2024 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
BUILDING TECHNOLOGIES OFFICE

BTO Peer Review:

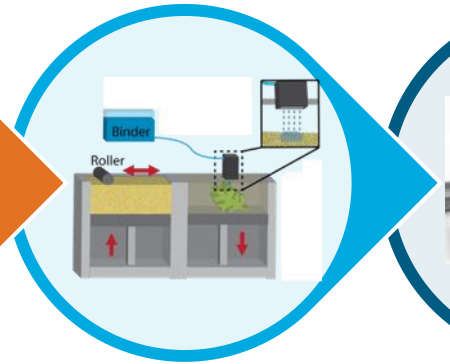
Low-carbon, fire-resilient (LCFR) exterior siding

Low-carbon, fire-resilient exterior siding

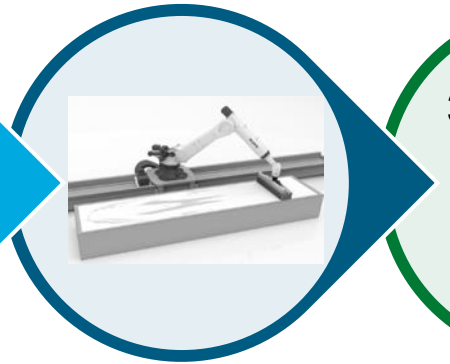
Recycled Glass

Recycled Crushed Glass

Small-scale prototyping with binder jet additive manufacturing



End of project goal:
Scale-up demo with robotic arm-based binding jet additive manufacturing system



Ultimate Project goal

3-in-1 solution
- Low carbon
- Fire resilient
- High thermal performance

Oak Ridge National Laboratory
Principal Investigator:
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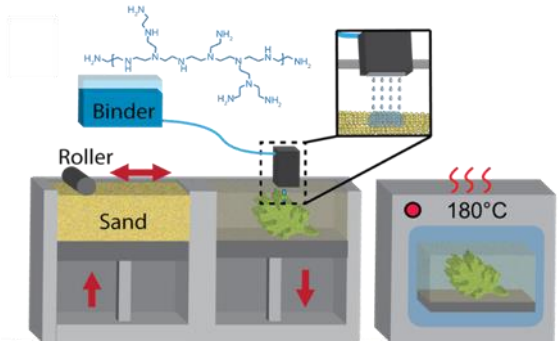
Project Summary

OBJECTIVE, OUTCOME, AND IMPACT

To develop and deploy a sustainable cladding material with 75% reduction in embodied carbon relative to fiber cement siding to support the environmental goals established in the national blueprint for decarbonization of the building sector



TEAM AND PARTNERS

OAK RIDGE National Laboratory

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Nolan Hayes (Buildings)
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Amy Elliot (Manufacturing Science)

VITRIFORM3D

Alex Stiles

THE UNIVERSITY OF TENNESSEE KNOXVILLE

Dustin Gilmer

STATS

Performance Period: 05/01/2024 – 04/30/2026

FY24 - FY26

DOE Budget: $634k, Cost Share: $0k

Milestone 1: Quantify performance metrics

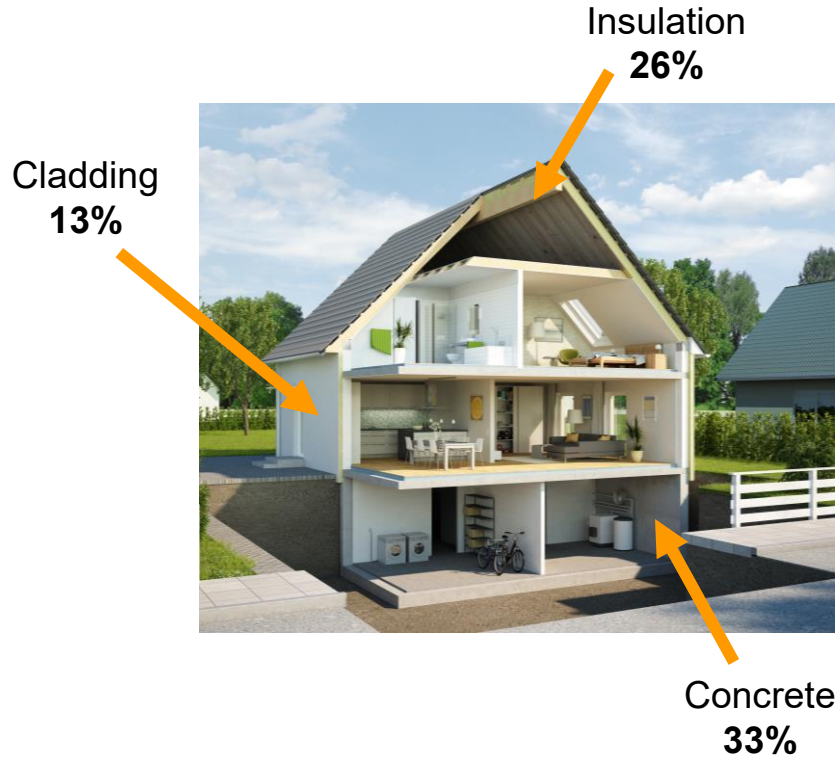
Milestone 2: Optimize binder formulation

Milestone 3: Prototype

Problem

- **7 million units:** US housing shortage
- **40%** of global greenhouse gas emissions come from building sector and **11%** come from building materials
- **Cladding** is third highest source of embodied carbon in single family residences
- **Fiber cement siding**
  - Portland cement is key component
  - 22B ft^2 (2B m^2) installed annually in US
  - Fiber cement board production emits 16,000 kilotons CO_2 emissions annually (2023)

https://www.freedoniagroup.com/industry-study/us-fiber-cement-siding-od



Source: Emissions of Materials Benchmark Assessment for Residential Construction. Passive Buildings Canada and Builders for Climate Action (2022).

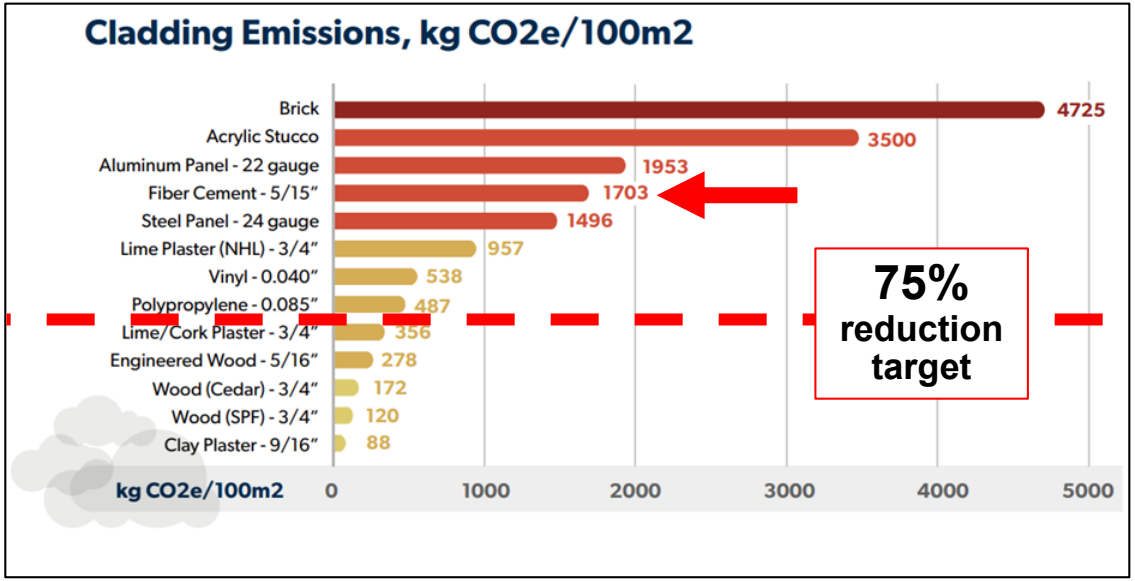
Why Change?

Heat
(1,500ºC)

$$CaCO_3 \longrightarrow CO_2 + CaO$$
(lime)

Downsides of cement production

1. High energy input
2. CO_2 is released as a byproduct



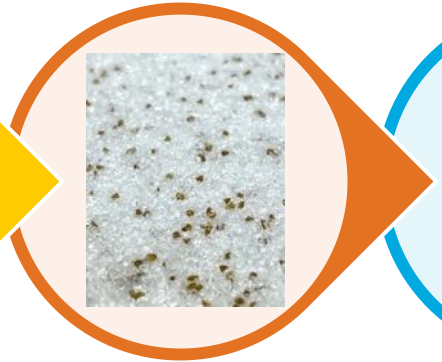
Cement is responsible for 8%–9% of global CO_2 emissions

Low-Carbon, Fire-Resilient Exterior Siding

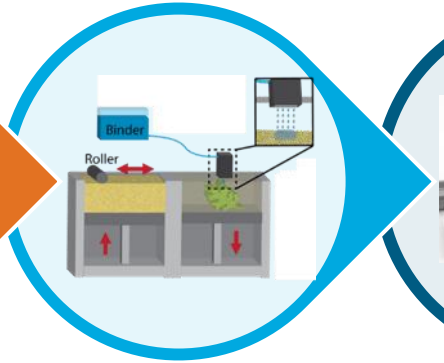
Technology Commercialization Funds to Deploy National Lab Technologies
Sponsored by BTO, AMMTO, IEDO

Recycled Glass

Recycled Crushed Glass



Small-scale prototyping with binder jet additive manufacturing



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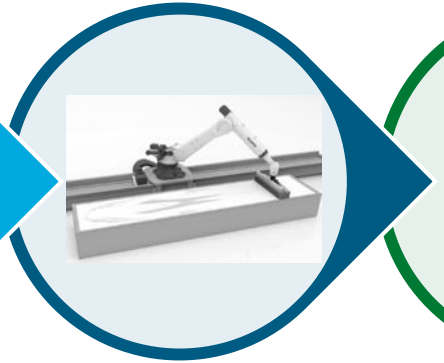


Ultimate Project goal

3-in-1 solution
- Low carbon
- Fire resilient
- High thermal performance

FY24–FY25

FY26–FY27

VITRIFORM3D
RECYCLED GLASS 3D PRINTING

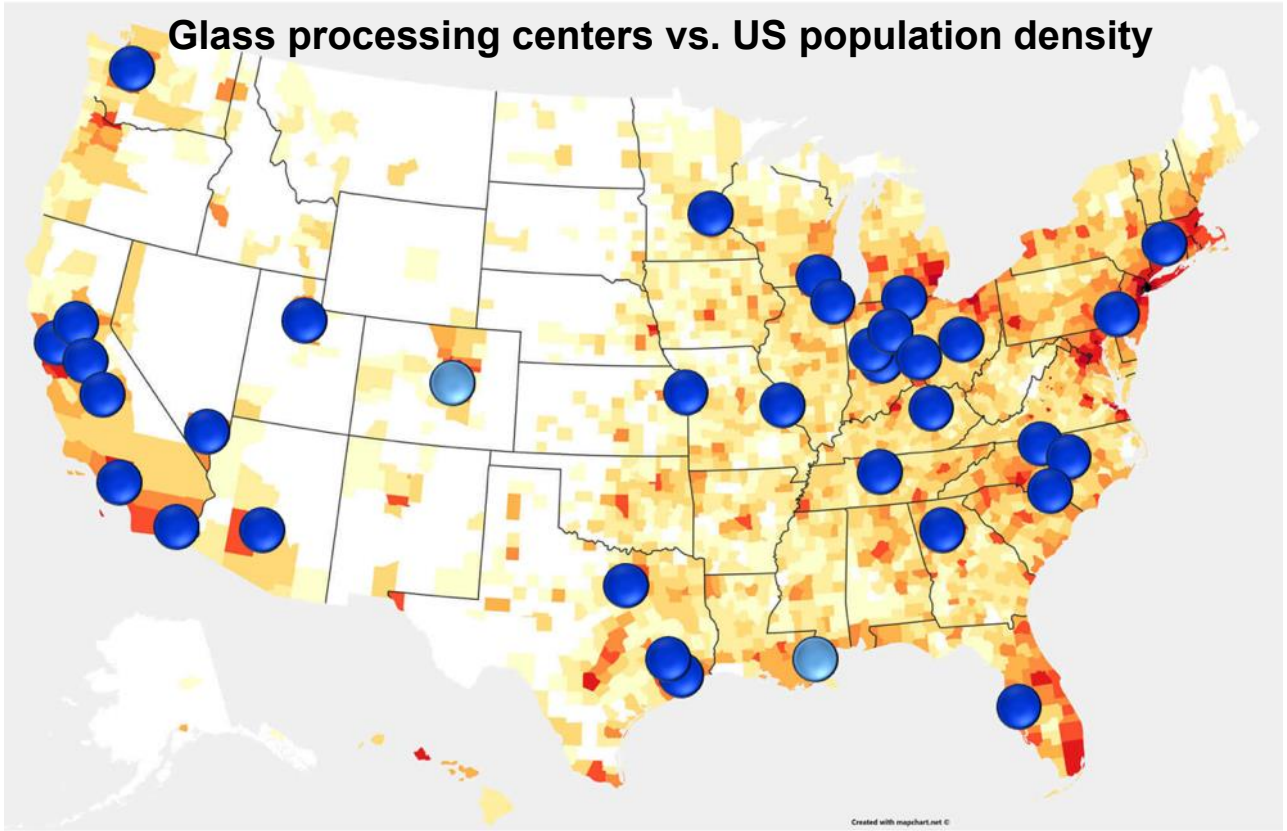
- Fire resistance comparable to or better than that of cement fiber siding
- 75%+ lower embodied carbon than that of fiber cement siding
- Production rate comparable to that of current manufacturing processes

Glass Waste in United States

33%
Glass recycling rate

8 million tons
Landfilled annually

- Low scrap value
- High shipping cost
- Costs cities $25-$80 per ton to dispose
- Ubiquitous potential low-cost feedstock



Recycled Glass for Siding Materials?

Chemical Composition: SiO_2: 66%–80%

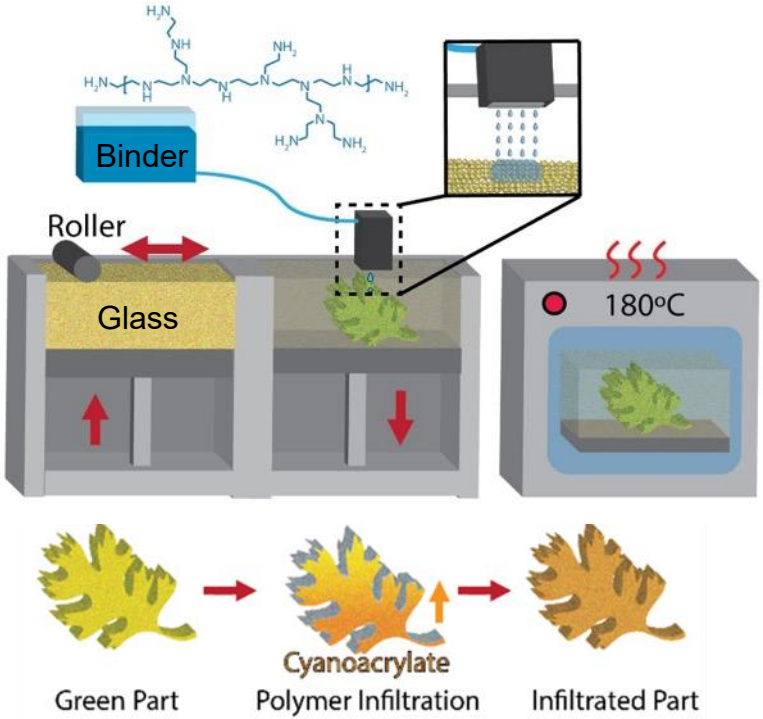
High melting temperature: 1,400ºC–1,600ºC

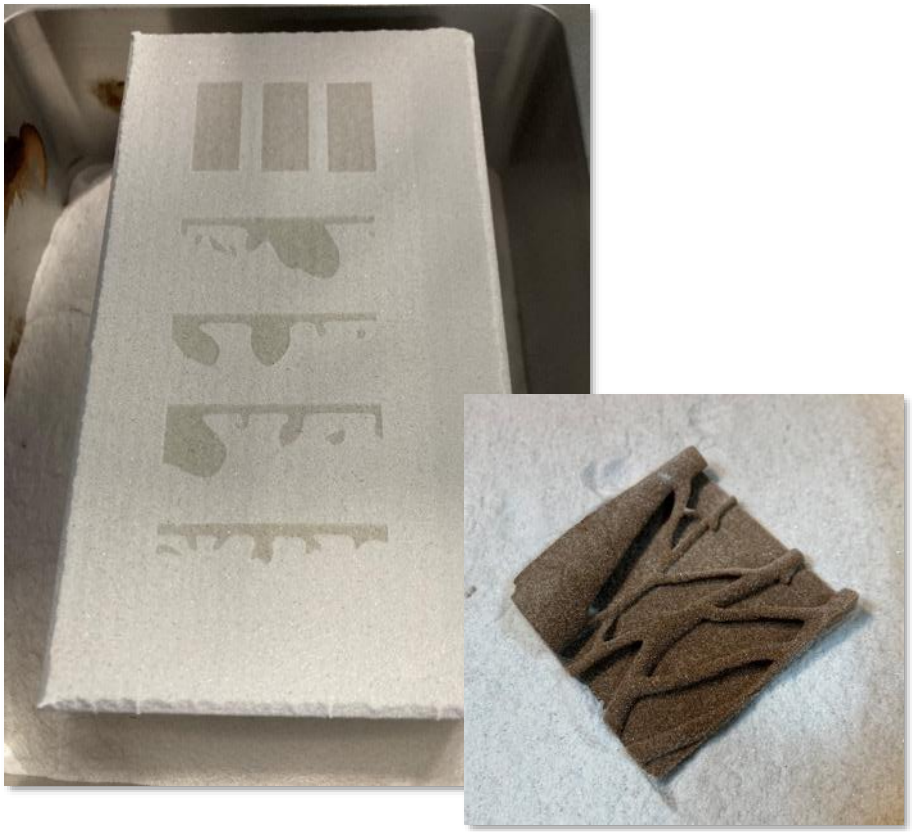
- High hardness
- Moderate heat capacity
- High corrosion resistance
- High UV resistance

1. Fire resistance
2. Exterior durability
3. Thermal sink

With binder jet additive manufacturing, recycled glass materials can be developed into commercially viable cladding materials

Binder Jet Additive Manufacturing





Dustin B. Gilmer, et al. *Nat Comm*, 2021, 12, 5144.
US Patent No. 11524427.
US Patent App. 2024/0017484

Industry Partnership

−$30 to −$80/ton

Cities pay to recycle glass waste

$8–$240/ton

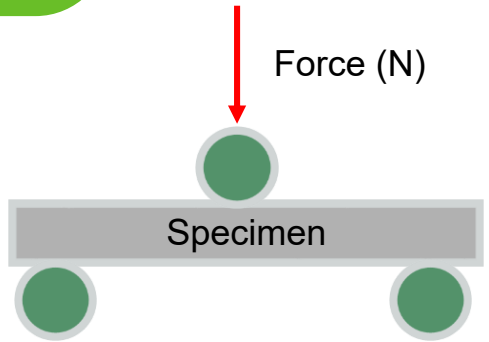
Glass crushed to fine sand

VITRIFORM3D

$2.5k–$100k/ton

Commercialize 3D printed building materials

Mechanical Testing ASTM B312



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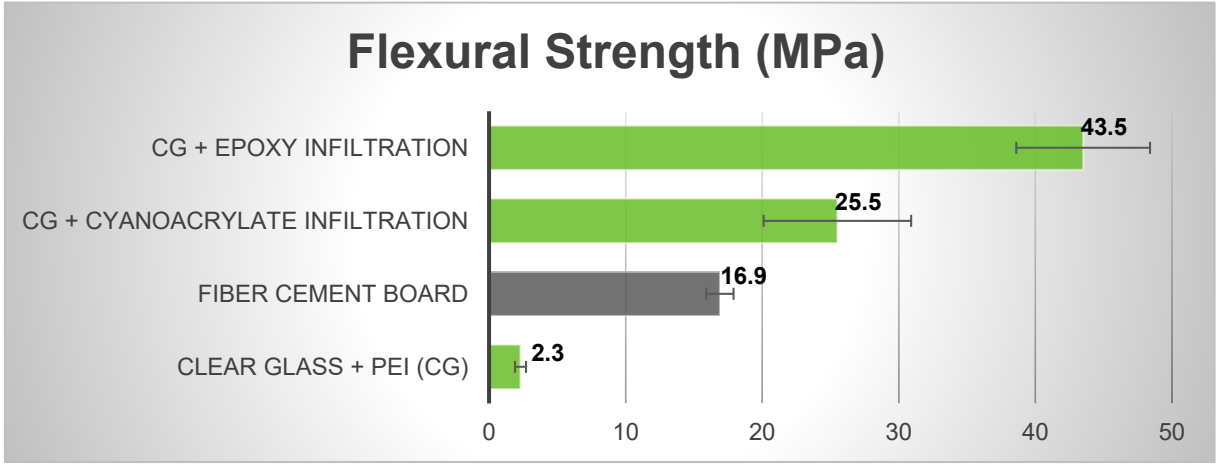
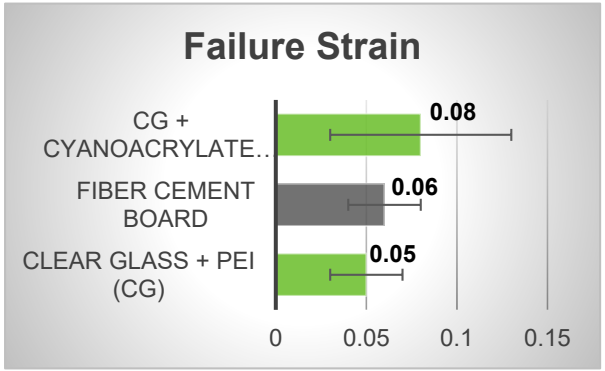
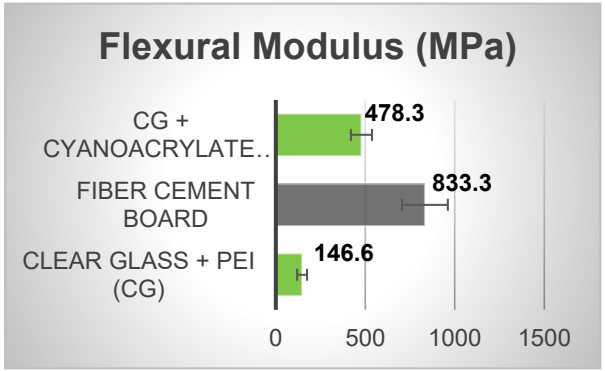
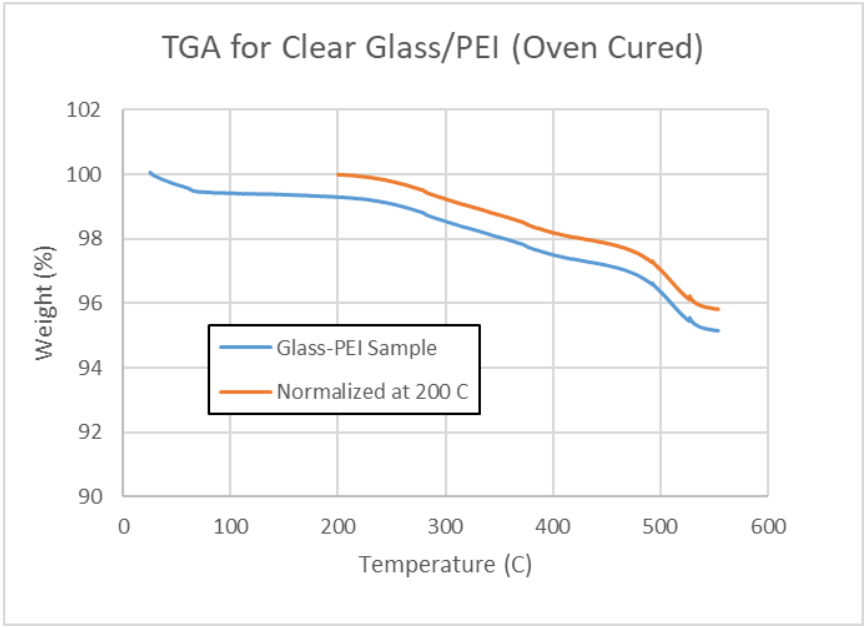


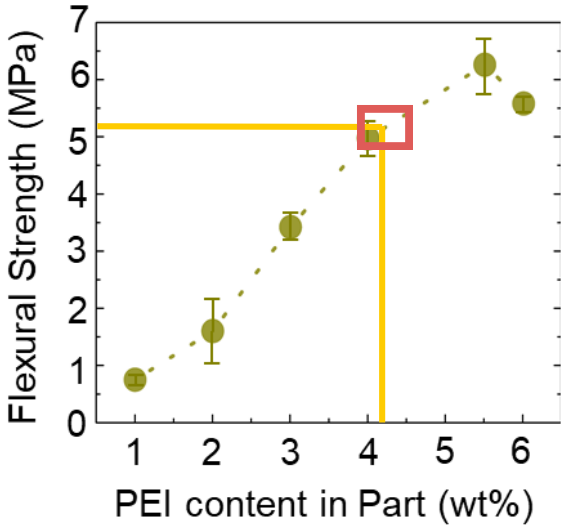




Preliminary TGA Results

- Ramp 10.00°C/min to 1,000.00°C
- ~4.2 wt % PEI for clear-glass printed part





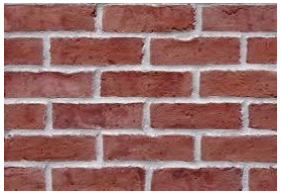
Dustin B. Gilmer, et al. *Nat Comm*, 2021, 12, 5144, US Patent No. 11524427.

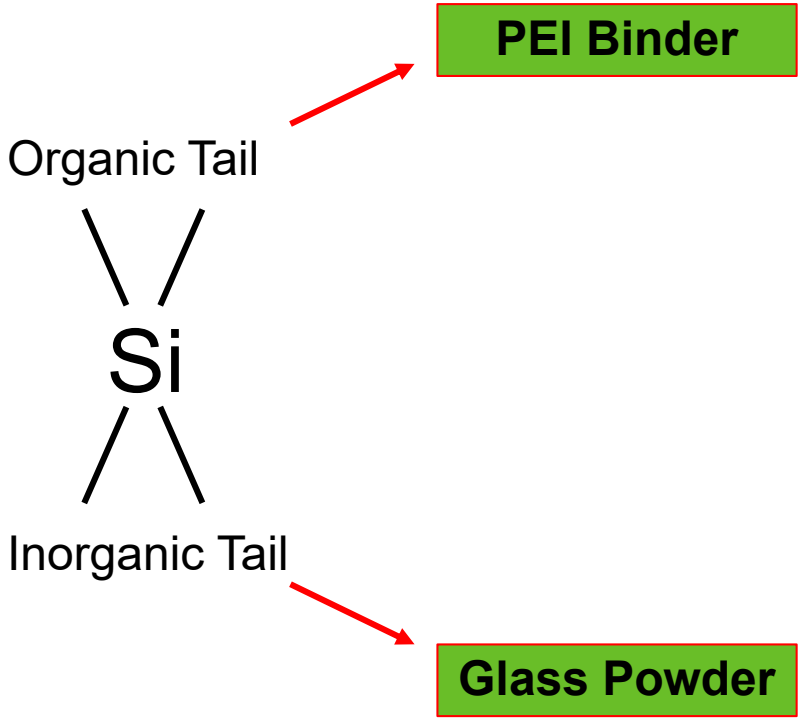
Ongoing Work Methods to Improve PEI Binder Performance

Porous Material

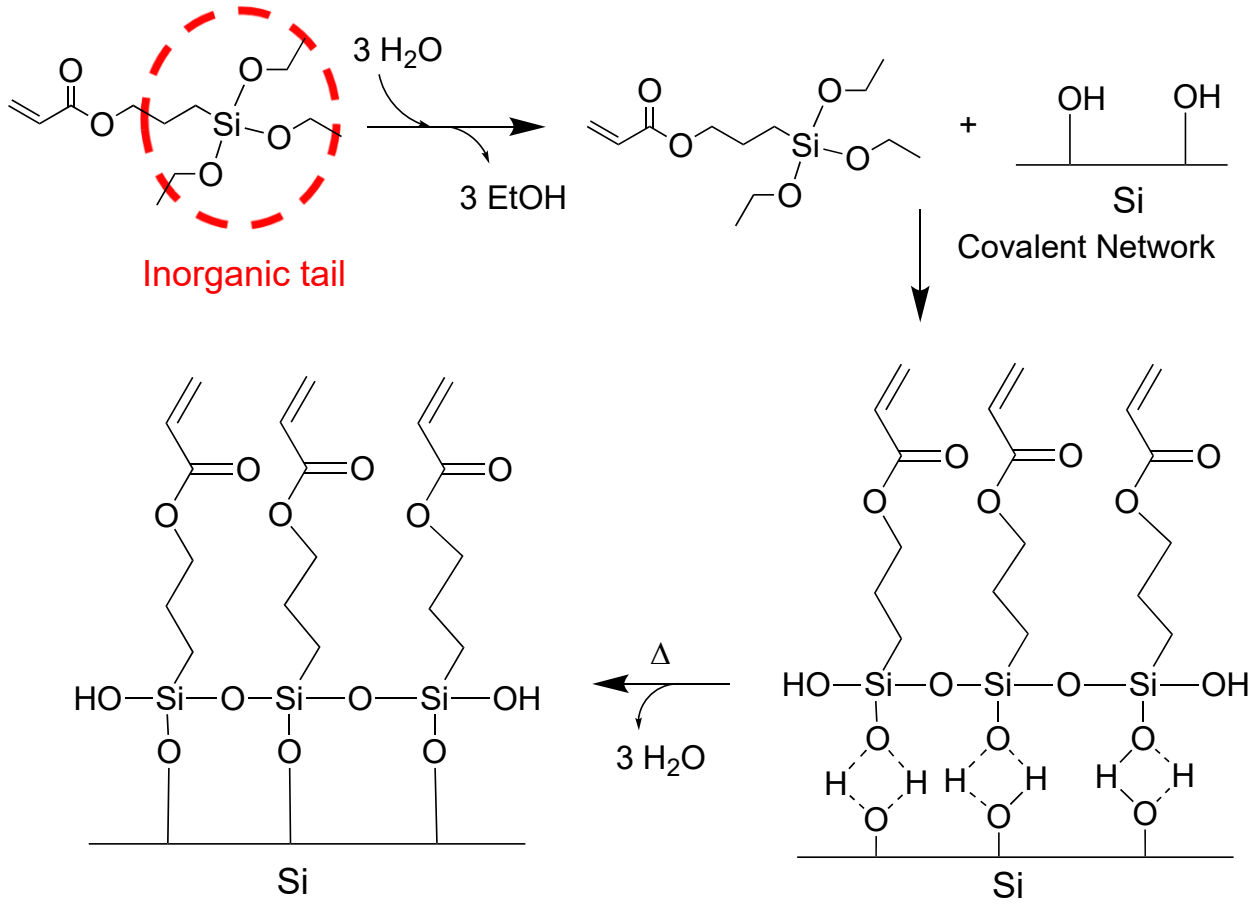
Organosilanes

Used as coupling or waterproofing agent for:



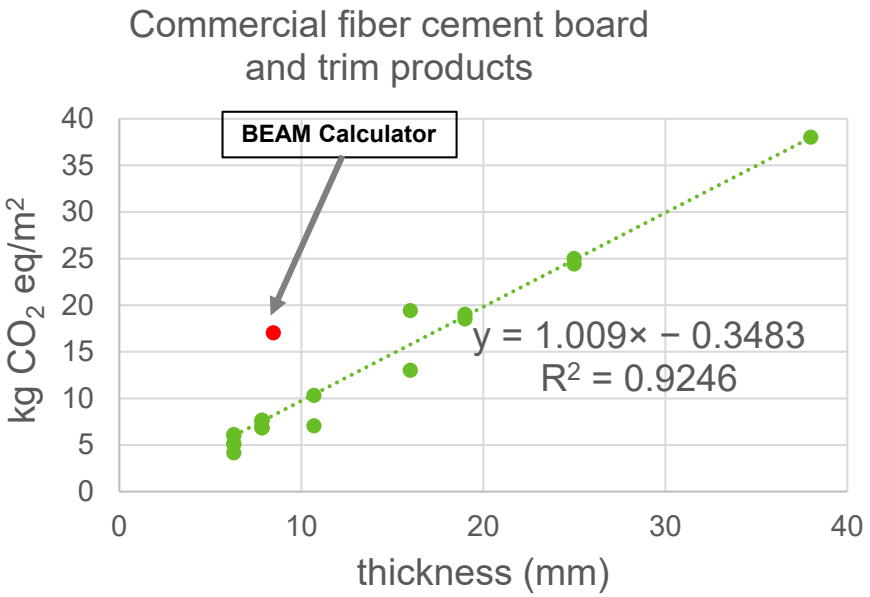


Expected Mechanism for Silane Grafting onto the Powder



Embodied Carbon and Cost Target

Embodied carbon



Cost of fiber cement siding

Cost of Goods Sold (COGS) Analysis	Plank	Panel
Cost by mass extrapolation		
Raw material cost (RMC)	$0.29	$0.29
Sales price	$1.87	$2.39
Margin and conversion cost	$1.57	$2.10
Margin (25%)	$0.47	$0.60
Conversion cost	$1.11	$1.50
Projected cost ($/kg)	**$1.40**	**$1.79**
Cost by area		
Projected cost @ 8 mm thickness ($/m²)	**$15.59**	**$19.98**

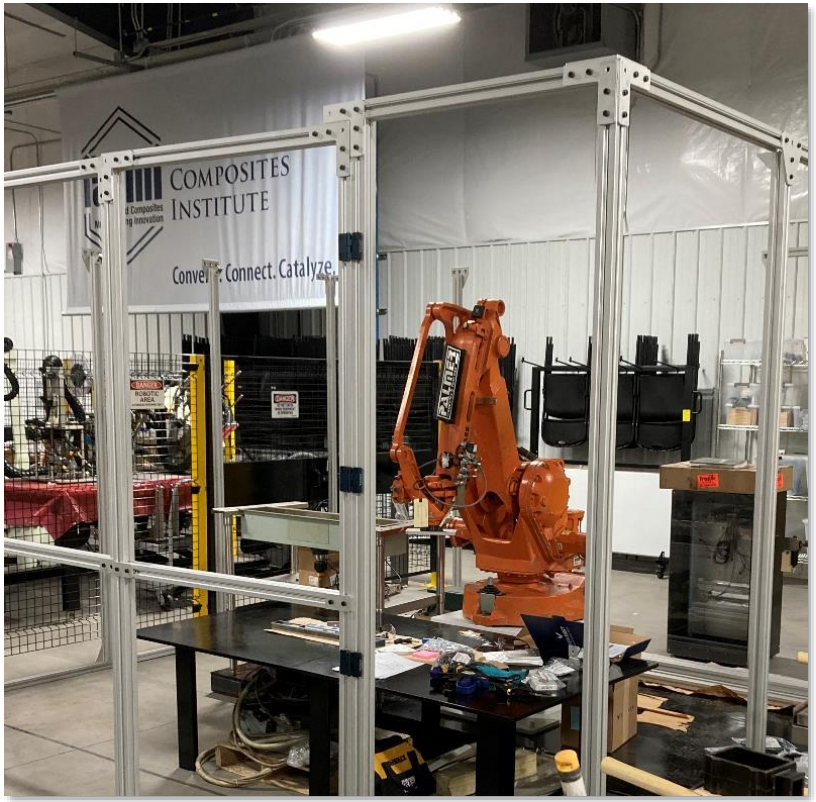
Note: unit density is 1,330 kg/m³

Source: https://www.treehugger.com/guide-to-carbon-emissions-building-materials-5271939

Vitriform3D Update

Scale-up progress

- Robot arm installation
  - Finishing enclosure
  - Arm operational
  - Printhead in development



Vitriform3D Update

Self-operated glass collection

- Launched November 2023
- 144 Knoxville subscribers
- >22,000 lb diverted from landfill as of September 2024
- Color separated, crushed, and sieved for testing

Demonstration projects

Dior samples

Artist collaboration

Promotional coasters

Future Work

Continue to work toward completing Subtasks 1.2 and 1.3

- Subtask 1.2: Binder Formulation for BJAM of Low-Embodied Carbon Recycled Glass Building Material
- Subtask 1.3: Selection of Low-Embodied Carbon Secondary Reinforcement

Consider other feedstock sources

- Wind turbine blade powder, borosilicate, and solar panel glass waste
  - Difficult to recycle
  - Not compatible with glass circular economy
  - “Billions of panels will eventually all need to be disposed of and replaced”–BBC
  - 2,000 tons/year processed in East Tennessee

Thank you

Oak Ridge National Laboratory

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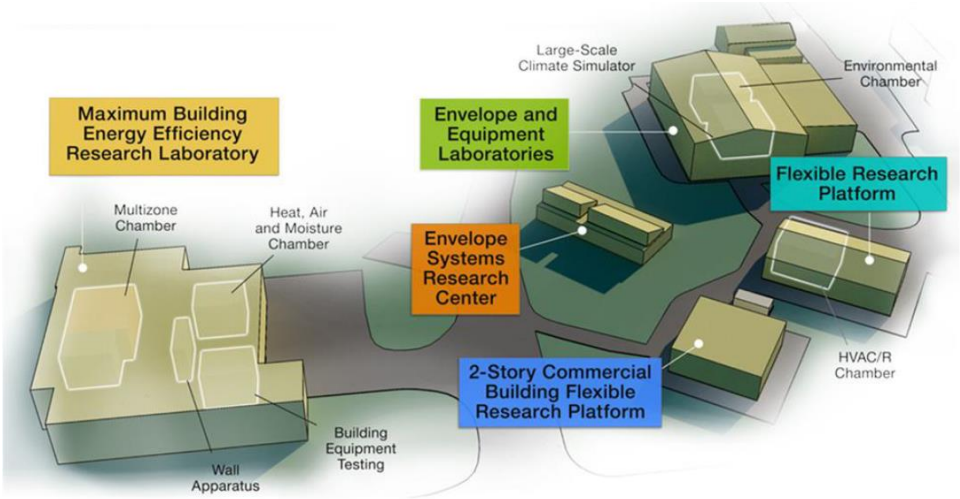

The **Building Technologies Research and Integration Center** (**BTRIC**) at ORNL has supported DOE BTO since 1993. BTRIC is comprised of more than 60,000 square feet of lab facilities conducting RD&D to develop affordable, efficient, and resilient buildings while reducing their greenhouse gas emissions 65% by 2035 and 90% by 2050.

Scientific and Economic Results
139 publications in FY24
140+ industry partners
60+ university partners
16 R&D 100 awards
64 active CRADAs

BTRIC is a DOE-Designated National User Facility

Reference Slides

Project Execution

	FY2024				FY2025				FY2026			
Planned budget	135				325				189			
Spent budget	39											
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Conduct a literature search and pursue LCA analysis or tools to achieve estimates without experimentation.												
Q2 Milestone: Performance, embodied carbon, and cost targets of commercial fiber cement siding products; provide update to DOE at quarterly meeting												
Q3 Milestone: Flexural strength and toughness results from low embodied carbon secondary reinforcement options.												
Q4 Milestone: Demonstrate that functional prototype meets the technical performance and raw material cost targets of a traditionally manufactured fiber cement siding board.												
Q1 Milestone: Demonstrate viability of powder composition from Task 1 with hopper recoating system.												
Current/Future Work												
Q3 Milestone: Demonstrate the scalability of BJAM to produce exterior panels that are 1 meter in length.												
Q4 Milestone: Demonstrate that the installation of the panel is comparable to commercially available siding with respect to customization and fastening to exterior sheathing.												

Team

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Senior R&D Member

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