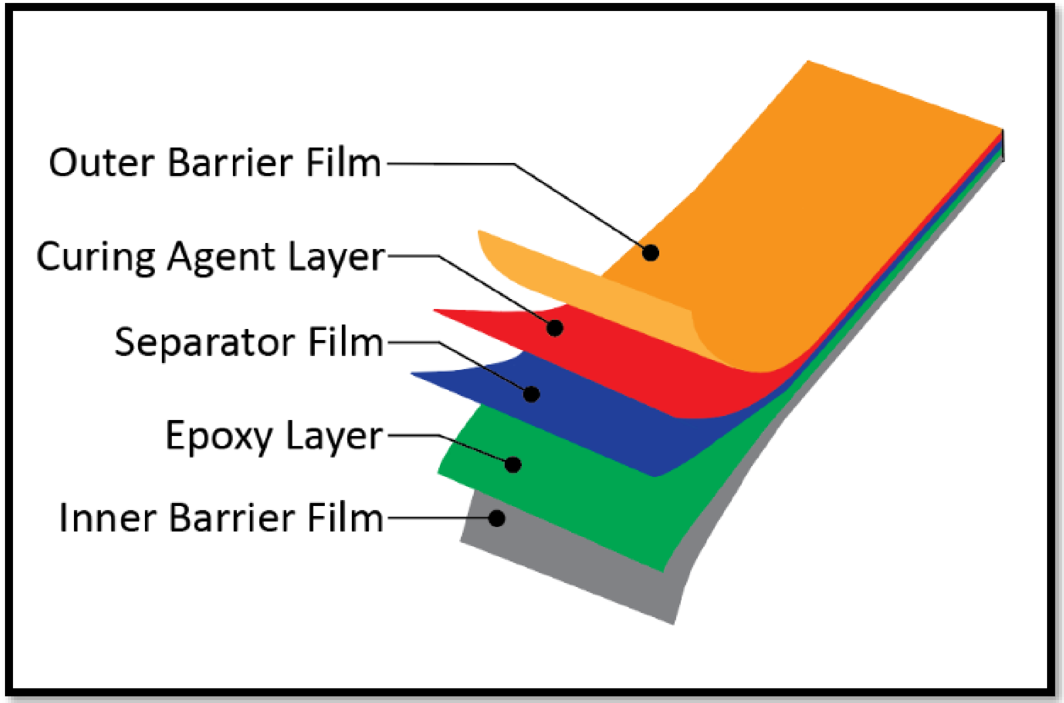
Self-healing Films to Improve Durability of VIPs



Oak Ridge National Laboratory, FLEXcon
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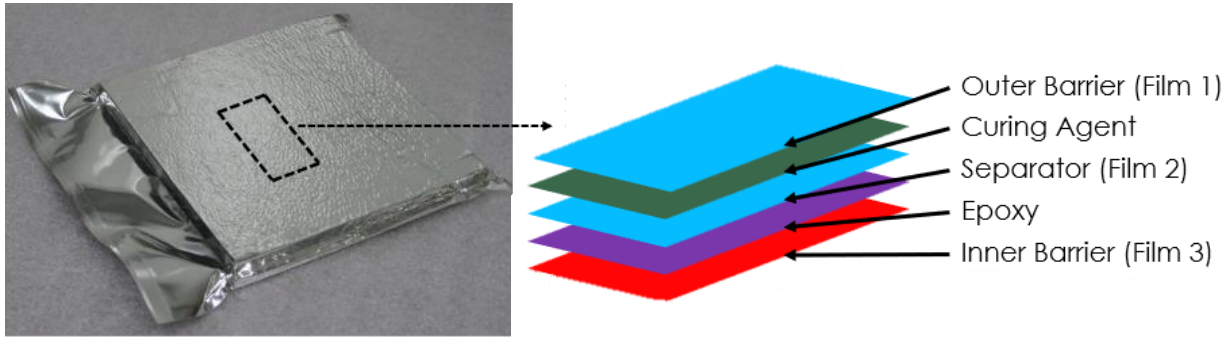
BTO-09.09.01.113

Project Summary

Goal: Increase robustness of VIPs through the development and manufacturing demonstration of a cost-effective self-healing barrier film

Outcomes

- Set commercialization path with FLEXcon for self-healing barrier film
- Increase use of VIPs in building envelopes because the self-healing barrier film makes them more resistant to construction environments



Team and Partners

Oak Ridge National Laboratory

FLEXcon

Stats

Performance Period: 4/1/2022-9/30/2023

DOE budget: $200k

Cost Share: $120k ORNL Royalty + $80k FLEXcon

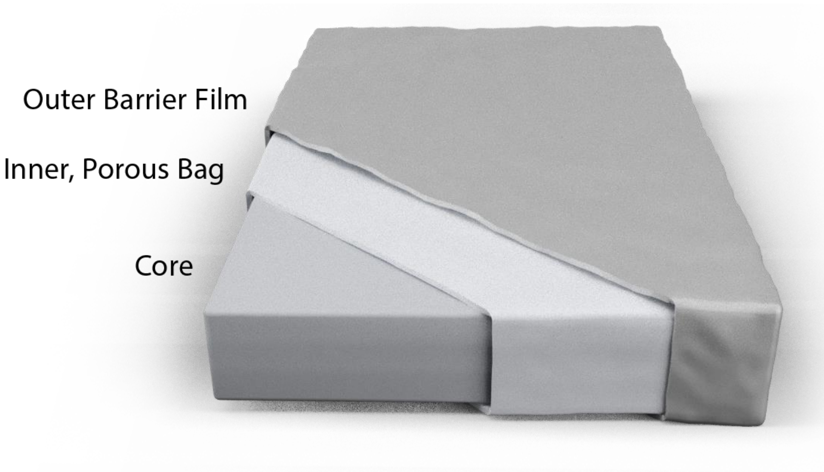
Milestone 1: Evaluate barrier property and self-healing capability of various substrate films

Milestone 2: Initial techno-economic analysis

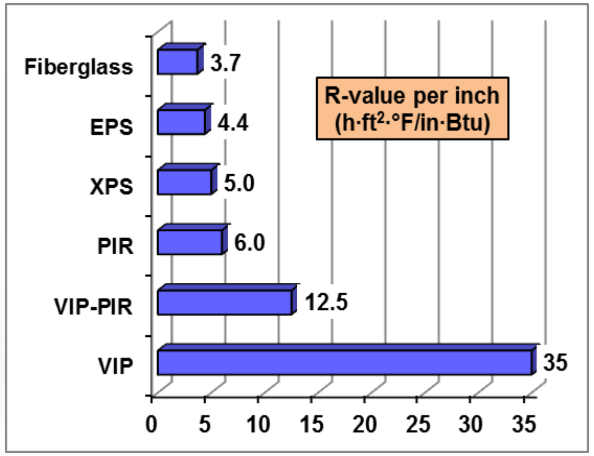
Milestone 3: Conduct at least one large scale trial at FLEXcon

Problem

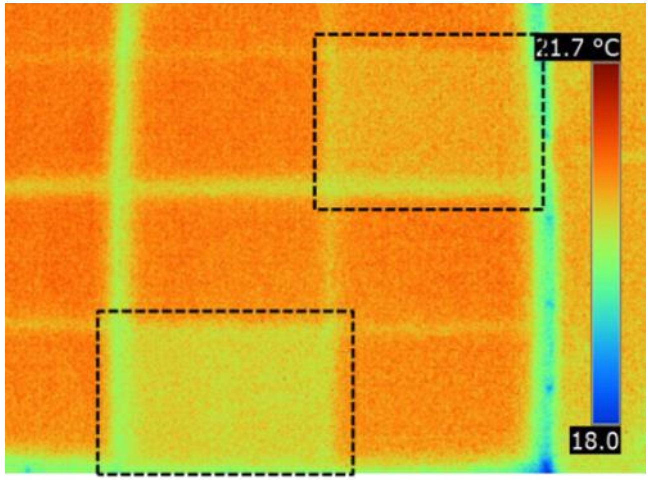
- Energy lost through building walls, windows, and roofs in 2015
  - ~7 quads of energy
  - ~8.5 % of total primary energy consumed
- ~50% of existing buildings
  - Built before there were energy codes
  - Lack or have minimal insulation
- Vacuum insulation panels high R-value/in
  - Simplify retrofit detailing
  - Insulate envelope areas with limited spaces
- Lack of robustness is a major challenge for VIPs to be used in constructions
  - Puncture to barrier films annuls vacuum and high thermal performance

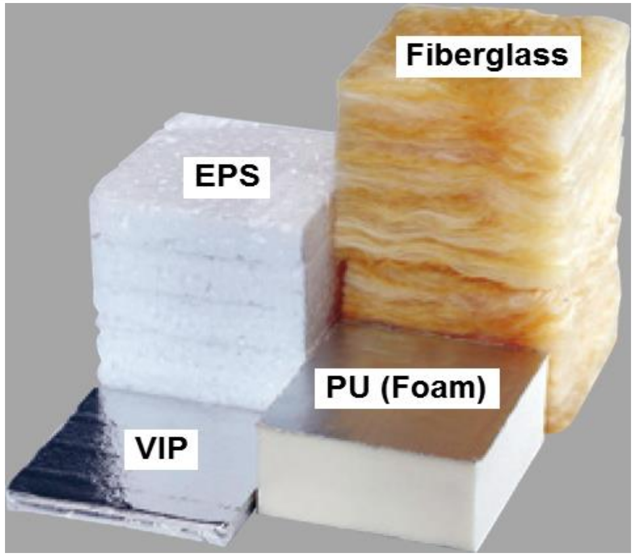


Insulation R-Value Comparison



Loss of VIP performance indicated in thermal image



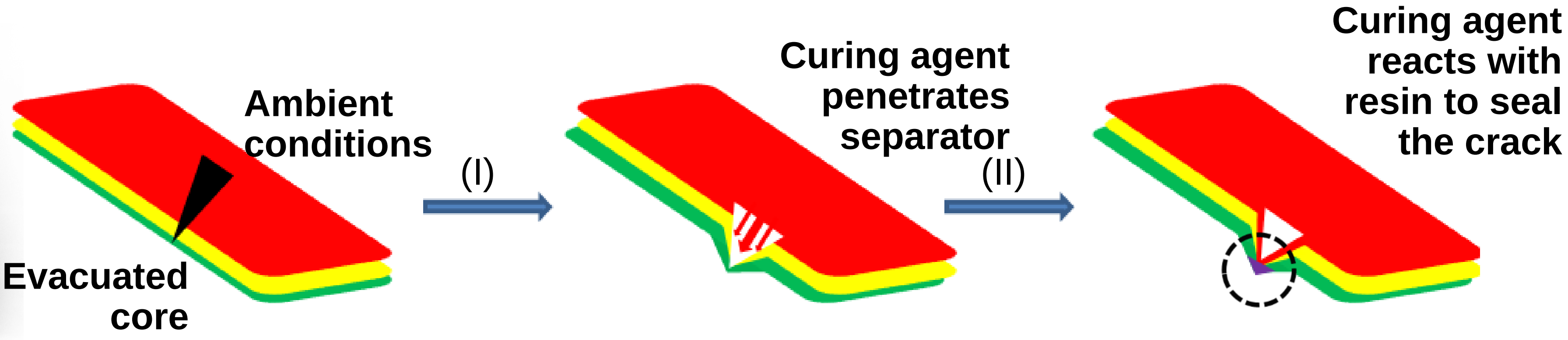


U.S. EIA – Energy Consumption & Efficiency Survey (2015) U.S. Census Bureau – American Housing Survey (2021)

Goal/Approach

- Develop multi-layered self-healing barrier films for VIPs
  - If punctured, the epoxy and curing agent would mix, react and seal the puncture
- Determine chemical slurries needed for two-part reaction that enable instant healing and substrate films to create high barrier properties
- Optimize slurries and substrate films for slot die roll-to-roll at ORNL and large R2R at FLEXcon
- Create a VIP with self-healing ability and validate performance
- Mature and de-risk the technology for commercialization: technology validation, TEA, understand the customers, and potential market penetration

Multi-layered self-healing barrier films



Alignment and Impact

Successful Development of Self-healing Barrier Films for VIPs

- Increase use of VIPs in building envelopes because the self-healing barrier film makes them more resistant to construction environments
- Higher use of VIPs in buildings increases demand and reduces cost

- Creating a path for widespread use of VIPs aligns with the EERE/BTO vision for a net-zero US building sector by 2050.
- According to the International Energy Agency, wider use of VIPs is likely to reduce CO_2 emissions by approximately 8%.
- Creating a durable self-healing R35 inch insulation panel will contribute to both energy savings and decrease in carbon emissions.
- Successful completion of this project will pave a way for the commercialization and scalability of the self-healing barrier film.

Increase building energy efficiency

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

Accelerate building electrification

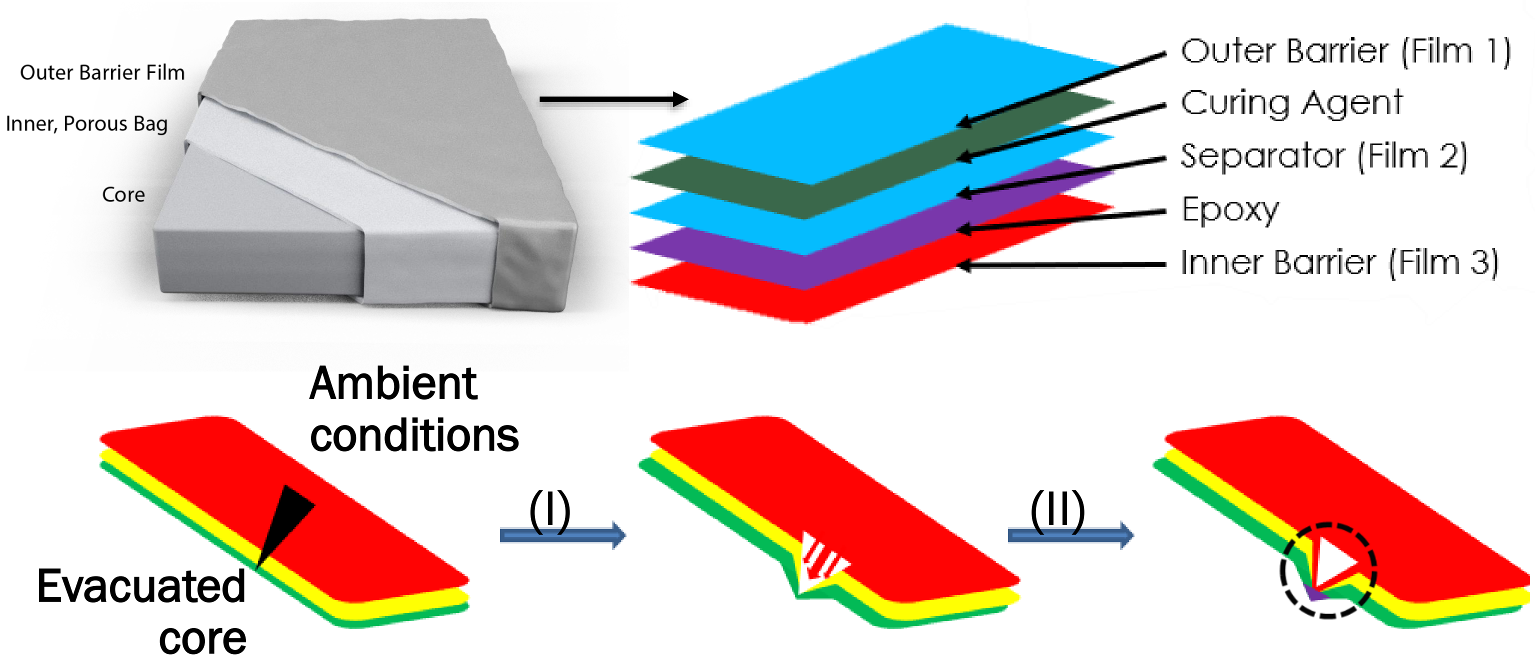
Reduce onsite fossil -based CO_2 emissions in buildings 25% by 2035 and 75% by 2050, compared to 2005

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.

Approach

Two-part chemistry in self-healing film



The reduced pressure in the evacuated core enables the curing agent on the outer side to flow and mix with the reactive agent

- Identify the formulation for self-healing
- Evaluate the self-healing kinetics
- Adjust viscosity and processability
- Ensure their long-term shelf life
- Evaluate barrier properties
- Choose and evaluate scalable substrates and formulation with FLEXcon
- Conduct R2R Trials at lab scale
- TEA to identify the cost-materials relationships
- Perform large scale R2R trials at FLEXcon and conduct refined TEA
- Evaluate self-healing VIP for their self-healability and R-value

Approach - Team

Oak Ridge National Laboratory

Tomonori Saito, PhD : PI, Synthetic polymer chemist, with expertise in self-healing chemistry, polymer chemistry, and manufacturing

Natasha Ghezawi, 3rd Year PhD Student

Diana Hun, PhD: Group leader for Building Envelope Materials Research

Catalin Gainaru, PhD: Physicist with expertise on diffusion

Sungjin Kim, PhD: Material scientist, expertise on polymer processing

FLEXcon

Mike Merwin: Director of New Technology

Yudhisthira Sahoo, PhD: Technology Discovery Specialist

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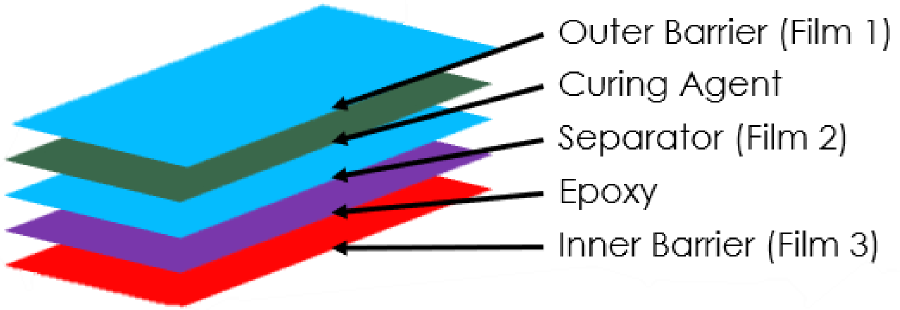
Amanda Young: Technology Discovery Specialist

Julie Beaudry: Technology Incubator Manager

CRADA Partner

Progress – Identify Self-healing Wet Chemistry



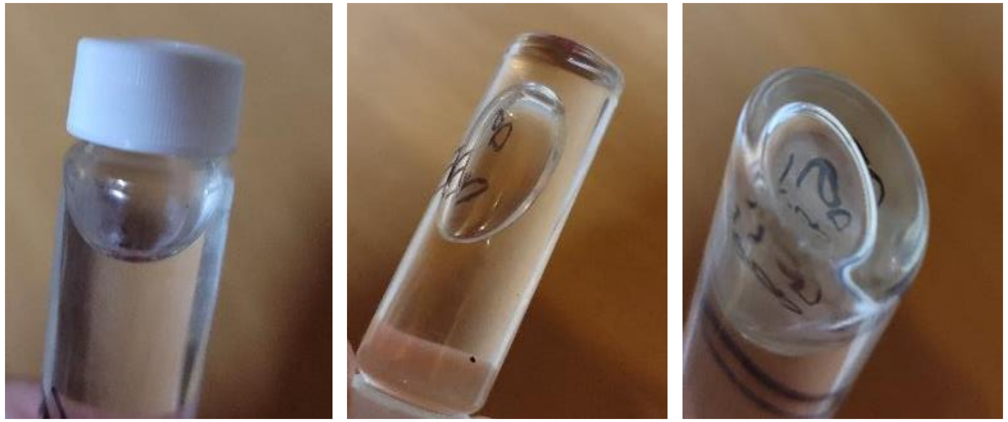
- Initial choice: EPON 8111 – Faster Cure

Optimized Choice

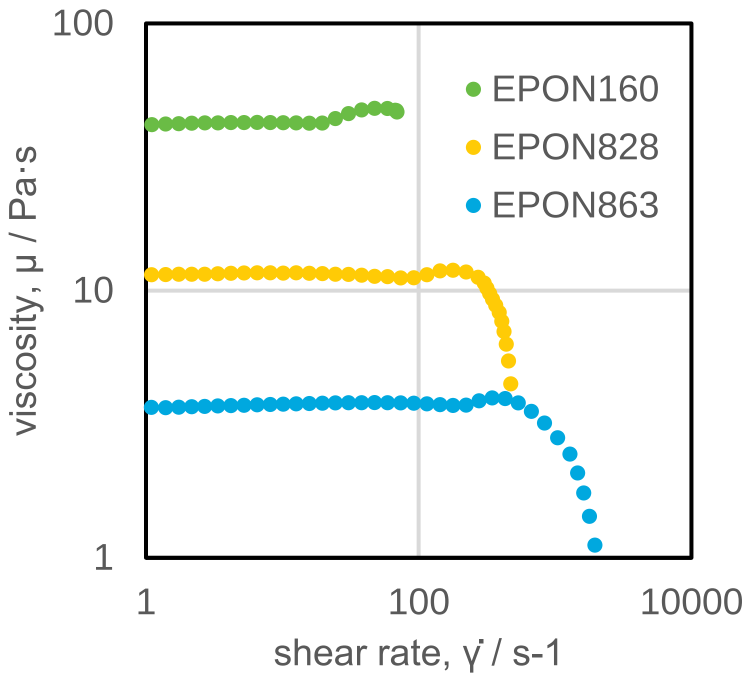
- Epoxy: EPON 160 (For processing 10% MEK added)
- Curing Agent: PEI-10K (For processing 50% water added)

EPON 8111 in an oven at 70ºC for 1 month solidifies

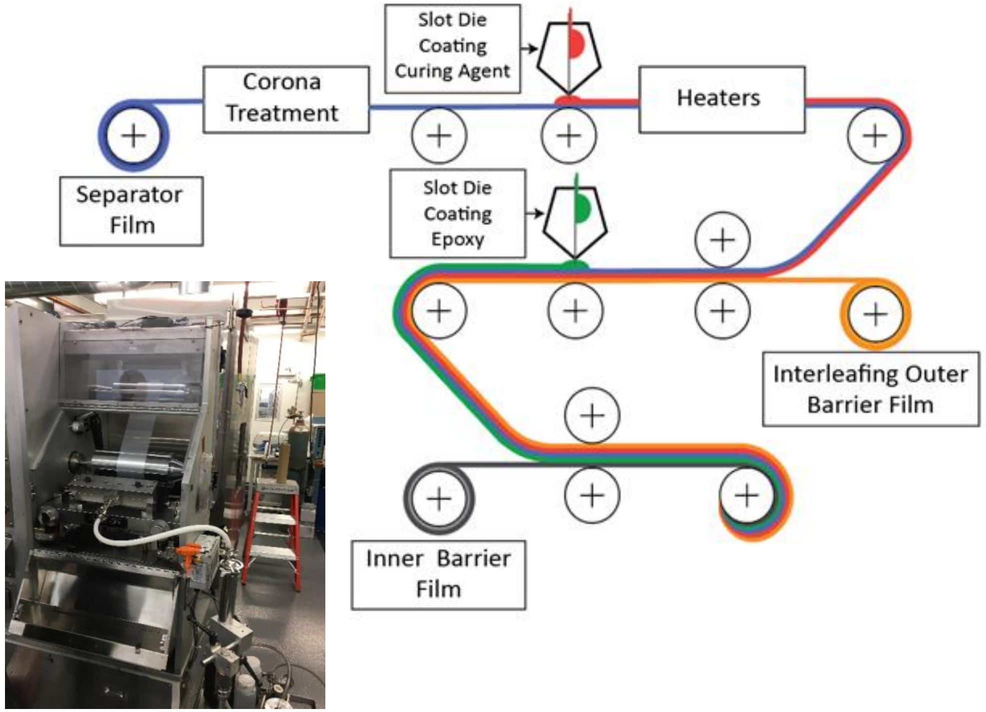
EPON 160 in an oven at 70ºC for 1 month shows no change

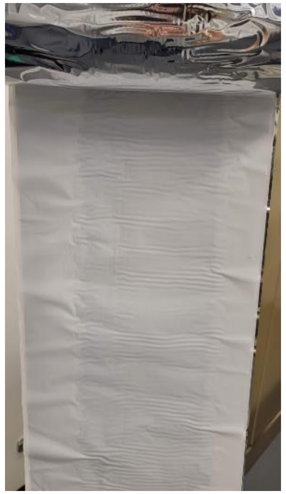


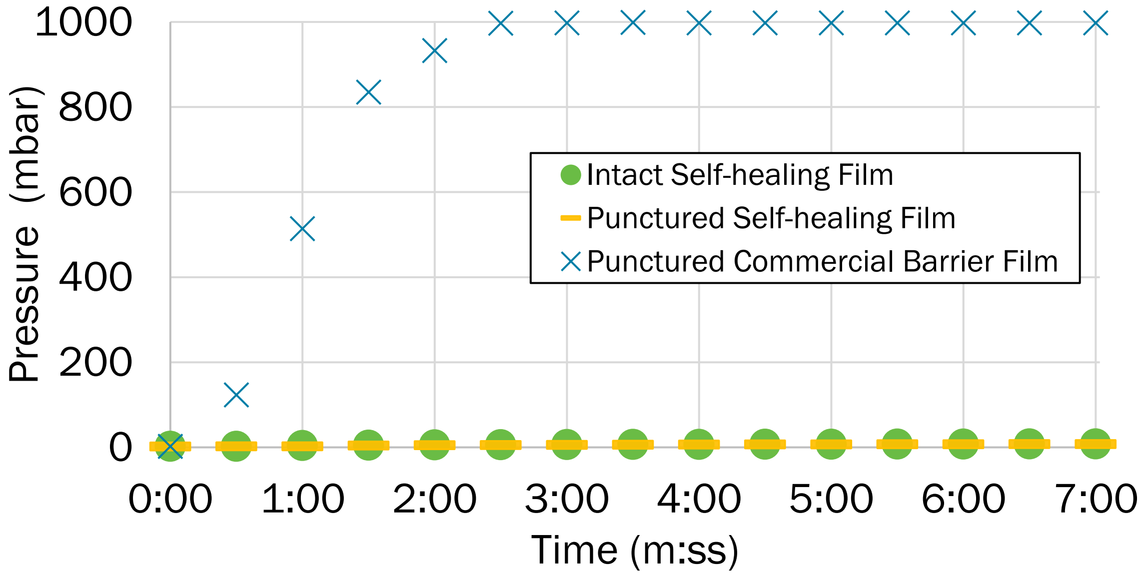
Higher Viscosity

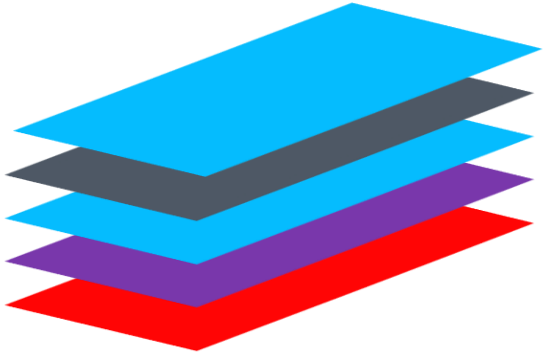


Progress– Successful Slot Die R2R and Puncture Test

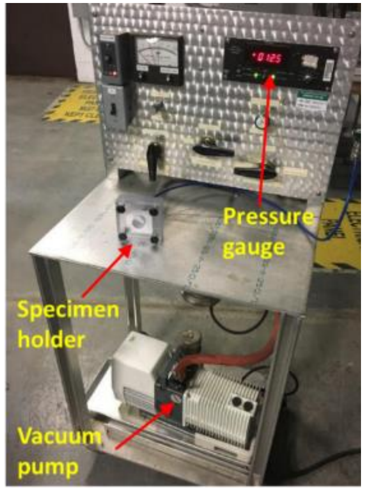


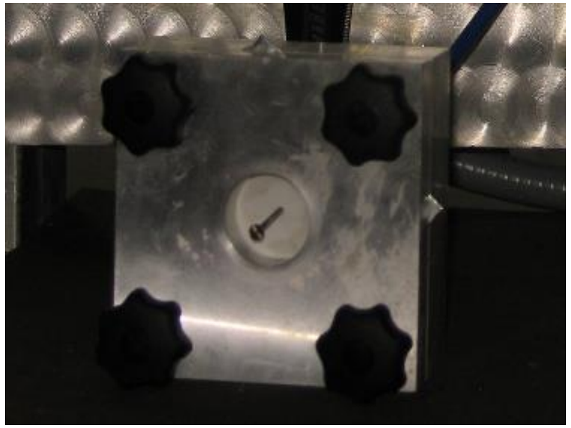






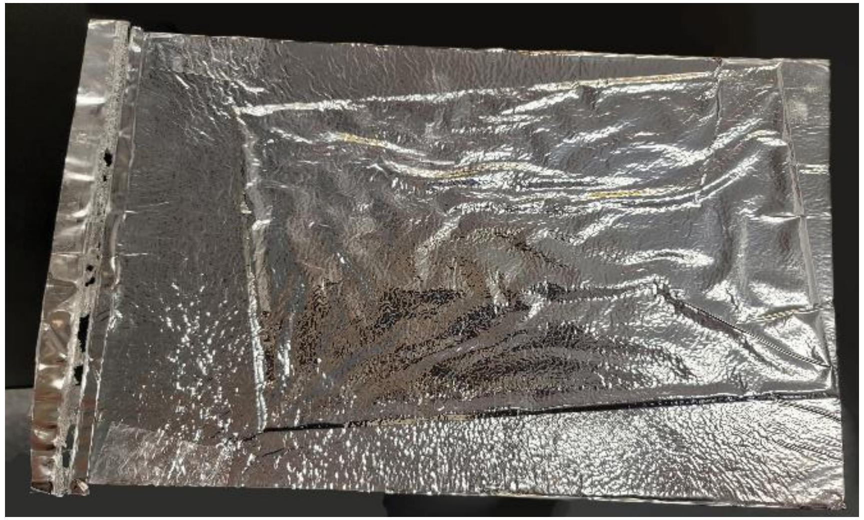
Overall Thickness: ~ 200 μm
PE: 40 μm
Epoxy: ~ 50 μm
PE: 40 μm
Curing agent: ~ 50 μm
mPET: 20 μm

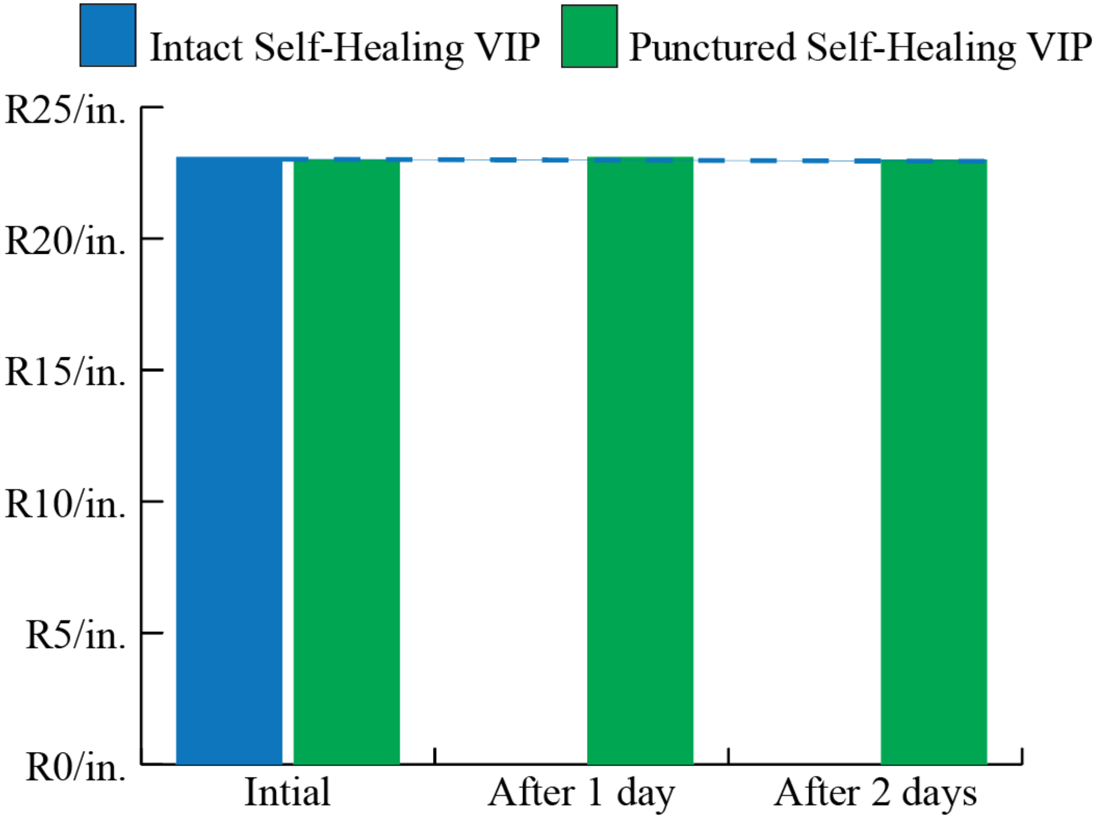




Progress - VIP Prototype and Thermal Resistance Testing

1. VIP is opened
2. Self-healing barrier film was placed inside
3. Panel evacuated and sealed
4. VIP is punctured with a nail
5. VIP's thermal resistance measured





✓ No measurable change in R-value

*Values are not as high as commercial; this is due to the vacuum level via sealing. (Commercial ~ R35/in)

Progress – Substrate Film Choice for Self-healing Films

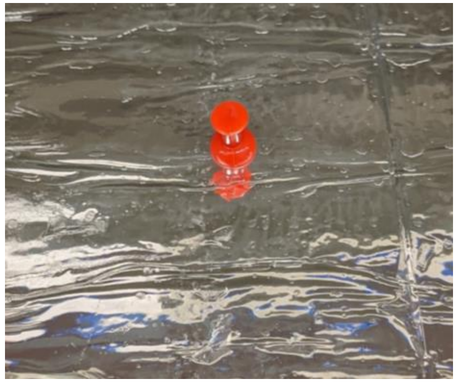
OTR and WVTR Data from MOCON

FILM	OTR (cc/m^2*day)	WVTR (g/m^2*day)
Commercial VIP: Multilayer Barrier Film	0.089	0.226
FLEXMARK Metalized Single-layer Barrier Film	0.636	0.039
FLEXGUARD Thin Clear Single-layer Barrier Film	0.651	0.160
Multilayer Self-Healing Barrier Film (Intact)	0.052	0.016
Multilayer Self-Healing Barrier Film (Punctured)	0.310	0.073

Estimated Correlation Between OTR and R-Value of our Self-healing Barrier Film

Knudsen Effect was used to calculate the relationship between OTR and thermal resistance

✓ Even with puncture, self-healing film is estimated to maintain R-Value (based on OTR)

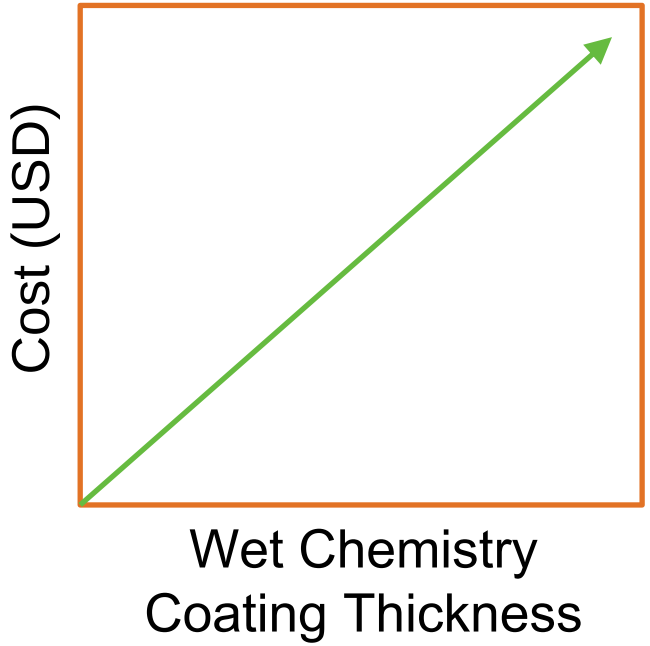


Front of Punctured Film

Back of Punctured Film

Progress – Initial TEA : Identifying the Major Cost Driver

- Technoeconomic analysis (TEA) for large scale production were conducted by FLEXcon
- Cost and potential earnings determine impact of wet chemistry on the cost of overall film
- Overall cost is competitive, but price increases with wet chemistry cost

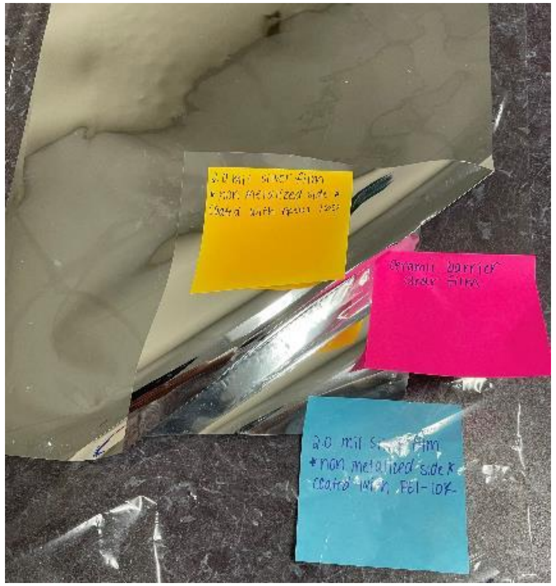


Thinner wet chemistry coating will be the most effective for reducing the cost.
⟶ Identical self-healing was achieved with half (25 μm) of the original wet chemistry thickness (50 μm)

Progress - Small Scale Coatings and Block Testing at FLEXcon

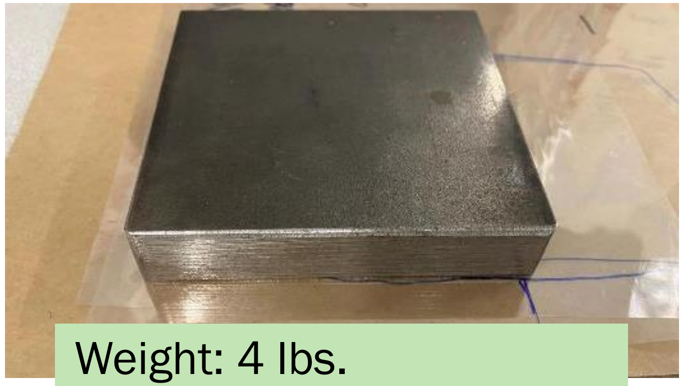
- FLEXcon has conducted several viscosity and adhesion tests to determine the processability of the current chemicals.

- Coatings of both PEI-10K and EPON 160 were tested on the non-metalized (left) and metalized (right) sides on the FLEXMark 2-mil film.

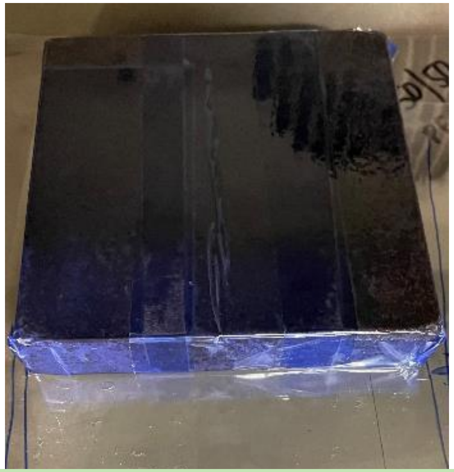


✓ <u>No obvious adjustment is needed for the viscosity and adhesion for initial fabrication trials.</u>

- Evaluated the oozing of wet chemistry when weight was applied for 5 days
- This determines the ability to keep the film wound tight and the long-term shelf life



Weight: 4 lbs.
Temperature: Room Temp.



Weight: 4 lbs.
Temperature: 100° F

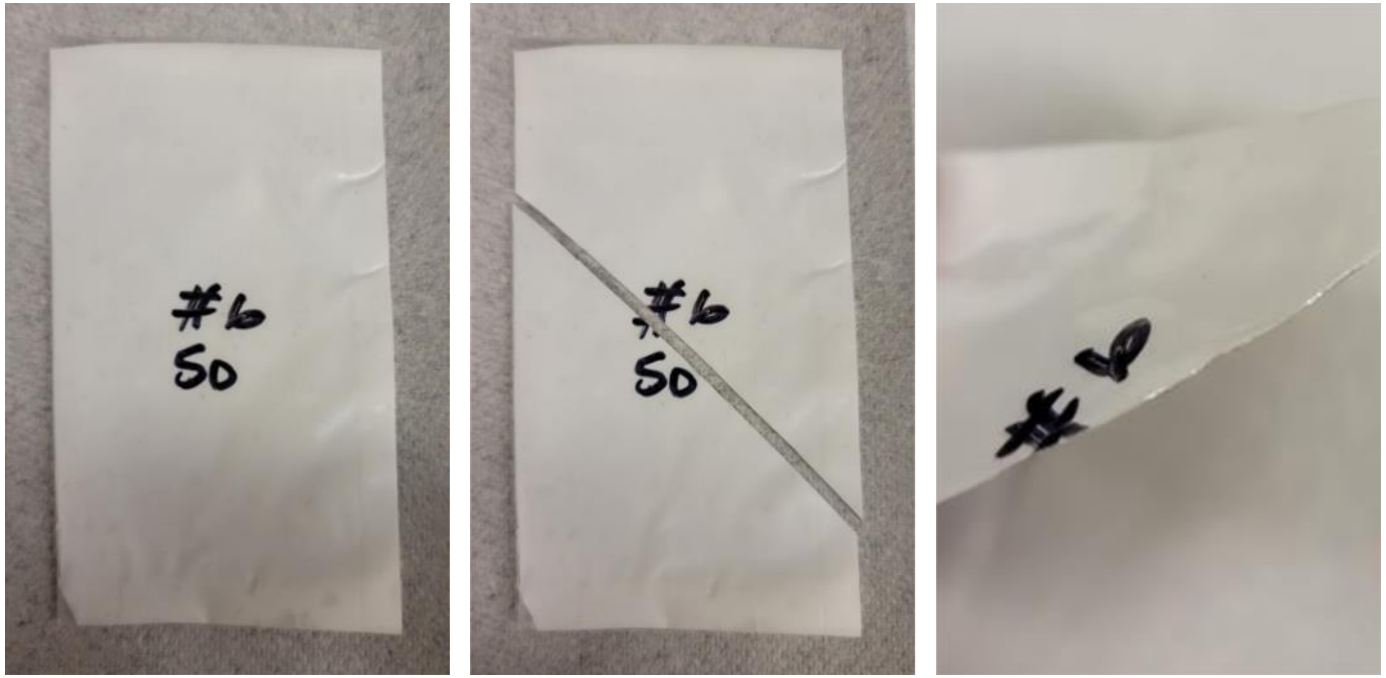
Progress – Barrier Film can be cut: Slicing Test

Slicing Test for Large Production

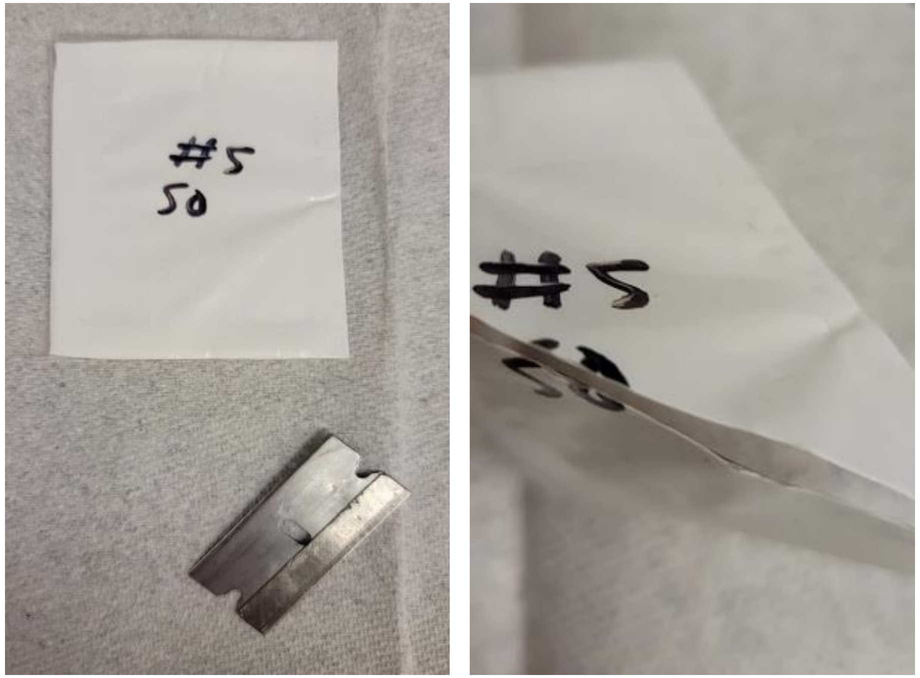
- FLEXcon will make bulk rolls and need to cut different sizes depending on the needs.
- Main concern was spillage of the chemicals when the film is cut from a roll.

✓ No spillage was observed

<u>Scissors : Cut from both sides</u>



<u>Razor: Cut from one side</u>



Progress - Trials at FLEXcon toward Industrial Manufacturing

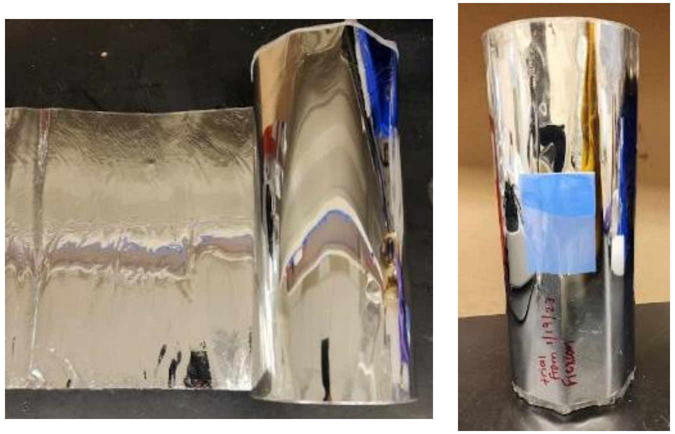
First Trial:

- Combination of surface energy and viscosity caused EPON 160 to flow to edges of film after coating

EPON 160

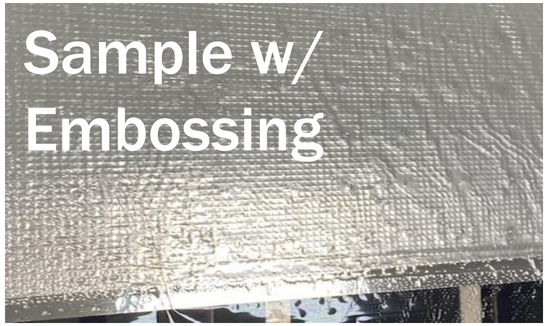
PEI-10K

Final Product

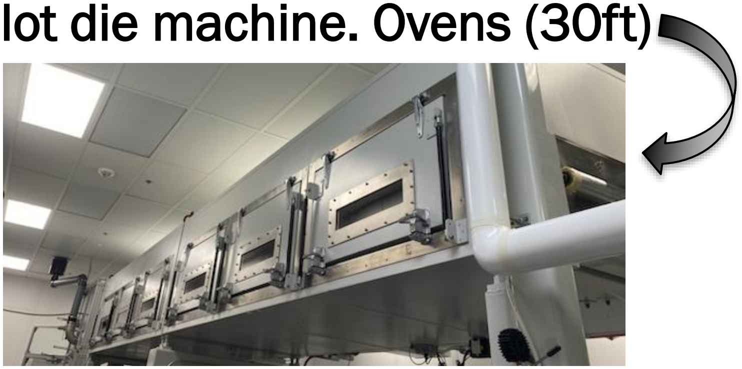


Recent Trials:

- Adjusted Corona treatment and oven temperature
- Added mesh layer or embossed film
- EPON 160 in place after storage > 1 week
- No spillage observed



Trials coated with 71 ft. long slot die machine. Ovens (30ft)



Future Plans

- ➢ Perform large scale R2R trials at FLEXcon
- ➢ Further model effect of WVTR and OTR on VIP performance and lifetime with selected substrates and chemistries
- ➢ Work on a refined techno-economic analysis
- ➢ Identify efficient and most economical material composition and manufacturing processes
- ➢ Create a prototype of self-healing VIP using a custom-built vacuum sealing device
- ➢ Confirm self-healing by puncturing VIP and measuring R-value over different time periods
- ➢ Summarize in Technology Commercialization Fund (TCF) report and pursue TCF Phase II

Publications and Intellectual Property

- Publications
  - Kaushik Biswas*, Dustin Gilmer, Natasha Ghezawi, Peng-Fei Cao, Tomonori Saito*, "Demonstration of self-healing barrier films for vacuum insulation panels", *Vacuum* 164 (2019) 132–139
  - Natasha Ghezawi, Kelsey Livingston, Mengyuan Wang, Mike Merwin, Tom Jarecke, Pengfei Cao, Diana Hun, Tomonori Saito, "Self-Healing Barrier Films For Vacuum Insulation Panels", 2022 Buildings XV International Conference Proceedings
  - Future papers
    - Natasha Ghezawi, Amanda Young, Christopher Kowalczyk, Catalin Gainaru, Mike Merwin, Yudhisthira Sahoo, Sungjin Kim, Diana Hun, Tomonori Saito, "Scalable Multipurpose Self-Healing Multi-layer Films (Working Title)"

- Intellectual property (Two US patents have been issued.)
  - Kaushik Biswas, David Lee Wood III, Kelsey M Grady, Natasha B Ghezawi, Pengfei Cao, Tomonori Saito, "Roll-to-roll slot die coating method to create interleaving multi-layered films with chemical slurry coatings" US Patent No. 11446915, Sep 20, 2022
  - Kaushik Biswas, Pengfei Cao, Tomonori Saito, "Self-healing barrier films for vacuum insulation panels", US Patent No. 11287079, Mar. 29, 2022

Thank you

Oak Ridge National Laboratory || FLEXCon
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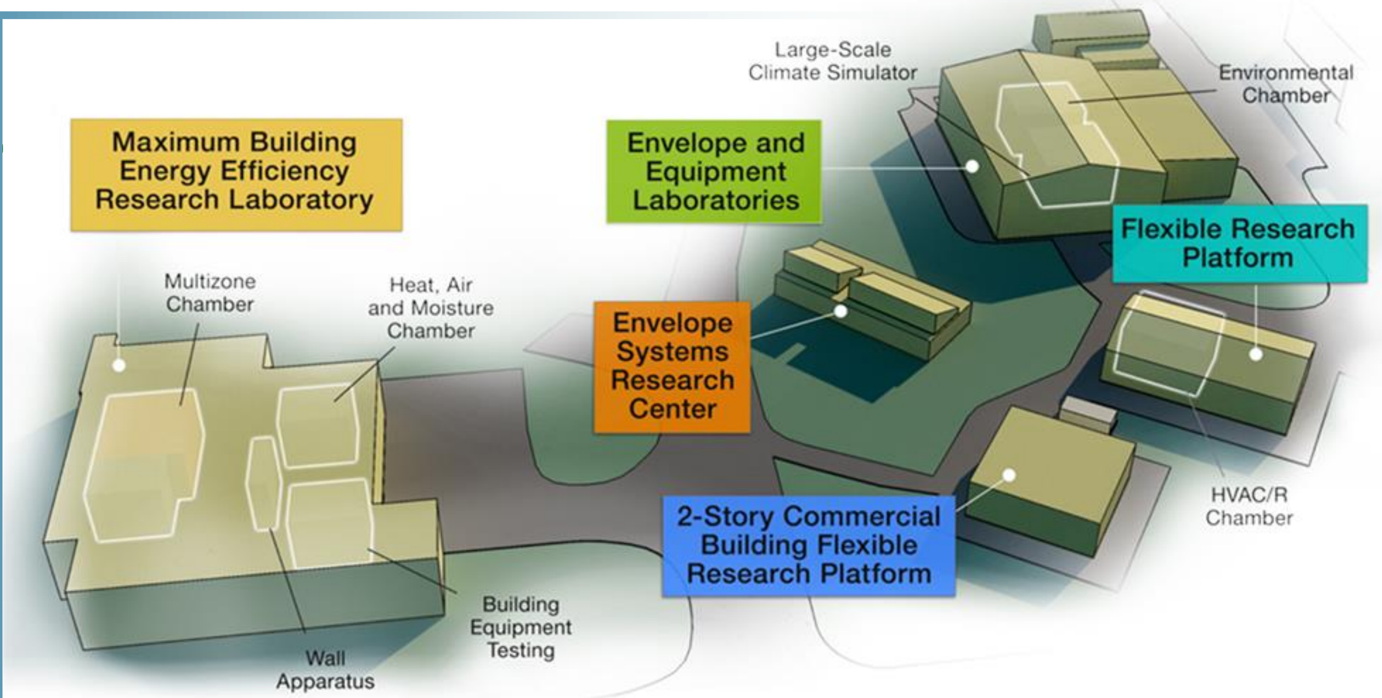

ORNL’s Building Technologies Research and Integration Center (BTRIC) has supported DOE BTO since 1993. BTRIC is comprised of 60,000+ ft^2 of lab facilities conducting RD&D to support the DOE mission to equitably transition America to a carbon pollution-free electricity sector by 2035 and carbon free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

	FY2022		FY2023			
Planned budget	100k		300k			
Spent budget	60k		160k			
	Q3	Q4	Q1	Q2	Q3	Q4
Past Work						
Conduct barrier property analysis and self-healing capability of various substrate films from FLEXcon	▨ ◆					
Initial techno-economic analysis based on screened substrates and reagents	▨	▨ ◆				
Identify optimal multi-layer film process on smaller R2R line and conduct at least one large scale trial at FLEXcon		▨	▨ ◆			
Current/Future Work						
Perform large scale R2R trials at FLEXcon and provide refined techno-economic analysis				▨	▨ ◆	
Identify an efficient and the most economical material composition and manufacturing processes, and summarize in TCF(CRADA) report					▨	▨ ◆

Team

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EERE/BTO goals

The nation’s ambitious climate mitigation goals

Greenhouse gas emissions reductions

50-52% reduction by 2030 vs. 2005 levels

Net-zero emissions economy by 2050

Power system decarbonization

100% carbon pollution-free electricity by 2035

Energy justice

40% of benefits from federal climate and clean energy investments flow to disadvantaged communities

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

Support rapid decarbonization of the U.S. building stock in line with economywide net-zero emissions by 2050 while centering equity and benefits to communities

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.

Prioritize equity, affordability, and resilience

Ensure that 40% of the benefits of federal building decarbonization investments flow to disadvantaged communities

Reduce the cost of decarbonizing key building segments 50% by 2035 while also reducing consumer energy burdens

Increase the ability of communities to withstand stress from climate change, extreme weather, and grid disruptions