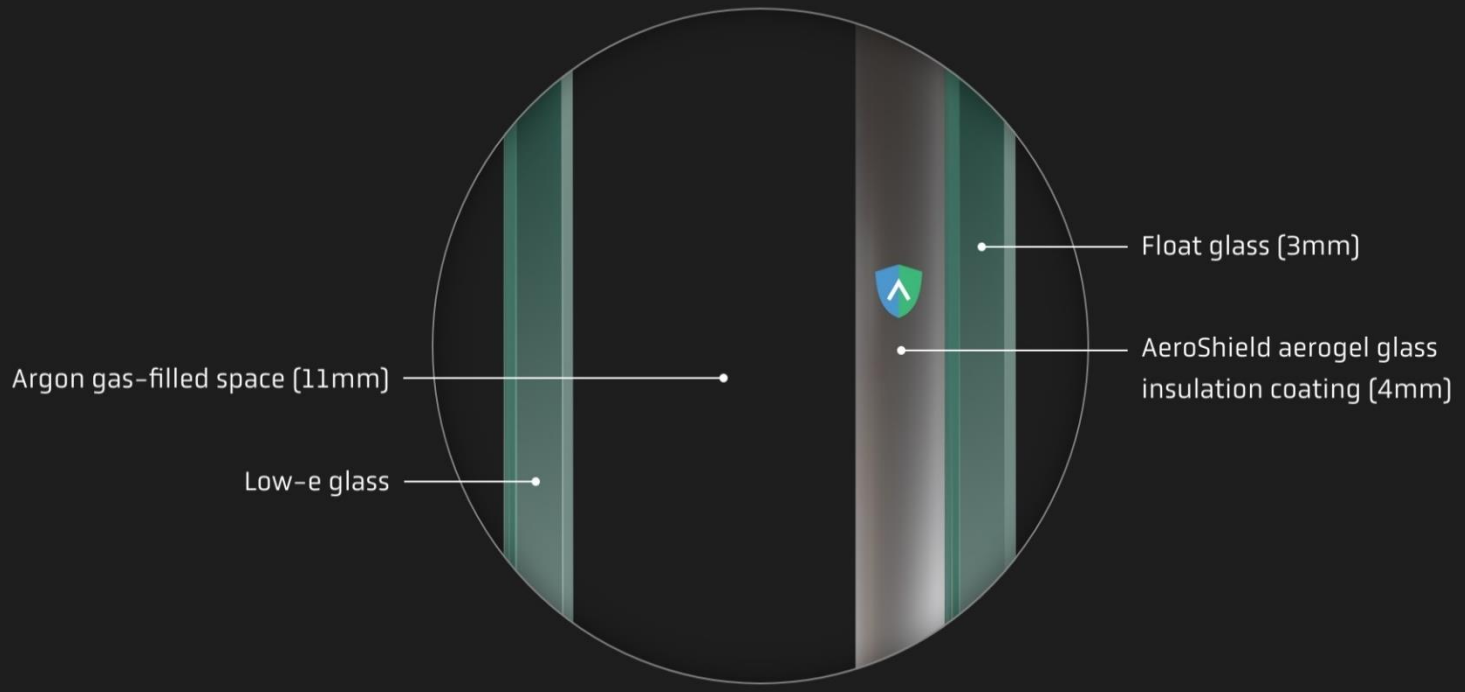
BOUNDLESS
IMPACT RESEARCH & ANALYTICS

"AeroShield's GHG Footprint is, on average, lower than all competing methods of thermal insulation technologies assessed in this report."

Additional Sustainability Benefits: Reduced Weight of High-Performance Unit

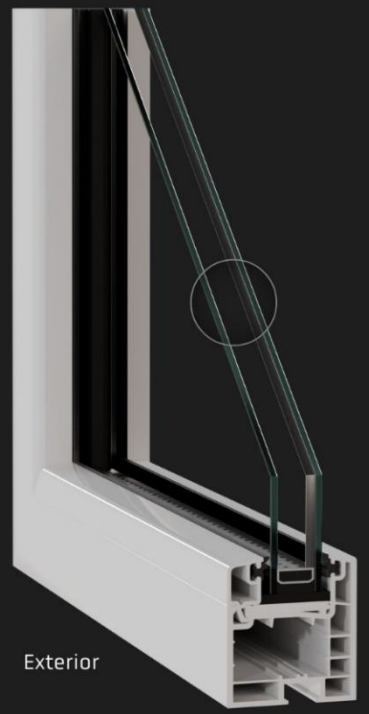


The promise of aerogels: improved thermal performance in a standard IGU stack



Aerogels bonded to glass inside the IGU, opposite Low-E

Aerogel bonded to glass like a macro-coating, opposite low-e coating, to dramatically improve U-Values



Resulting aerogel insulated unit drops into standard frames

Aerogel insulated units provide improved U-Values at same thickness and weight as standard IGUs, use standard frames

History of Aerogels

Why Has It Taken So Long to Adopt?

Historically, aerogels have been too hazy for use in standard window applications

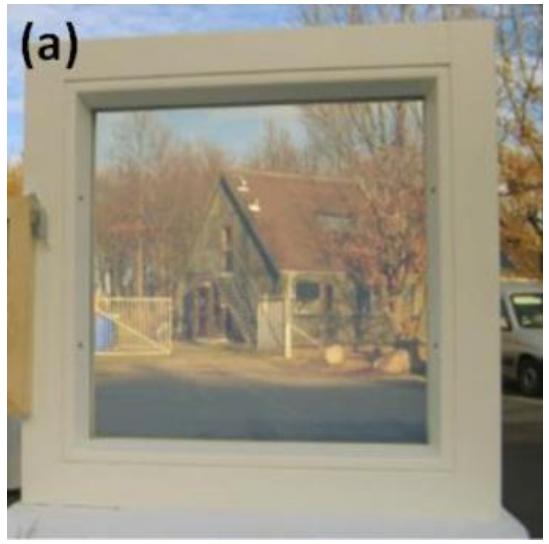
1992
T_{vis} < 76%

Wittwer V. Development of aerogel windows. *J Non Cryst Solids*. 1992.

1998
T_{vis} < 75%

Duer K, Svendsen S. Monolithic silica aerogel in super-insulating glazings. *Sol Energy*. 1998.

2016
T_{vis} < 80%

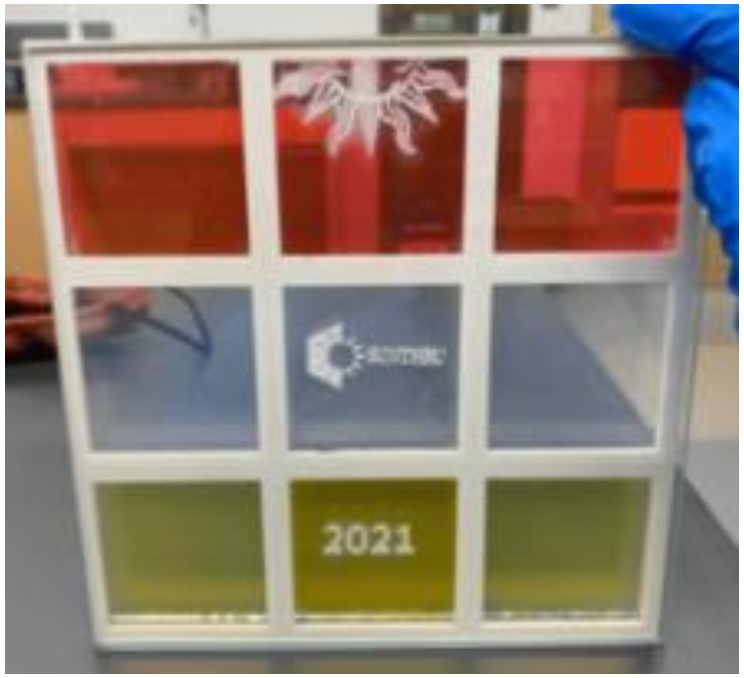


Gao, Tao & Jelle, Bjørn & Gustavsen, Arild. Building Integration of Aerogel Glazings. *Procedia Engineering*. 2016.

Early aerogel manufacturing could only achieve small sizes and tiled prototypes

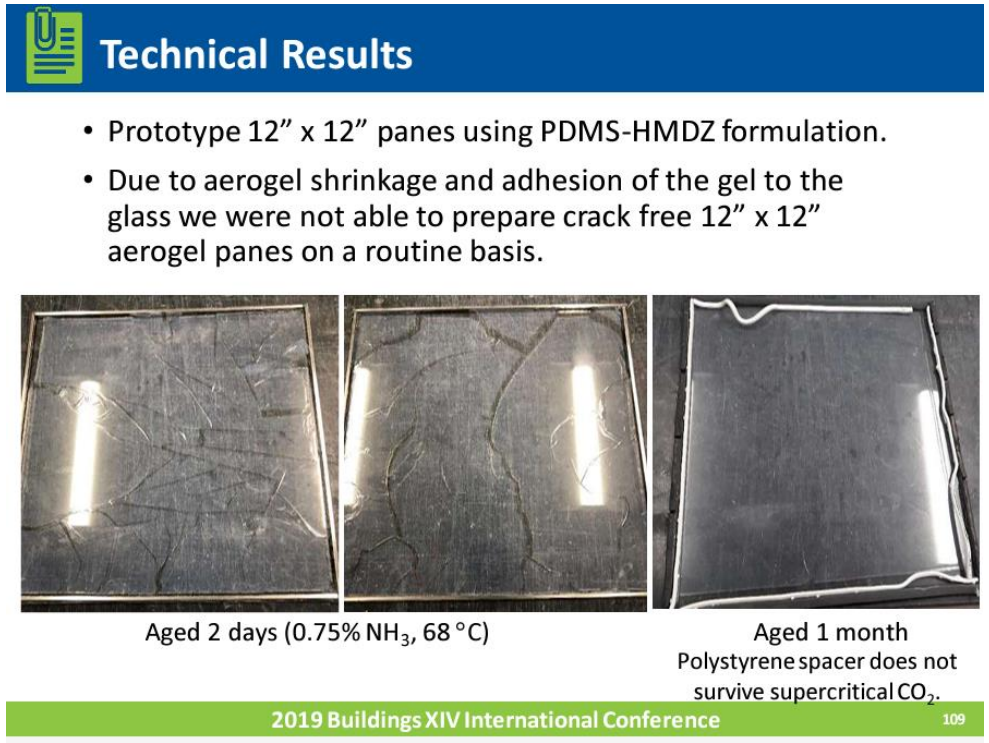
Source: Tiem Factory

Source: AeroShield



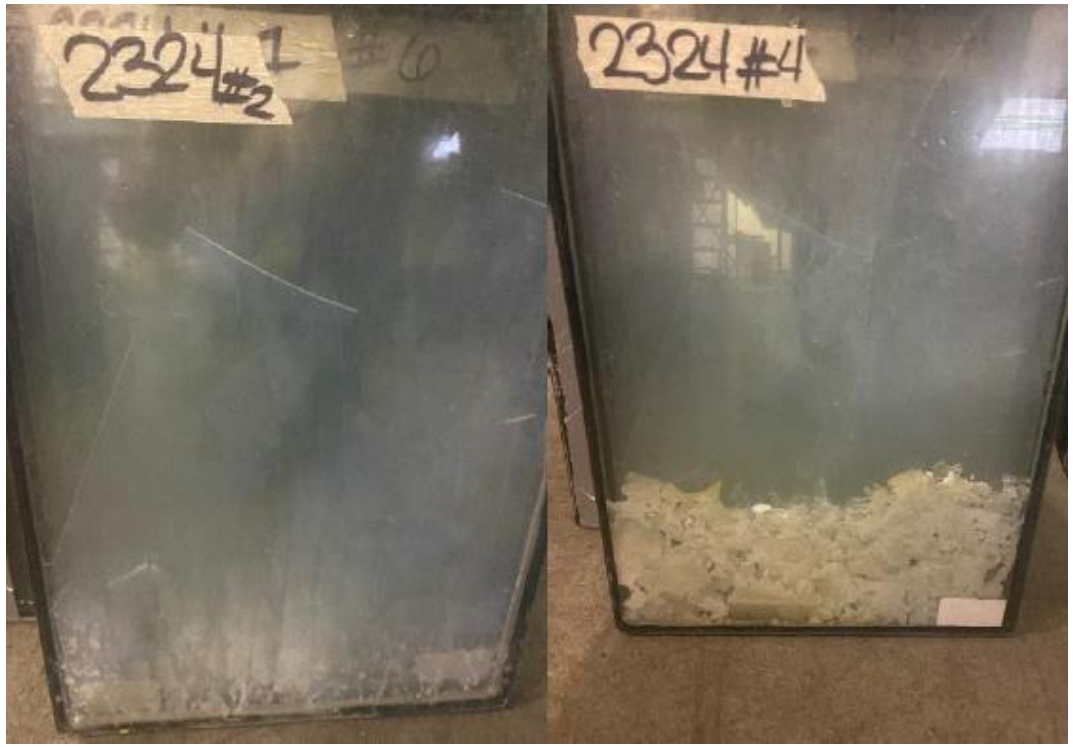
Source: Sunthru

Prior aerogel-IGU integration methods didn't pass durability tests



Source: Aspen Aerogels / ARPA-E SHIELD

ARPA-E. (2019). SHIELD Closeout MASTER deck. *U.S. Department of Energy.* Retrieved October 9, 2024, from https://arpa-e.energy.gov/sites/default/files/2019-12-06-SHIELD%20Closeout%20MASTER%20deck-rev.pdf



Source: AeroShield – *Early IGU samples with seal failure*

Recent Breakthroughs in Aerogels

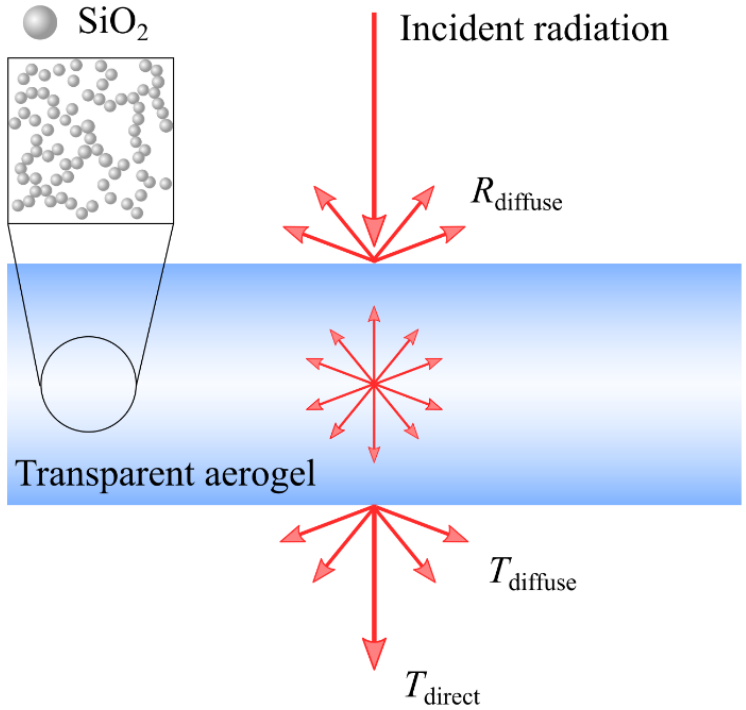
Why We Are Seeing Major Advances in Aerogels for Windows

Clarity

Fundamental Understanding of Aerogel Optics Has Unlocked More Transparent Aerogels

Aerogel Structures Interact With Light

Aerogels are a 3D network of pores and particles, with pockets of air filling the space between. Those pores interact with light.



Zhao, L., Strobach, E., Bhatia, B., Yang, S., Leroy, A., Zhang, L., & Wang, E. N. (2019). "Theoretical and experimental investigation of haze in transparent aerogels". *Optical Express*, 27(4), A39-A50. https://doi.org/10.1364/OE.27.000A39

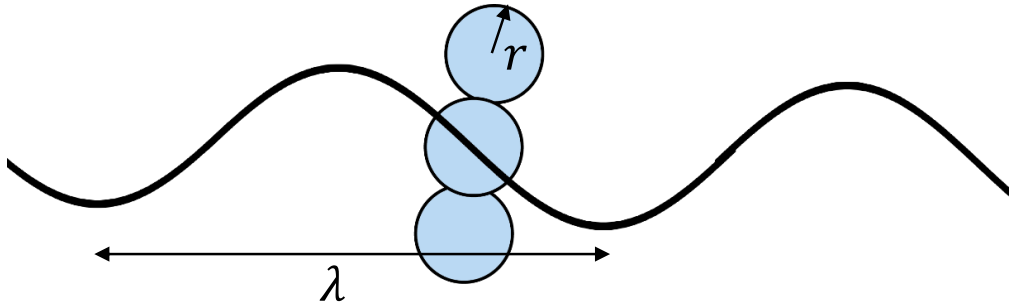
Pore Size Governs Light Scattering

These tiny pores can be approximated using the Rayleigh Scattering Model.

$$\sigma_s = 32\pi^4 \frac{r_{scatter}^3}{\lambda^4} \frac{\rho_{ap}}{\rho_{SiO_2}} \left(\frac{n^2-1}{n^2+2}\right)^2$$

$$haze \propto \rho_{ap} r_{scatter}^3$$

$r_{particle} << \lambda_{visible}$

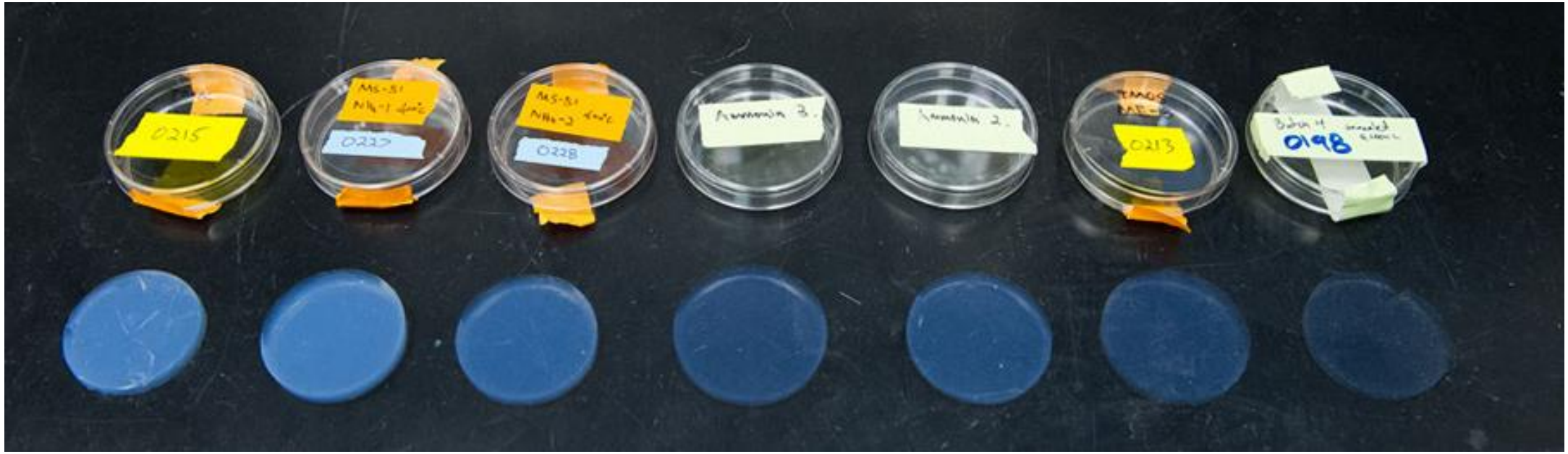


$R_{particle}$ ~ 1 nm

R_{pore} ~ 10 nm

Zhao, L., Strobach, E., Bhatia, B., Yang, S., Leroy, A., Zhang, L., & Wang, E. N. (2019). "Theoretical and experimental investigation of haze in transparent aerogels". *Optical Express*, 27(4), A39-A50. https://doi.org/10.1364/OE.27.000A39

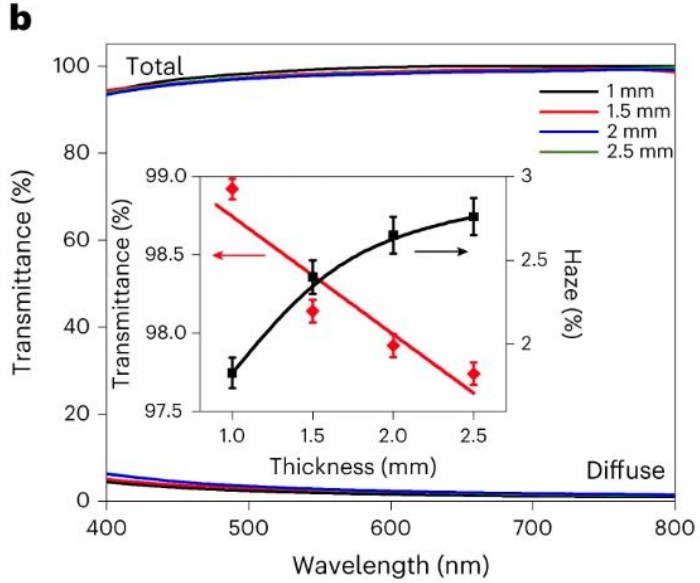
By Reducing Scattering Size, Haze Can Be Reduced Significantly



Lower scattering size, lower haze

Higher clarity

There Are a New Generation of Highly Transparent Aerogels Being Developed



Abraham, E., Cherpak, V., Senyuk, B. *et al.* Highly transparent silanized cellulose aerogels for boosting energy efficiency of glazing in buildings. *Nat Energy* **8**, 381–396 (2023). https://doi.org/10.1038/s41560-023-01226-7

University of Colorado Boulder

VT @ 1mm: ~99% **VT @ 2.5mm: ~97.5%**
Haze @ 1mm: 1.8% **Haze @ 2.5mm: 2.8%**

There Are a New Generation of Highly Transparent Aerogels Being Developed

Source: AeroShield

Source: AeroShield

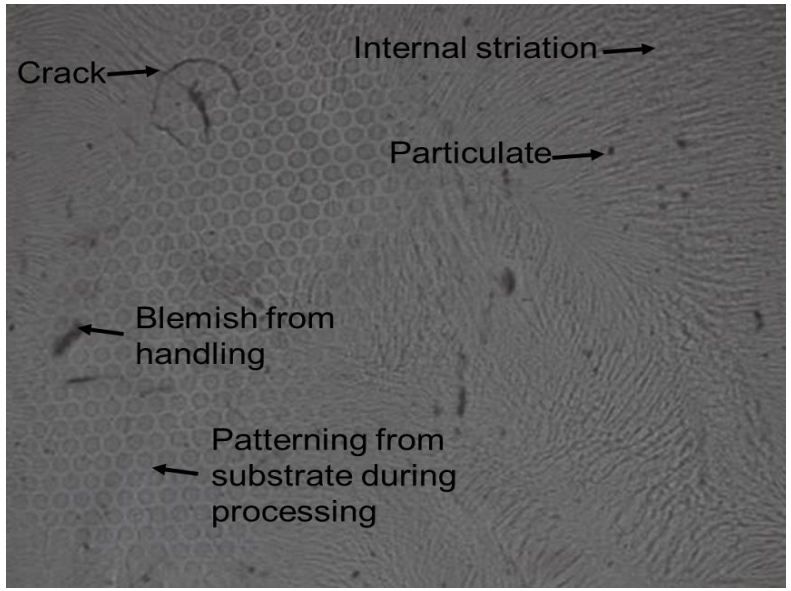
VT @ 4mm: ~98.4%
Haze @ 4mm: 1.5%

AeroShield

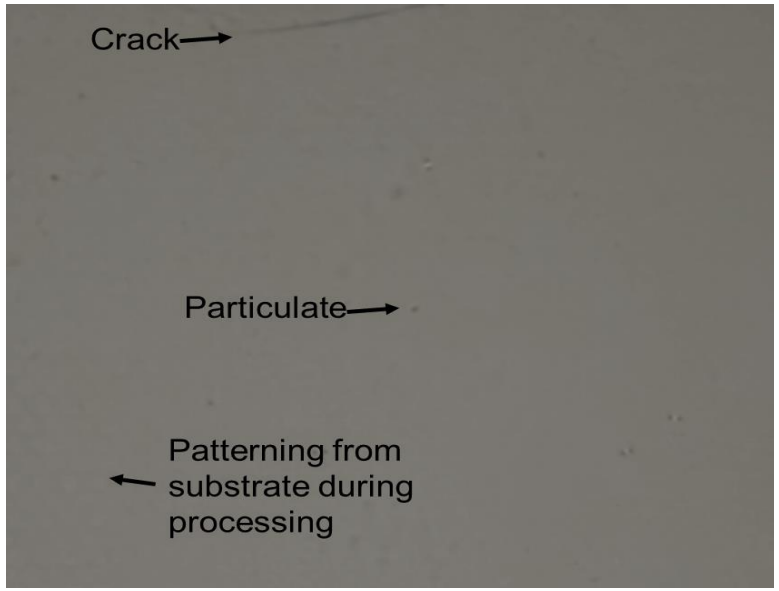
Aerogel processing has also seen step changes in quality and defect reduction

Aerogel manufacturing methods are beginning to approach ASTM C1036 standards and beyond.

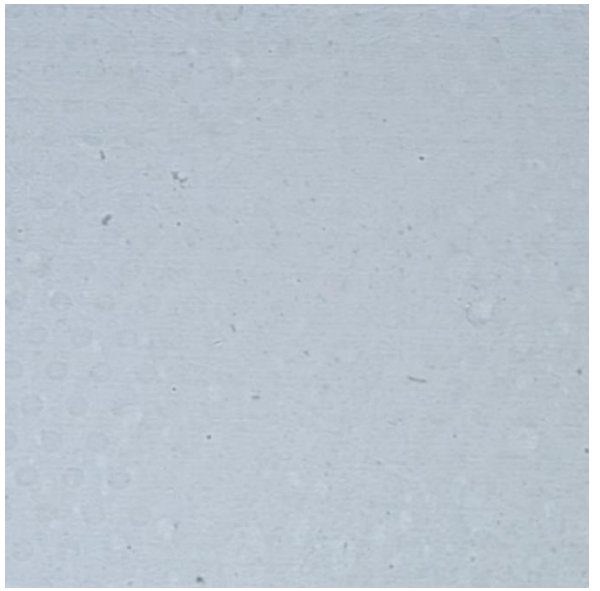
Nov 2022



May 2023



Q1 2024



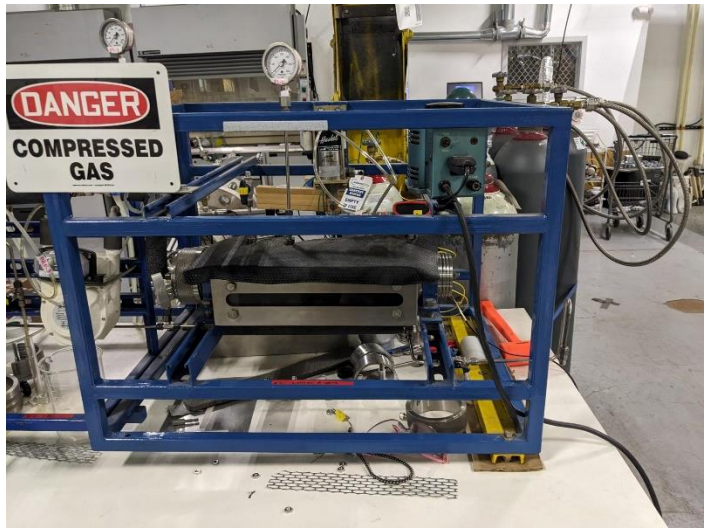
Source: AeroShield

Size and Scale

Bigger Critical Point Dryers and Alternatives

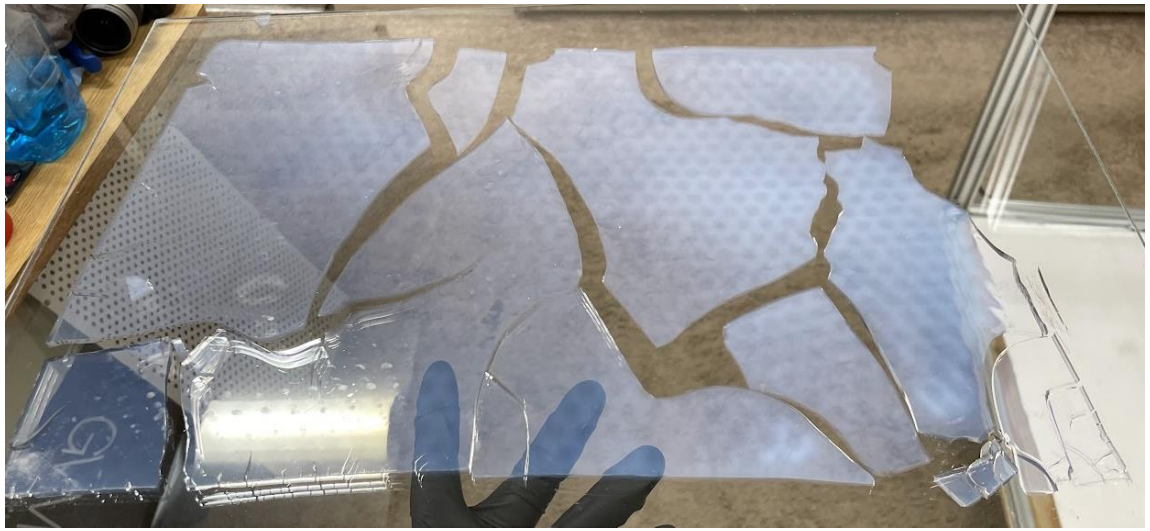
Equipment Size and Aerogel Shrinkage Were the Two Main Barriers to Larger Sizes

Critical point drying has historically been done at small scale for aerogels



Source: AeroShield

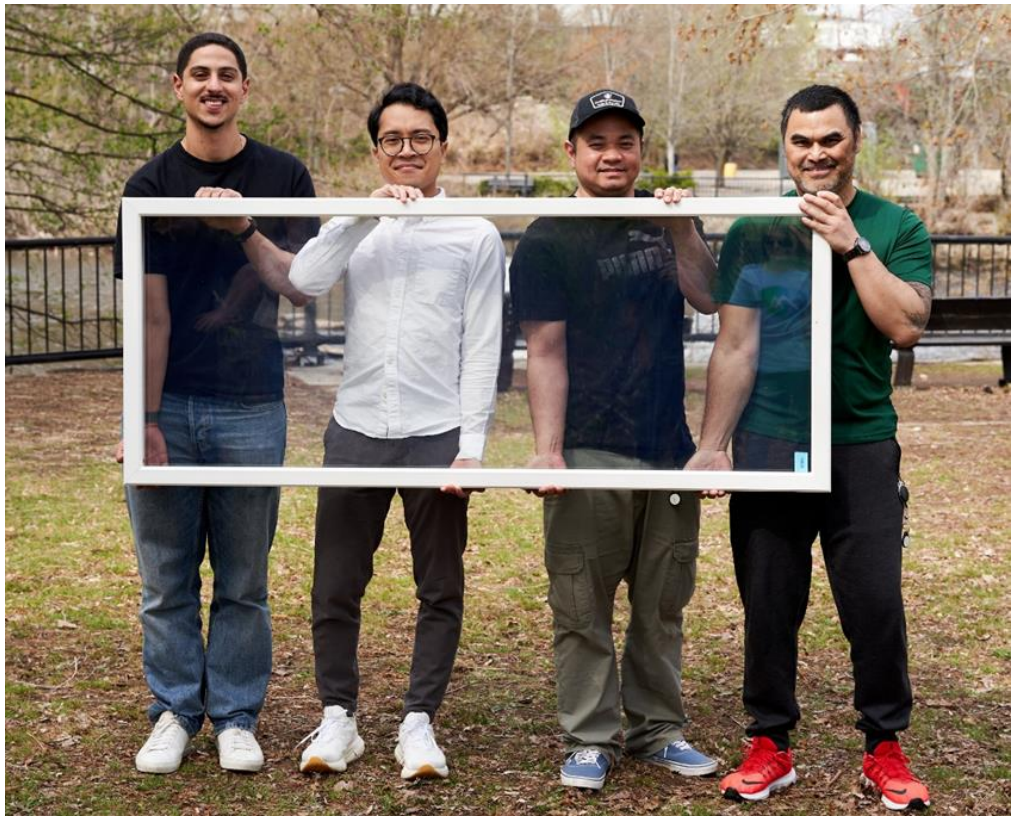
Achieving large monoliths has been a major issue due to shrinkage during processing



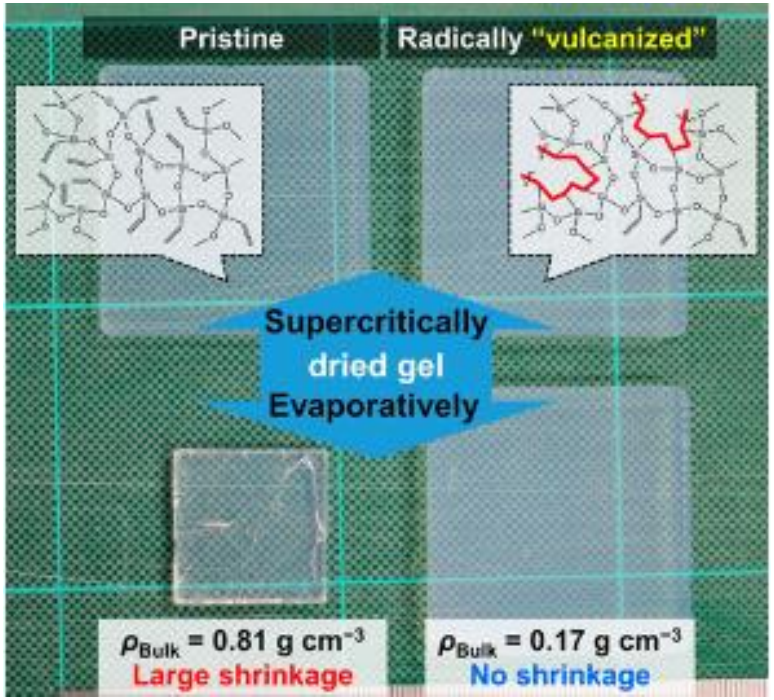
Source: AeroShield

New Approaches to Achieving Size and Scale of Aerogel Production

AeroShield has reduced shrinkage and purchased larger CPDs, enabling large sizes



Groups are finding ways to modify aerogels to allow for ambient point drying



Shimizu, T. art al. Silicone-based organic–inorganic hybrid aerogels and xerogels. *Chem. Eur. J.* **23**, 5176–5187 (2017)

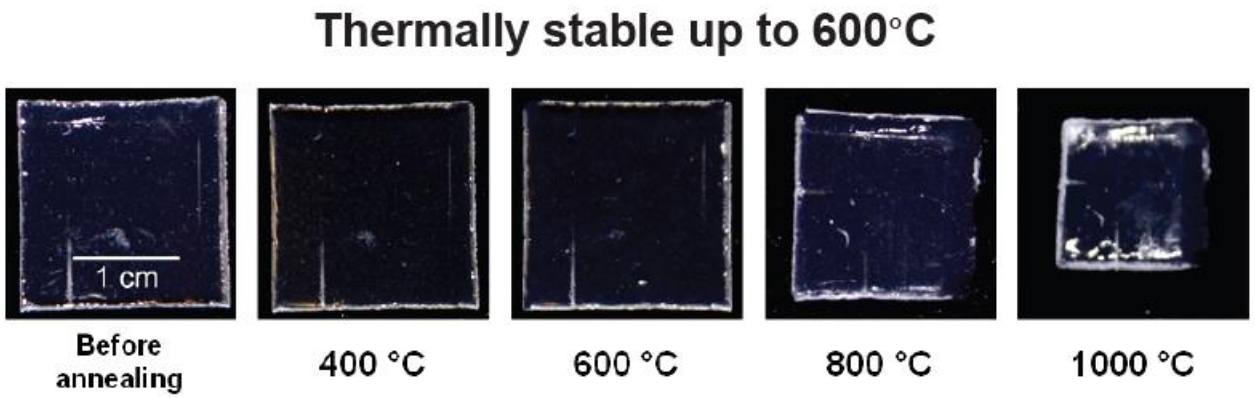
Durability

Passing Window Durability Testing Requirements

Some IGU Tests Are Intrinsic to the Aerogel; Some Are a Test of Integration

Tests intrinsic to the aerogel	Tests of aerogel & IGU integration
UV stability	ASTM E2190/2189/2188
Off gassing	Slam testing (e.g. door slam)
Compatibility	

Silica Aerogels Have Proven Highly Stable



Strobach et al.; High temperature stability of transparent silica aerogels for solar thermal applications. *APL Mater.* 1 August 2019

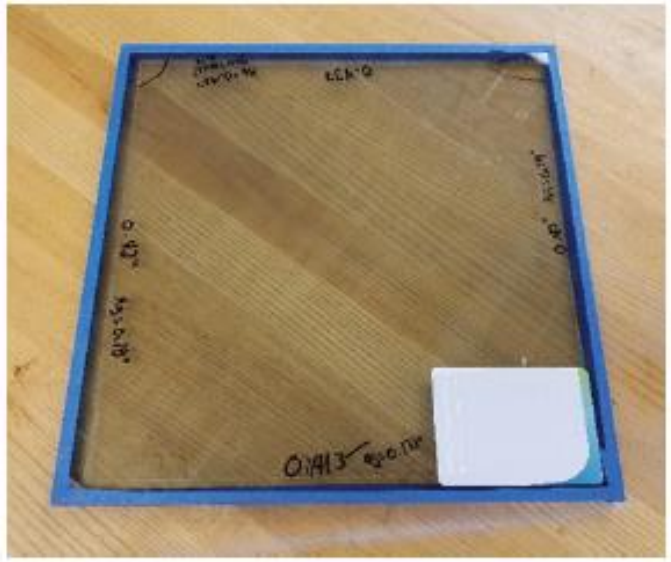
Test completed	Result
NREL: 2500 hr UV-A exposure study	*"Little to no observable change in optical properties"*
NREL: 2500 hr UV-B exposure study	*"Little to no observable change in optical properties"*


Aerogel prototype surviving
50,000 door slams

Opportunities & Challenges

New Products and Integrating in the Window Industry Value Chain

Aerogel Thermal Conductivity Has Been Validated Through Testing at LBNL



12” x 12” sample used to measure thermal conductivity at NREL

ID #: 2021 Name: Aaron | LoE272-3 Arg-11 AS-4 Clr-3

3 Tilt: 90 ° IG Height: 1500.00 mm

Environmental Conditions: NFRC 100-2010 IG Width: 1200.00 mm

Comment:

Overall 21.043 mm Mode:

1 2 3

	ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond	Comment
Glass 1	2011	LoE272-3.CIG	#	3.0	☐	0.429	0.325	0.418	0.793	0.056	0.043	0.000	0.840	0.042	1.000	
Gap 1	2	Argon		11.0												
Glass 2	2	AeroShield in Argon		4.0	☐	0.970	0.007	0.007	0.980	0.009	0.009	0.126	0.547	0.547	0.010	
Gap 2	2	Argon		0.0												
Glass 3	102	CLEAR_3.DAT	#	3.0	☐	0.834	0.075	0.075	0.899	0.083	0.083	0.000	0.840	0.840	1.000	

*Layer , #2 do not have spectral data.

Center of Glass Results | Temperature Data | Optical Data | Angular Data | Color Properties | Radiance Results

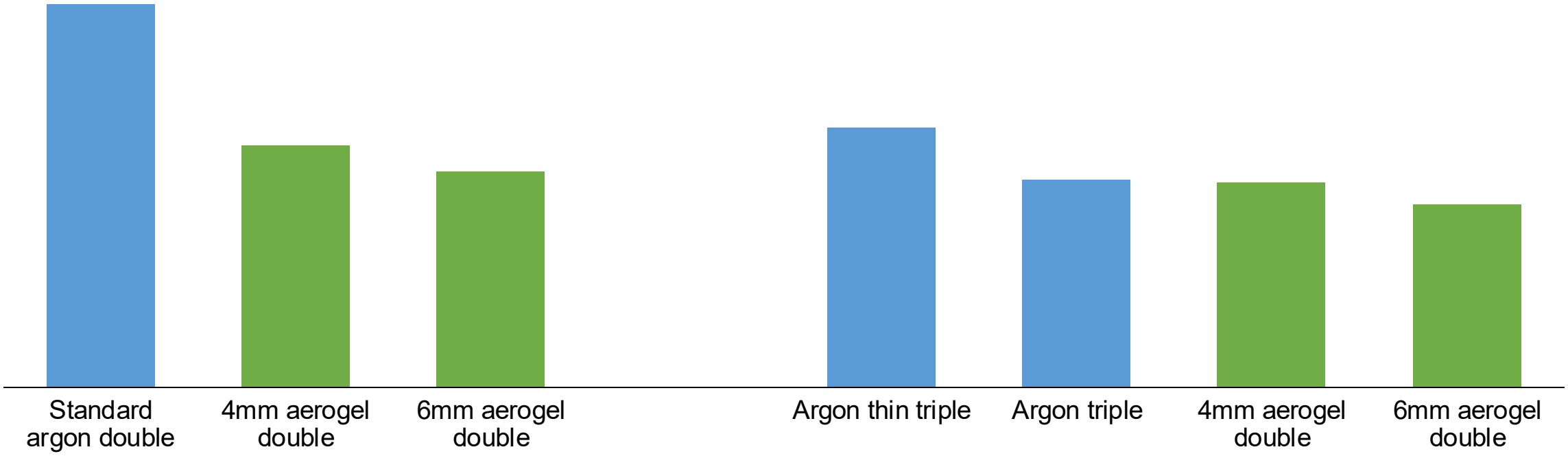
Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff	Gap 2 Keff	Layer 3 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K	W/m-K	W/m-K
0.920	0.466	0.406	301	0.702	0.0233	1.0000	0.0192	0.0100	0.0208	1.0000

Worked with LBNL to enable the aerogel to be modeled in WINDOW

Opportunity: Aerogels can provide better than triple performance inside a double-pane unit

Customer example: Residential IGUs (3mm glass)

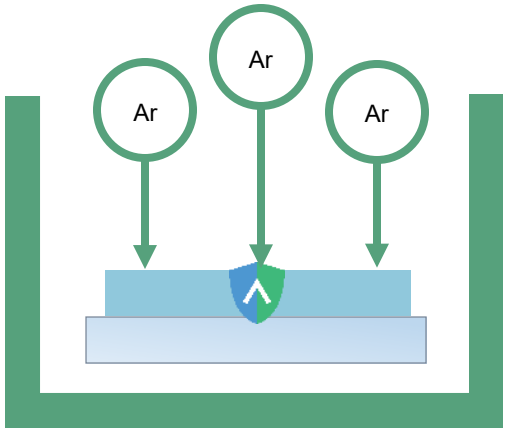
U-value for IGU (Center of glass – redacted)



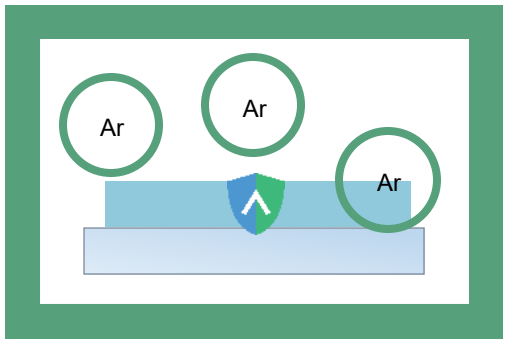
Challenge: Aerogels in argon perform better than aerogels in air – how do we certify?

In argon-filled IGU, argon penetrates the aerogel pore network and reduces thermal conductivity ~15%

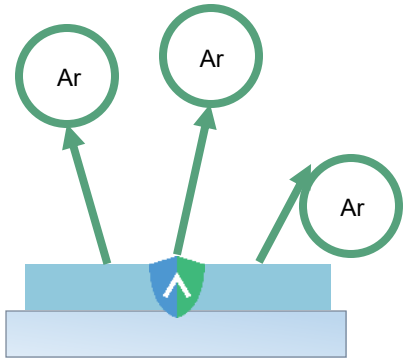
In production



During Transport



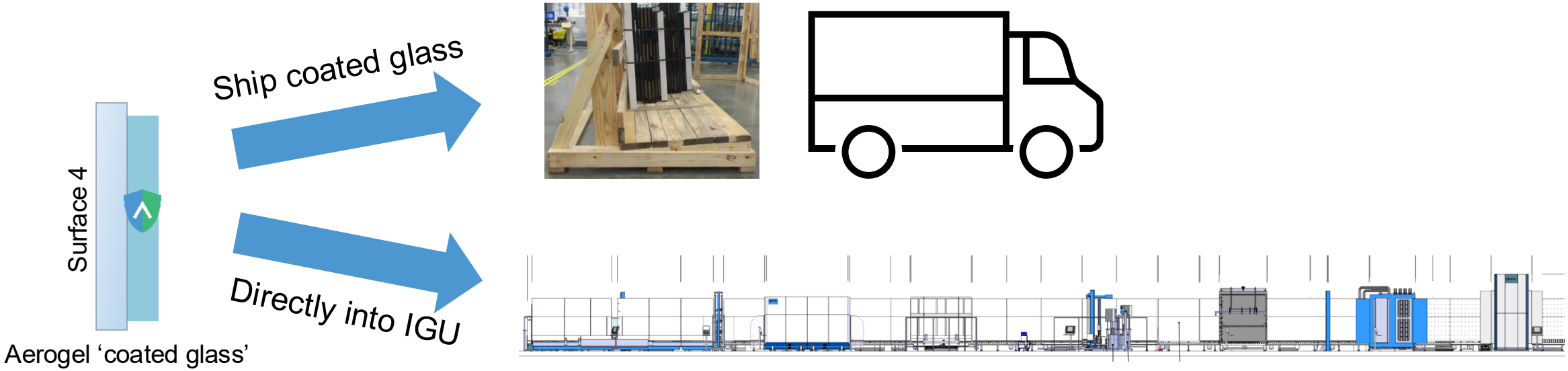
While Measuring



Current NFRC materials testing requirements make it hard to demonstrate – is there a way to demonstrate the thermal conductivity in a closed environment?

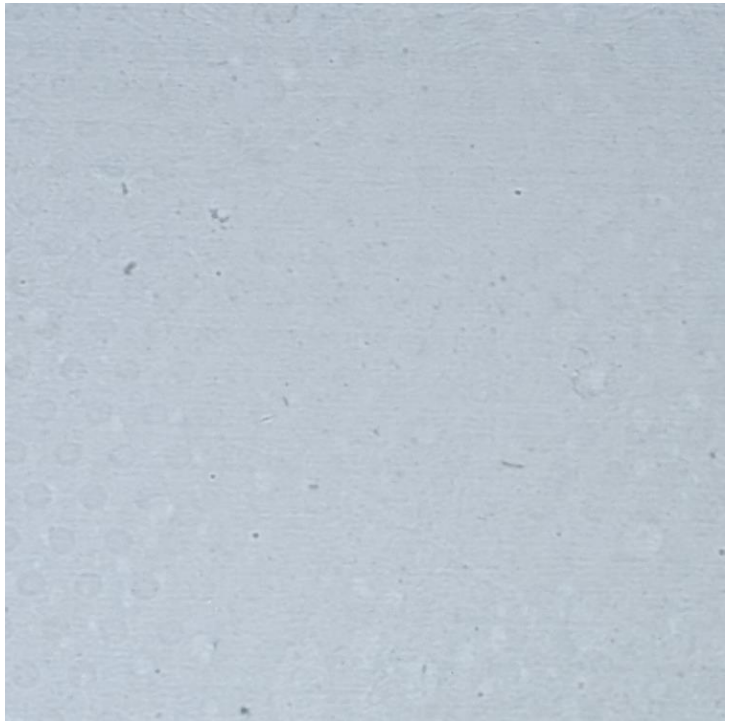
Challenge: Shipping aerogel coated glass introduces potential for defects

Coated glass is typically shipped, but shipping aerogels can introduce defects. Should they be incorporated directly into IGUs off the production line? Who will vertically integrate?



Challenges: Developing new optical standards for novel coatings

Aerogels have different optical defects not caught by ASTM C1036 or seen at all angles/light



Source: AeroShield - Image of aerogel using a proprietary inspection process.

Help aerogels improve!

We appreciate your feedback about AeroShield, the prototype you saw, and the future of fenestration. Please help us by answering this short survey

Collaborating with the Fenestration Industry for Success

Join us to discover more about aerogels and explore how we can advance their use in the fenestration industry.

contact@aeroshield.tech