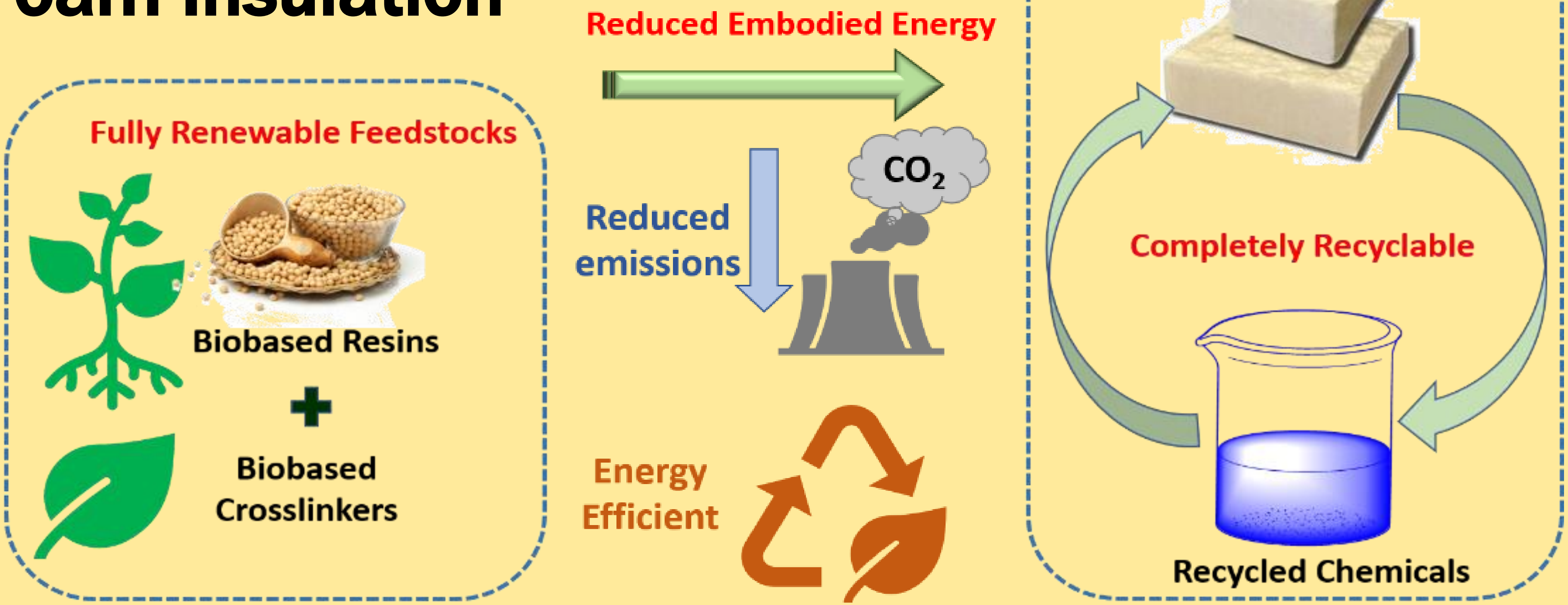
Low-carbon, Recyclable, Biobased Foam Insulation



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BTO-03.04.06.97, DE-FOA-0002099

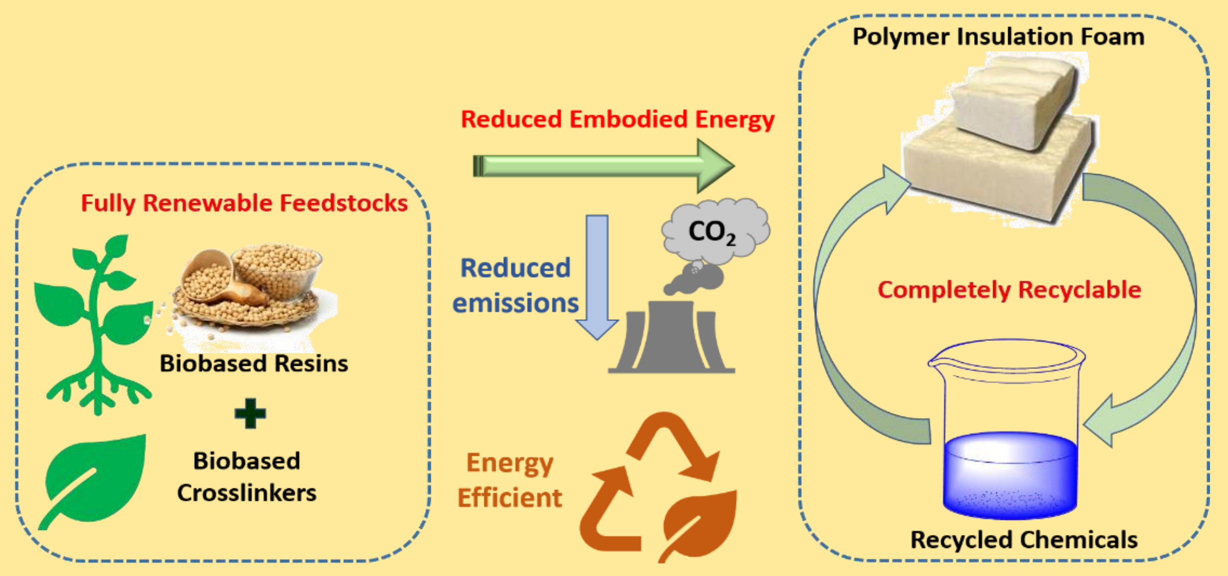
Project Summary

Objective: Reduce embodied carbon of thermoset foam insulation

Outcome:

Thermoset foam insulation

- R-value ≥6/inch
- 50% lower embodied carbon
- Recyclable through low energy thermal process



Team and Partners

- Building Envelope Materials Research Group
- Soft Matter and Membranes Group

Stats

Performance Period: 10/1/21 to 9/30/24

DOE budget: $900K

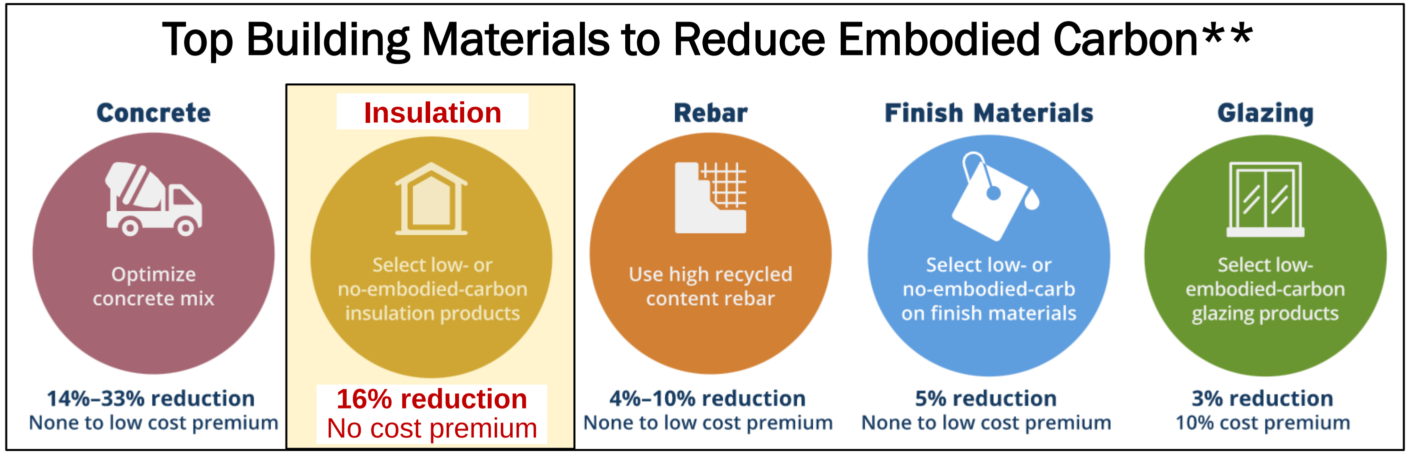
Milestone 1: Synthesize polymer foams with dynamic covalent bonds that have at least 60% negative carbon content

Milestone 2: Fabricate 4×4-inch polymer foam samples that have at least 5% reduction in embodied energy and R-value ≥3.5/inch.

Milestone 3: Fabricate 4 × 4 × 3/8-inch polymer foam with long-term R-value ≥6/inch, compressive strength ≥15 psi, ≥50% reduction of embodied energy, and recyclable with 95% of original toughness.

Problem

- Polymer-based foam insulation
  - ~1/3 of North American thermal insulation market*
  - Primarily petroleum-based polymers and blowing agents with high global warming potential (GWP)
  - Higher embodied CO_2 than other insulation materials
- Efforts to decrease embodied carbon primarily focus on low GWP blowing agents
- Biopolymers
  - Plants sequester ~1.83 kg of CO_2 per 1 kg of biomass growth
  - Used in paints, coatings, and lacquers
  - Limited use in biobased foam insulation



*https://www.grandviewresearch.com/industry-analysis/insulation-market
** RMI

State-of-the-Art for Biobased Foam Insulation

Commercial Polyurethane (PU) Biobased Foams

- R6/in to R7/in
- Uses isocyanate
  - Can cause skin sensitization, asthma, skin or mucous membrane irritation
  - Personal protective equipment needed
- ~22% biobased content
  - 20% max lower embodied carbon
- Non-recyclable

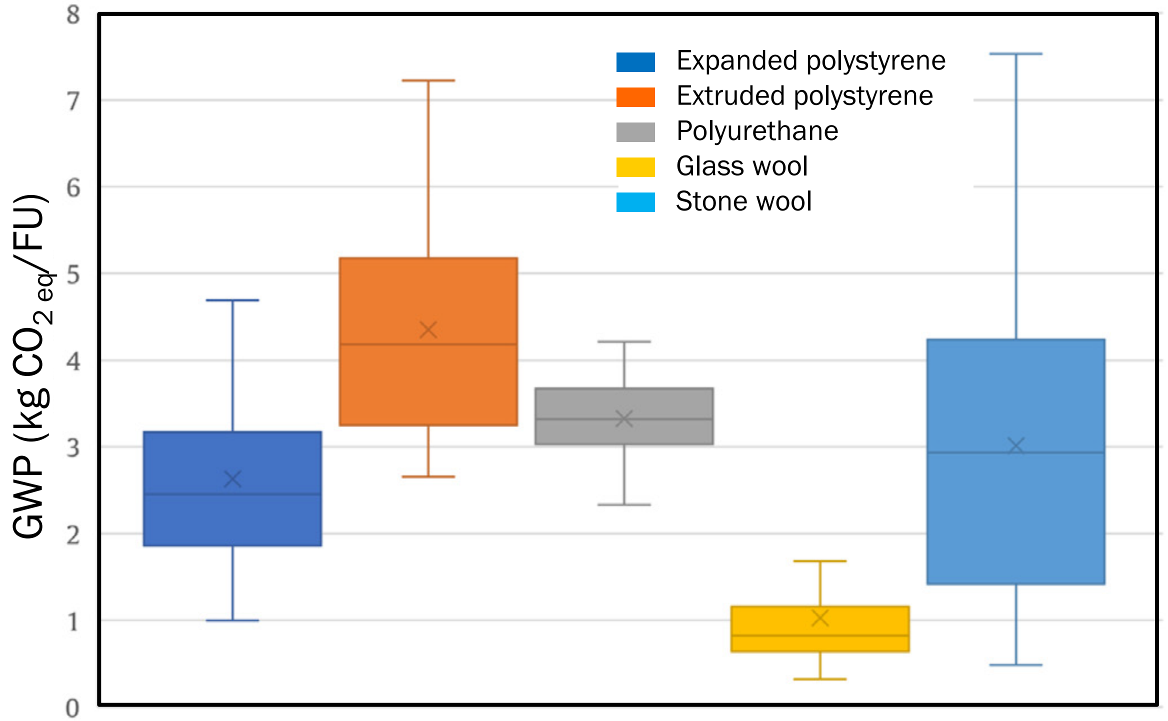
Biobased Foams from the Literature

- Examples
  - PU foams with biobased polyols
    - ~30% max lower embodied carbon
  - Extruded polylactic acid-based foam
  - Cellulose-based foams
- Challenges
  - <R4/in
  - <15 psi compressive strength
  - Non-recyclable

Do not meet R/in and compressive strength of commercial foams

Goals

- R-value ≥6/inch
- ~50% lower embodied CO_2 than PU foam with low GWP blowing agents
- Recyclable via thermal processes with low energy intensity
- Nontoxic components and emissions
- Applications
  - Boards
  - Spray applied



Grazieschi et al. 2021

Alignment and Impact

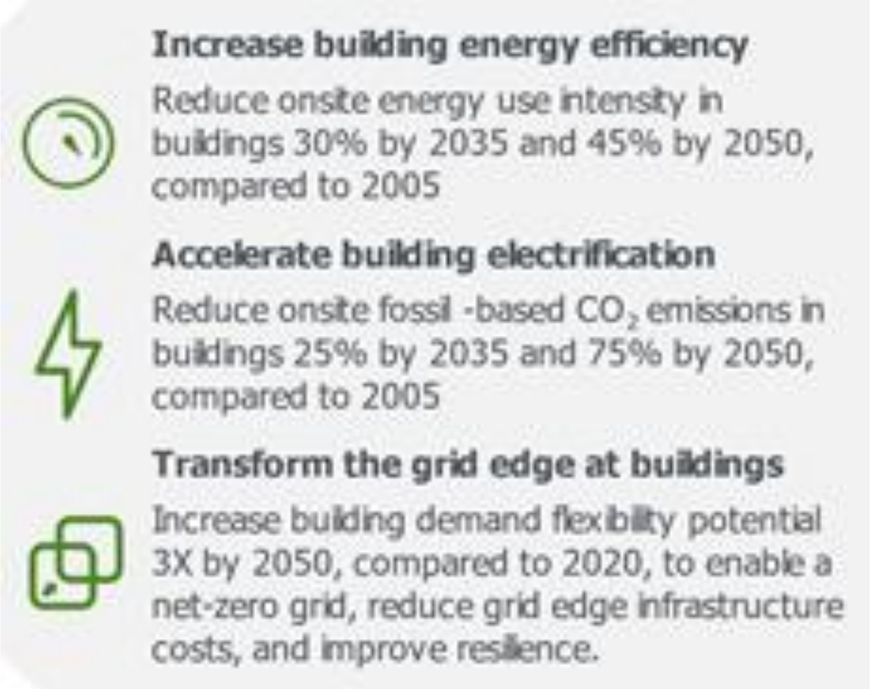
Successful biobased foam insulation

- Produced with current manufacturing practices
- Similar cost as PU foam with low GWP blowing agents

Contribution to EERE/BTO goals

- Heat transfer thru opaque envelope responsible for ~7% of US primary energy use
- New biobased foam insulation will reduce <u>both</u> embodied and operation carbon emissions

EERE/BTO's vision for a net-zero U.S. building sector by 2050



Increase building energy efficiency
Reduce onsite energy use intensity in buildings 30% by 2035 and 45% by 2050, compared to 2005

Accelerate building electrification
Reduce onsite fossil -based CO_2 emissions in buildings 25% by 2035 and 75% by 2050, compared to 2005

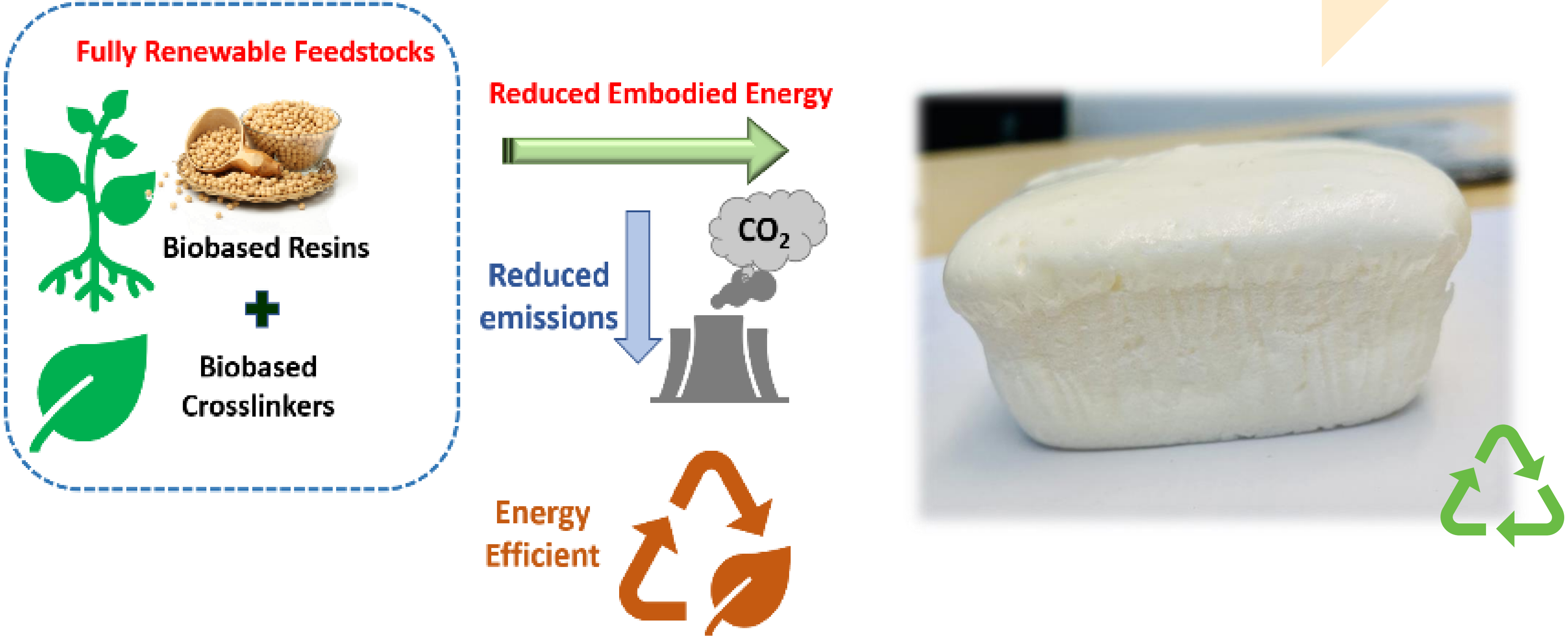
Transform the grid edge at buildings
Increase building demand flexibility potential 3X by 2050, compared to 2020, to enable a net-zero grid, reduce grid edge infrastructure costs, and improve resilience.

Concept

Good Thermal Insulation

Low Embodied Carbon

Recyclability



Specifications

Biobased Foam	Insulation properties: R ≥6/inch
	Embodied carbon ~50% < PU foam made with low GWP blowing agent
	Recyclable through process with low energy intensity
	Compressive strength ≥ 15 psi
	Gelation time = 2 - 5 min
	No toxic emissions, safe for customers
	Compatible with current foam manufacturing practices
	Low energy manufacturing process

Low Embodied Carbon Foams

AESO
Acrylated Epoxidized Soybean Oil

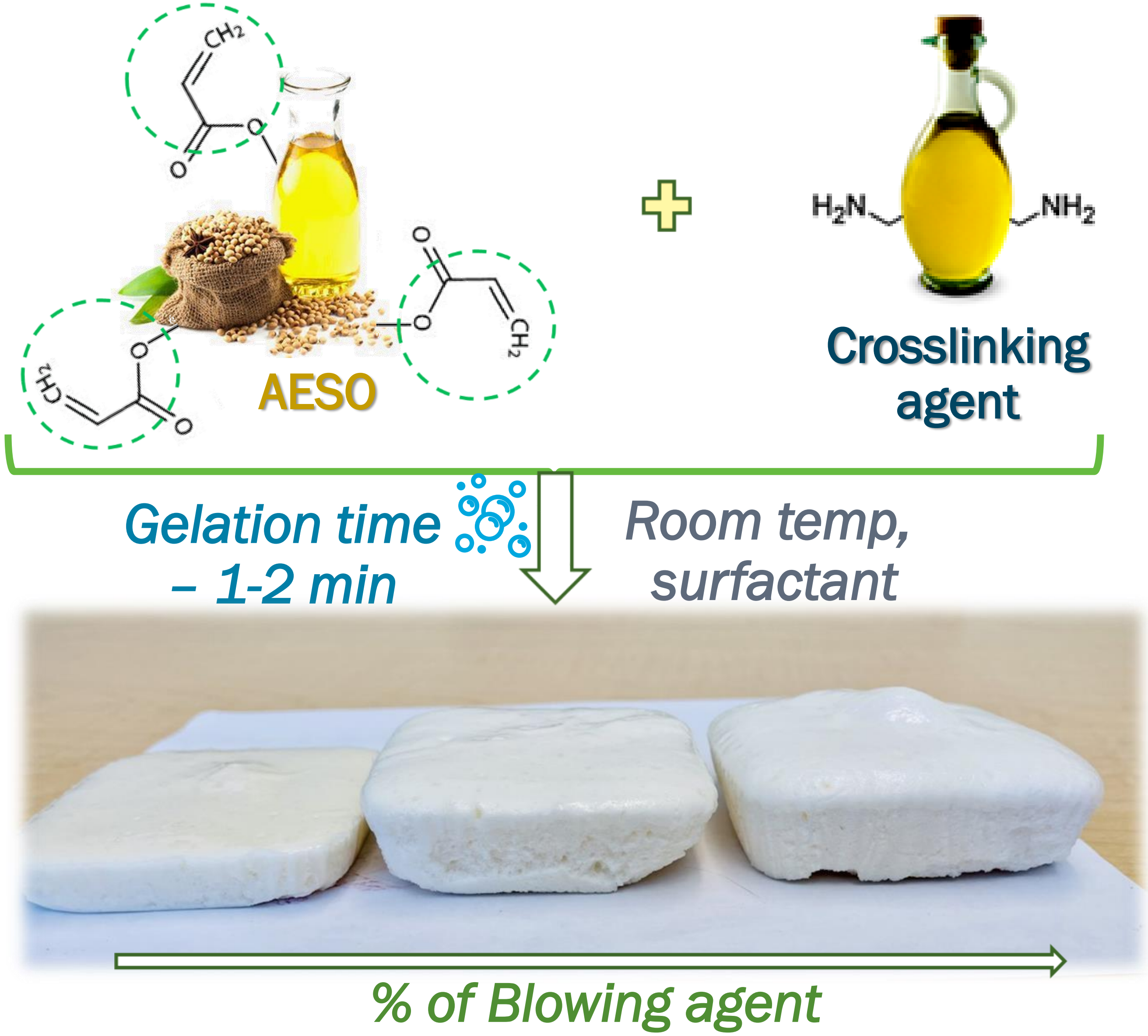
- High biocarbon content (>90 %)
- Readily available
- Eco-friendly (i.e., not volatile)
- Biodegradable

Crosslinking agent (Amines)

- Preferably biobased
- Highly reactive

Blowing agent

- Low GWP
- Miscible with polymer matrix



Challenges, Risks, Commercialization, Validation

Technical challenges

- Applying new chemistry to foam fabrication
  - Chemical reactivity
  - Processing
  - Aging

Risks and mitigation strategies

- New chemistry not adopted by foam industry
  - Consult with manufacturers to ensure that new formulation(s) meet their requirements
- Availability of biobased feedstock
  - Use feedstock with known structure and composition and production that can be expanded based on demand
- Misconception that polymer-based, biobased materials are prone to mold growth and fast deterioration
  - Biodegradability occurs at conditions that typical building materials are not expected to perform in
  - Mold growth does not depend on material source (bio- vs. petro-based)

Stakeholder engagement

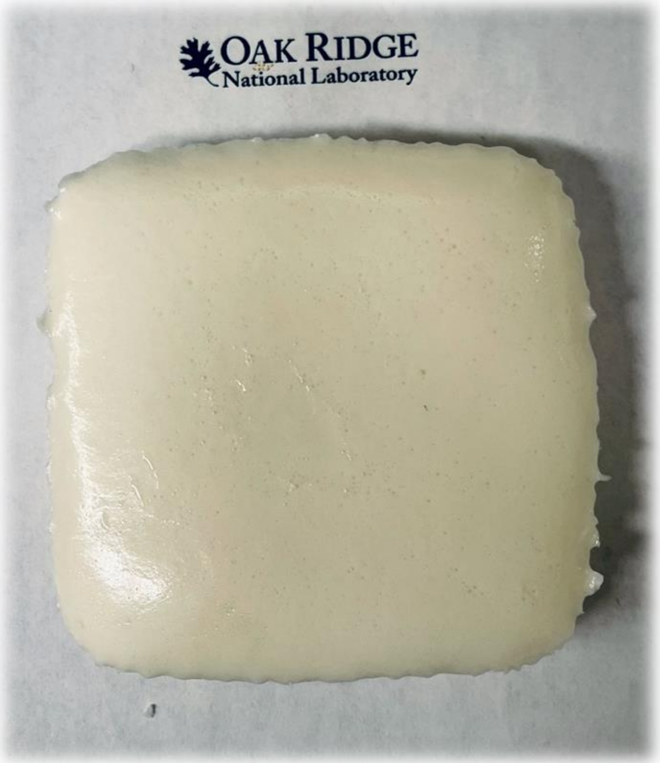
- Advisory group
  - Suppliers of biobased building blocks
  - Manufacturers of foam boards
  - Spray foam equipment suppliers
- Advise on feedstock availability and manufacturing requirements
- Participated in IMPEL 2023 to develop and articulate value proposition

Validation

- Perform LCAs throughout the foam development process to ensure that the pursued approaches can attain the targeted embodied carbon reductions

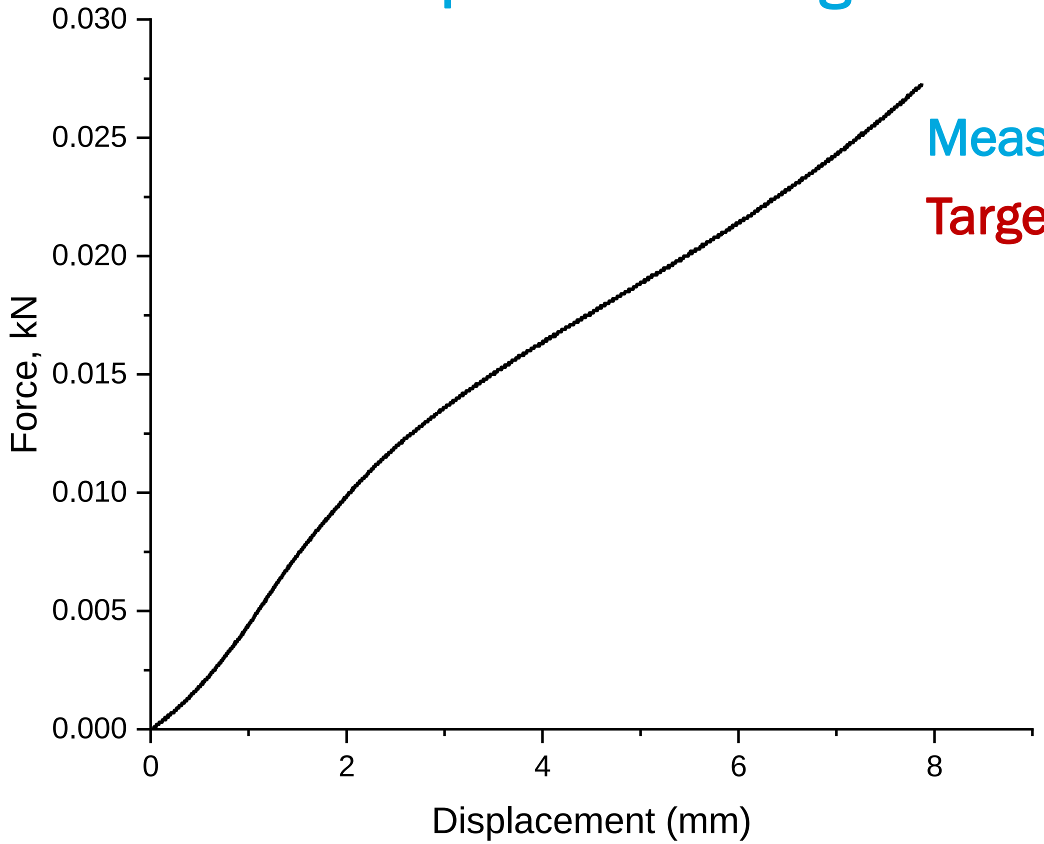
Progress: Initial Prototype Development

	Biobased content, %	Density, g/cm^3	R value	Gel Content
AESO Biofoam 1	95-98	0.35	2.1	97%



Chemical blowing agent MH-15 was used

Compressive strength



Measured: 8 psi

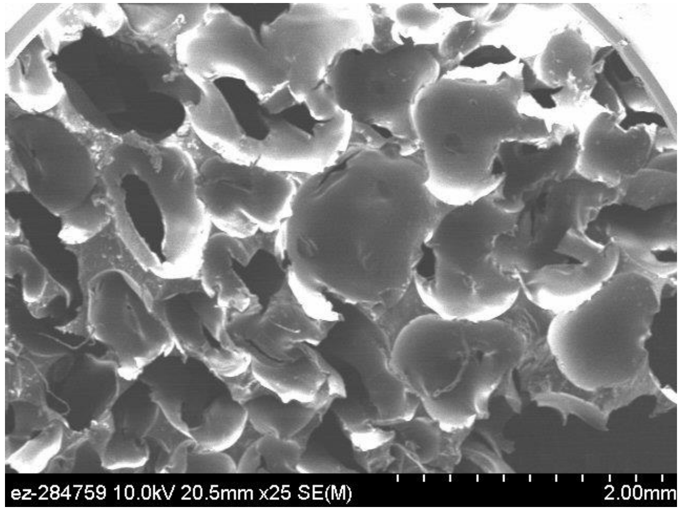
Target ≥15 psi

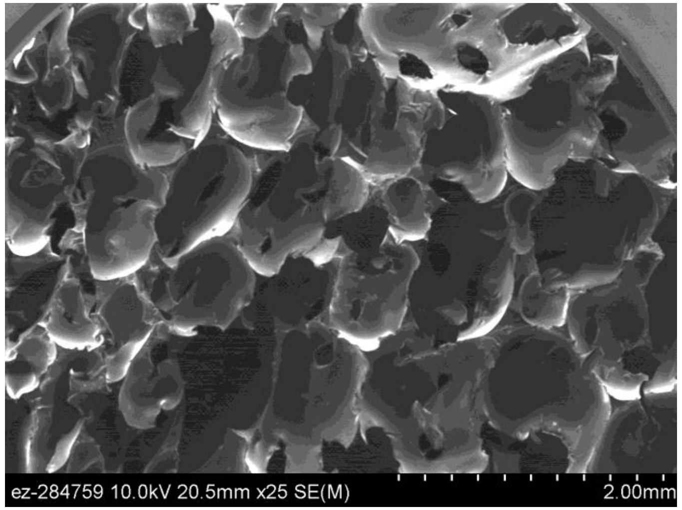
Progress: Morphology of Preliminary Biobased AESO Foams

Porosity ≥ 87%

Target > 95 %

- Attained high porosity and uniform pore distribution
- Open-cell structure from initial trials
- ~R3.5/in



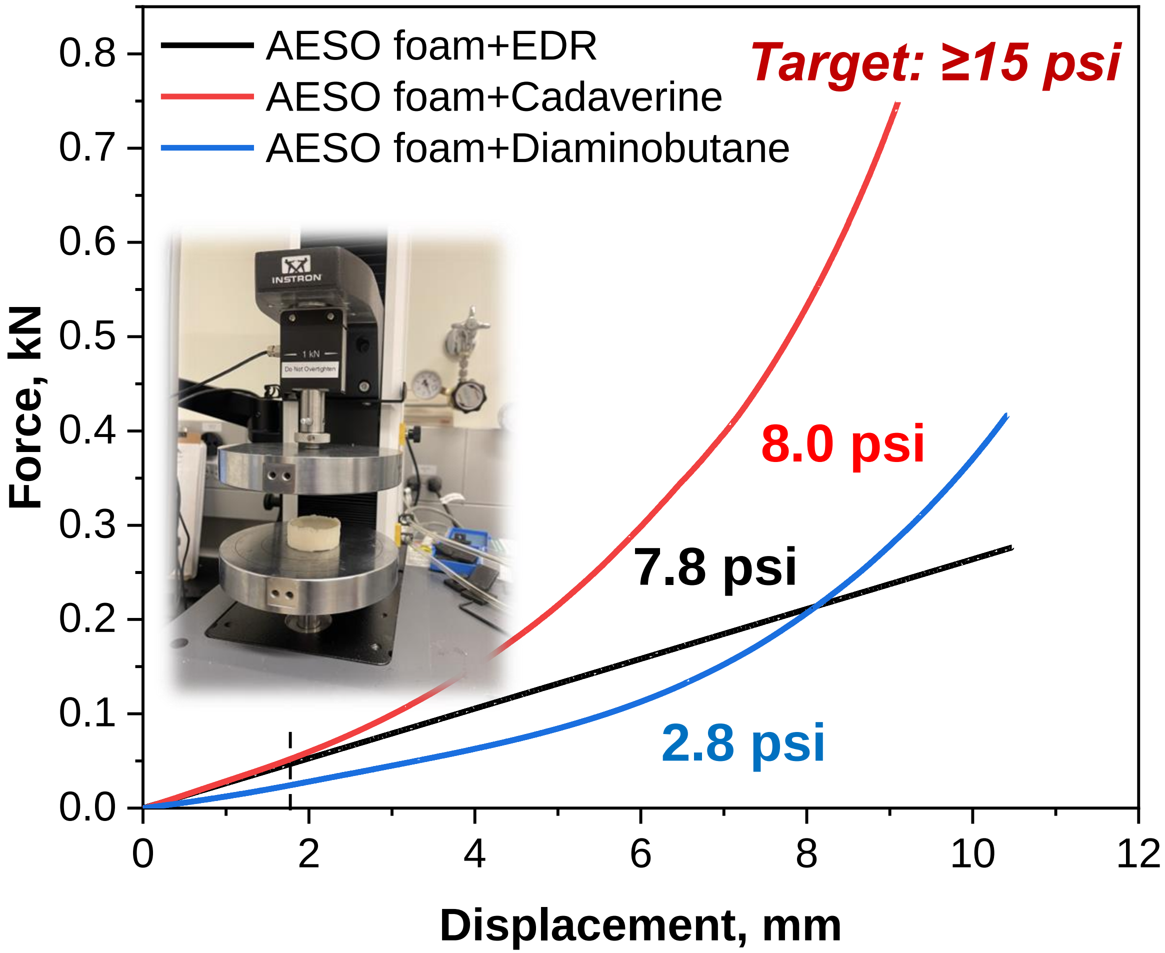


Progress: Recyclability

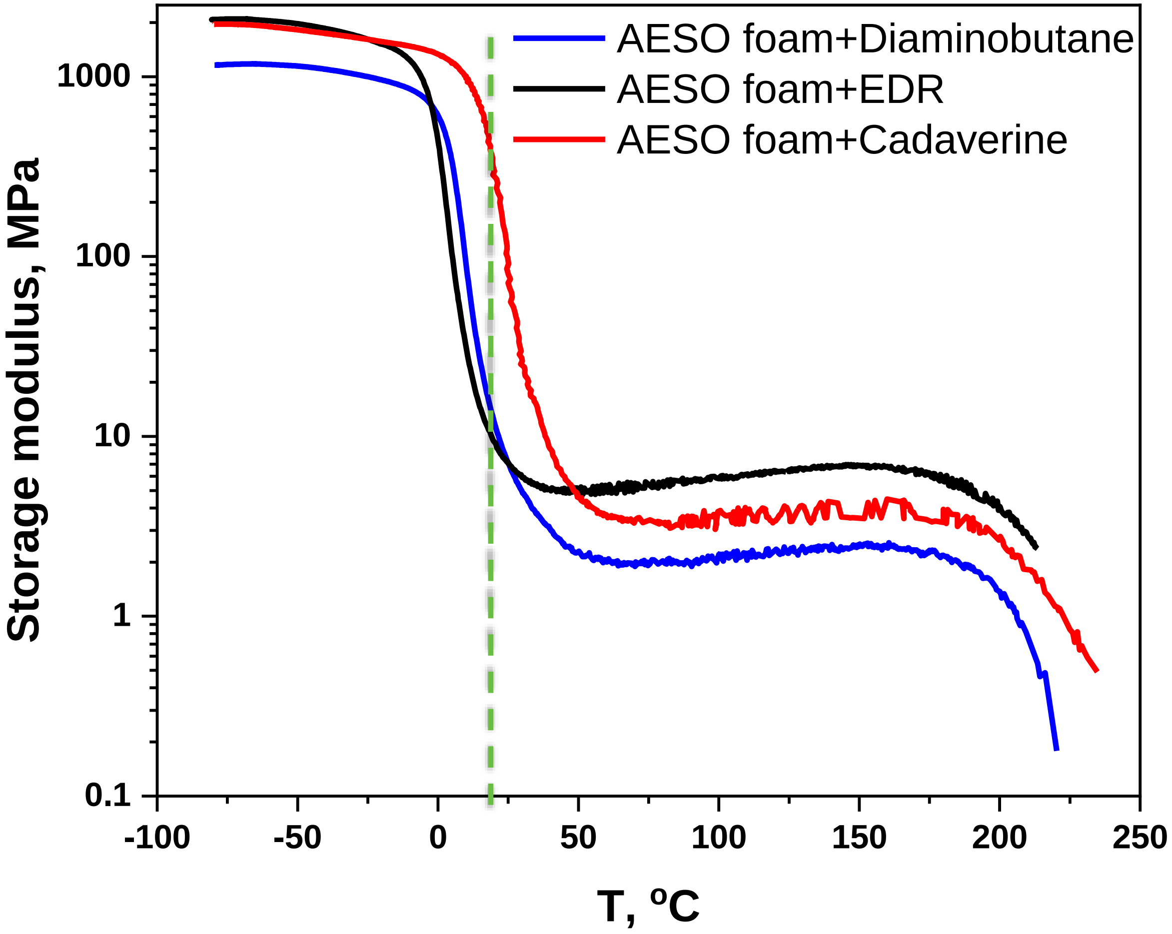
- AESO foams have dynamic covalent bonds that allow recyclability with certain triggers
- Low-energy recycling steps
  - <160 ºC
  - 15-30 min
- New products
  - Elastic films for adhesives or membranes
  - Stretch goal: Insulation foam

Progress: Compressive Strength and Storage Modulus

Compressive Strength

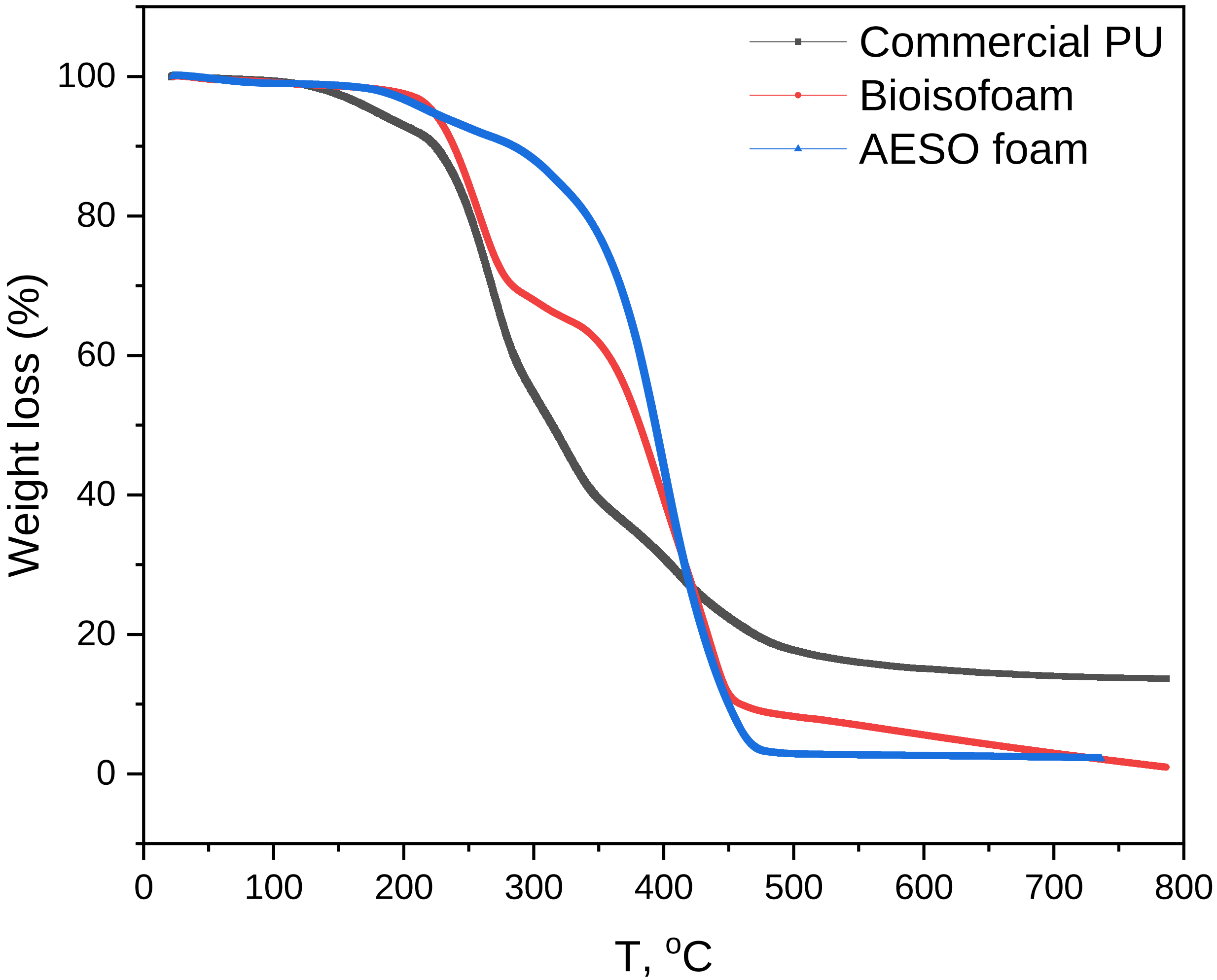


Mechanical Test



- Cadaverine has significant impact on the mechanical performance of AESO foams
- Aromatic curing agents will be evaluated to increase compressive properties of AESO foams

Progress: Thermal Stability



Foam	$T_{5\,\%}$, °C	$T_{50\,\%}$, °C
Commercial polyiso	178	312
Bioisofoam (ref.)	222	381
AESO-EDR foam	219	394

Biobased AESO foam is more resistant to higher temperatures than commercial polyiso foam

Progress: Effect From Blowing Agents (BA)

Targeted R-value ≥6/inch
Targeted density ≤2 lbs/ft^3

Chemical BA

- 5% PHMS*
- R2.4/inch
- 10.9 lbs/ft^3

Chemical and Physical BAs

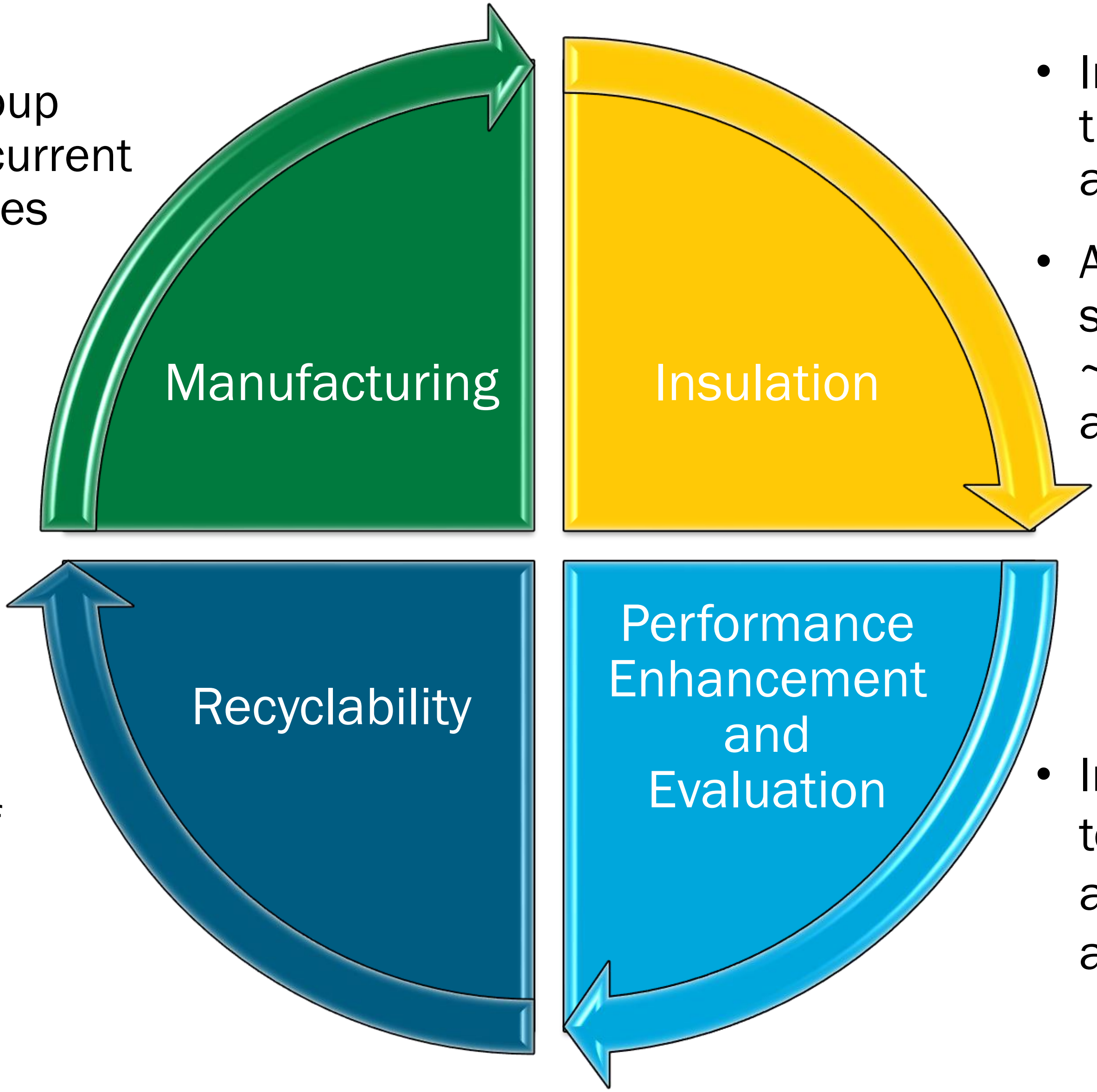
- 5% PHMS8 + 15% low GWP physical blowing agent
- R3.9/inch
- 9.49 lbs/ft^3

*PHMS-*polymethylhydrogensiloxane*

Generated sufficient data for proof of concept and filing of invention disclosure #202305321

Future Work

- Assemble advisory group
- Minimize changes to current manufacturing practices
- Run LCAs



- Improve thermal performance by tuning blowing agent, surfactant and catalyst
- Attain uniform closed cell structure, 100-400 um pore size, ~95% porosity, and low blowing agent diffusion

- Study recyclability and properties and uses of resulting elastomers

- Improve compressive strength to ≥15 psi by introducing additives (CNC, hydrotalcite) and using aromatic crosslinkers

Thank you

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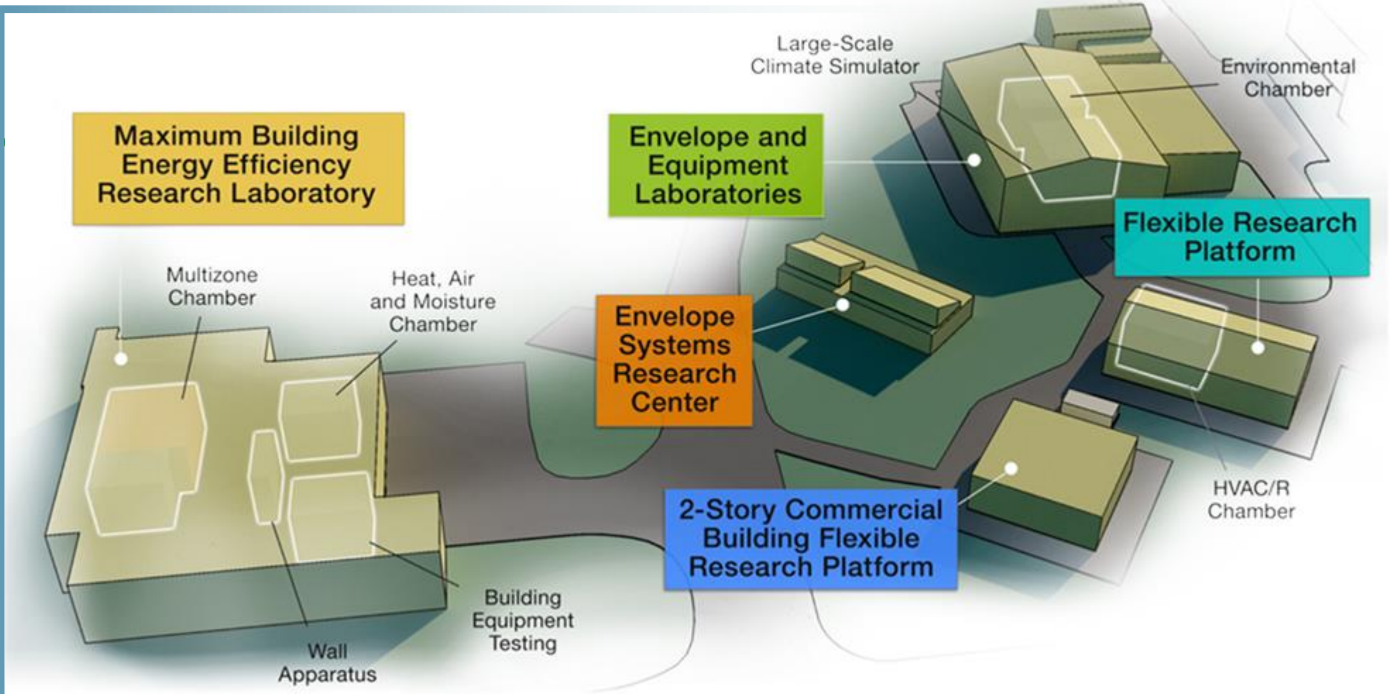

ORNL's Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 60,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free economy by 2050.

Scientific and Economic Results
236 publications in FY22
125 industry partners
54 university partners
13 R&D 100 awards
52 active CRADAs

BTRIC is a DOE-Designated National User Facility

REFERENCE SLIDES

Project Execution

No.	Deliverable/Milestones	Year 1				Year 2				Year 3			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1: Identify at least 3 main renewable bio-materials and 2-3 chemical reaction approaches that are suitable for the production of recyclable polymer insulation foams													
M1	Selected at least 3 different bio-resource and 2-3 different chemical approaches												
Task 2: Prototype Development													
M2	Produced at least 2 intermediate products from the initial modification of the biomass												
M3	Synthesized polymer foams with dynamic covalent bonds from biomass that have at least 60% negative carbon content.												
G/NG M4	Fabricated 4×4-inch polymer foam samples that have at least 60% negative carbon content, 5% reduction in embodied energy, and R-value ≥3.5/inch.												
M5	Fabricated 4×4-inch polymer foam samples with R-value ≥3.8/inch and compressive strength ≥10 psi.												
M6	Fabricated of 4×4-inch polymer foam samples with at least 60% of biobased carbon content with a reduction of CO_2 emission by 30%.												
M7	Fabricated 4×4-inch polymer foam samples with R-value ≥4.0/inch and compressive strength ≥15 psi.												
M8	Demonstrated thermo-recycling of the polymer film from the used polymer foam within 2 h.												
G/NG M9	Fabricated 4×4-inch polymer foam samples with R-value ≥4.5/inch and compressive strength ≥20 psi.												
M10	Fabricated 4×4-inch polymer foam samples with at least 70% of negative carbon contents and 30% reduction of embodied energy.												
M11	Fabricated 4×4-inch polymer foam samples with R-value ≥5.5/inch.												
M12	Demonstrated chemical recycling of the polymer foam to a new polymer foam. The recycled foam will have mechanical toughness that are ≥70% of the original polymer foam.												
M13	Fabricated 4×4-inch polymer foam samples with R-value ≥6/inch, compressive strength ≥30 psi, and ≥30% reduction of embodied energy.												
M14	Demonstrated chemical recycling of the polymer foam to a new polymer foam. The recycled foam will have mechanical toughness that is ≥95% of the original polymer foam. Determined the process that is most feasible with regard to processing energy and large-scale adoption.												

Team

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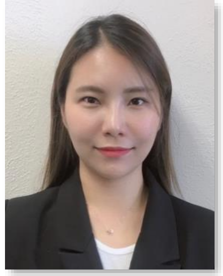
Diana Hun, PhD


Som Shrestha, PhD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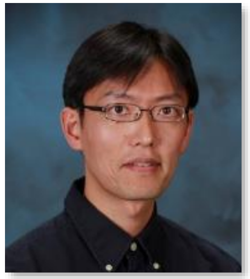
Characterization

Integration


Zoriana Demchuk, PhD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Synthesis

Life cycle assessments