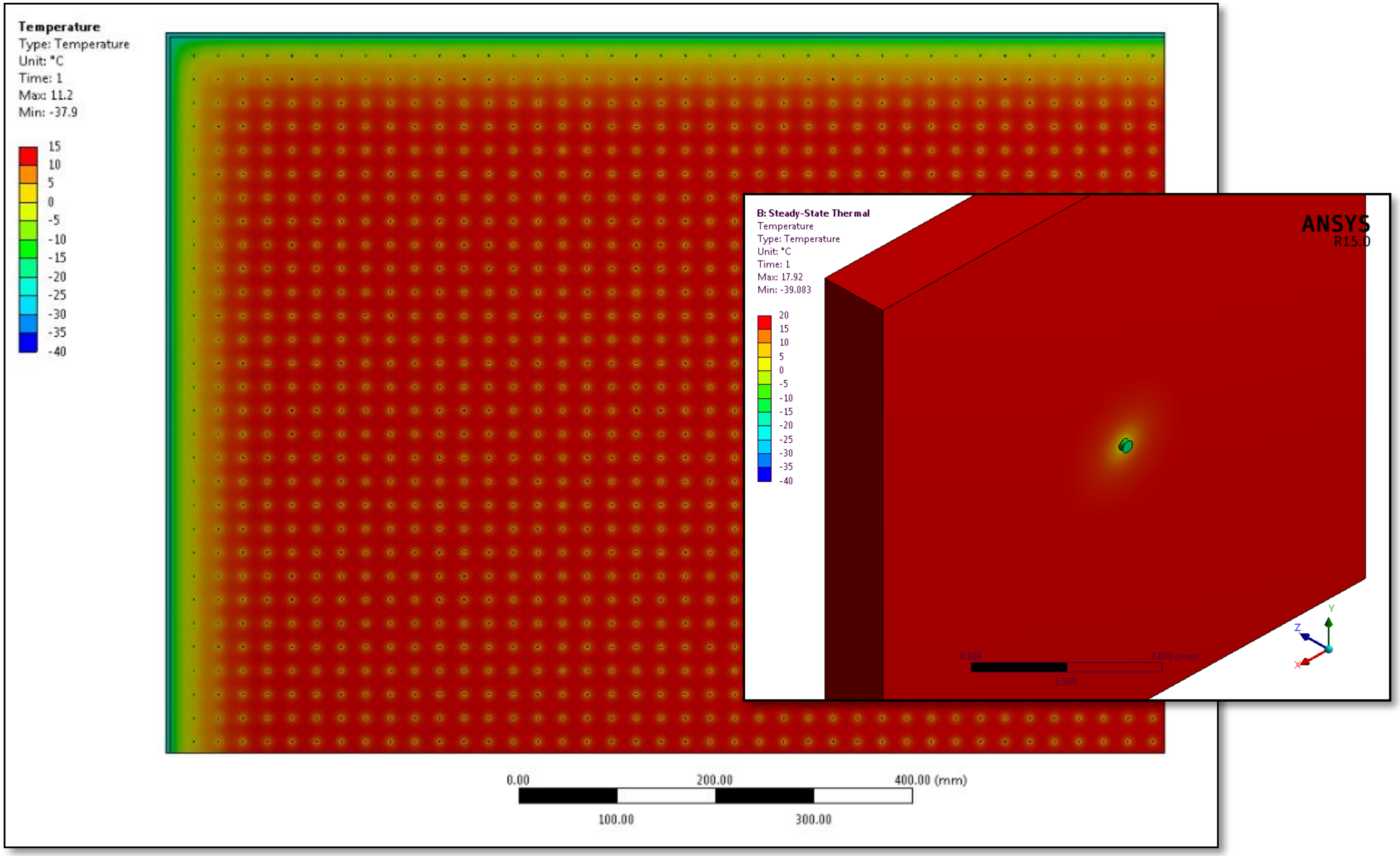
FABRICATE-ON-DEMAND VACUUM INSULATING GLAZINGS

2016 Building Technologies Office Peer Review



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Project Summary

Timeline:

Start date: 10/01/2014

Planned end date: 09/30/2017

Key Milestones

1. Edge Seal and Pillars Are Feasible: 12/31/2015
2. Demo Edge Seal and Pillars in VIG: 12/31/2016
3. Prototype VIG Built: 09/30/2017

Budget:

Total Project $ to Date:

- DOE: $634,281
- Cost Share: $332,059

Total Project $:

- DOE: $1,650,000
- Cost Share: $857,723

Key Partners:

Gyrotron Technologies, Inc.

GED Integrated Solutions, Inc.

Oak Ridge National Lab

Project Outcome:

Design a fabricate-on-demand manufacturing process to overcome the cost and supply chain issues preventing widespread adoption of VIGs.

Enable commercially-viable VIG windows that meet or exceed the cost and performance metrics.

Purpose and Objectives

Problem Statement:

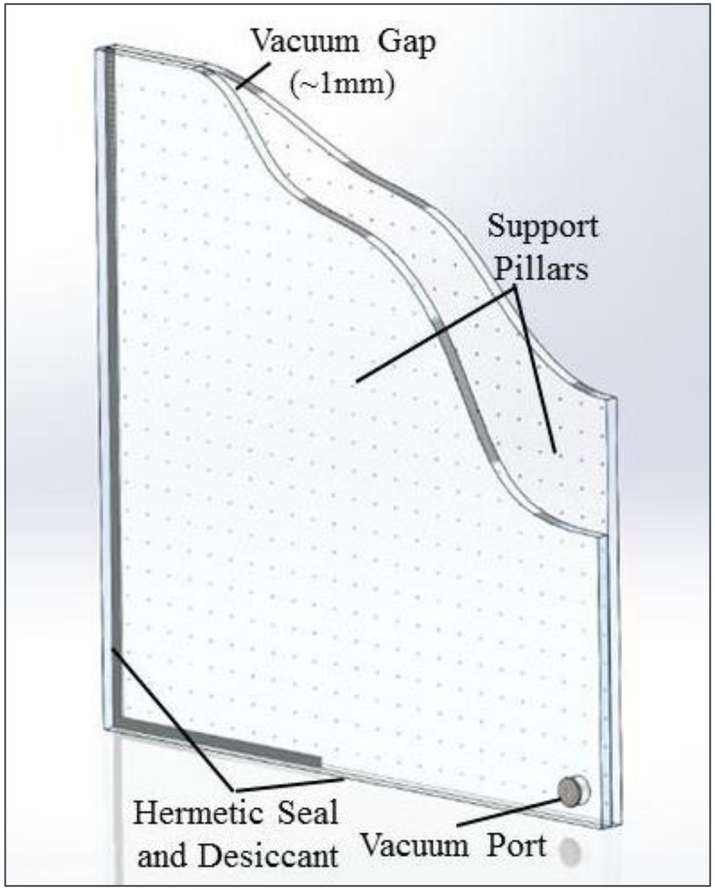
High-performance windows (HPW) made using Vacuum Insulated Glazing (VIG) units can yield substantial energy savings only if manufacturing costs and customer needs are met. VIG manufacturing is expensive and lacks flexibility in product offerings and therefore has had limited acceptance and success.

Target Market and Audience:

- Window Manufacturers
- Residential Market (~1600TBtu)
- Anticipated Savings: 2 Quads

Impact of Project:

- Overcome the cost and supply chain issues
- Provide high adoption rate and market penetration
- Units would enter the market as early as 2018



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Approach

Approach:

Improve three areas impacting VIG adoption

- Edge Sealing
- Pillar Design/Placement
- Evacuating the VIG

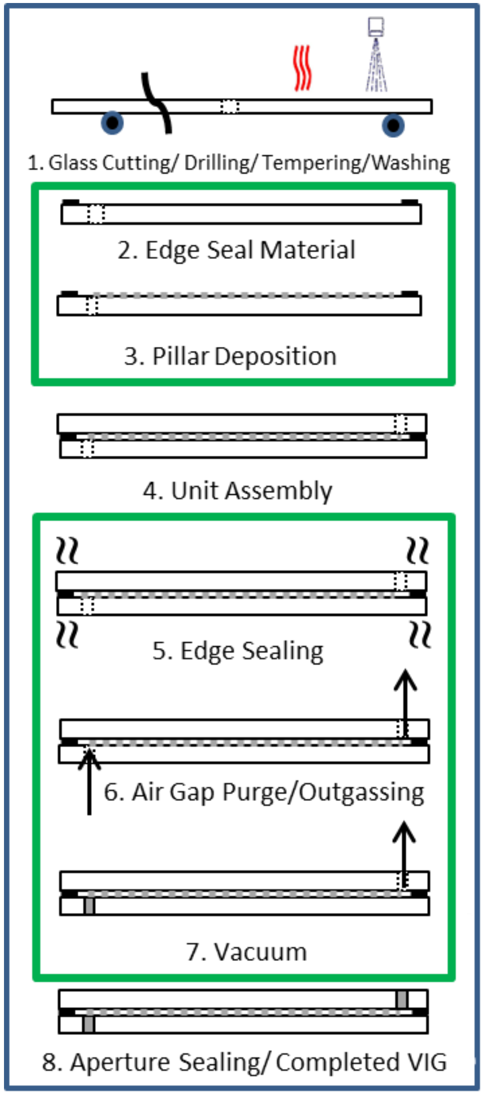
Key Issues:

Technical solutions solve one or more issues

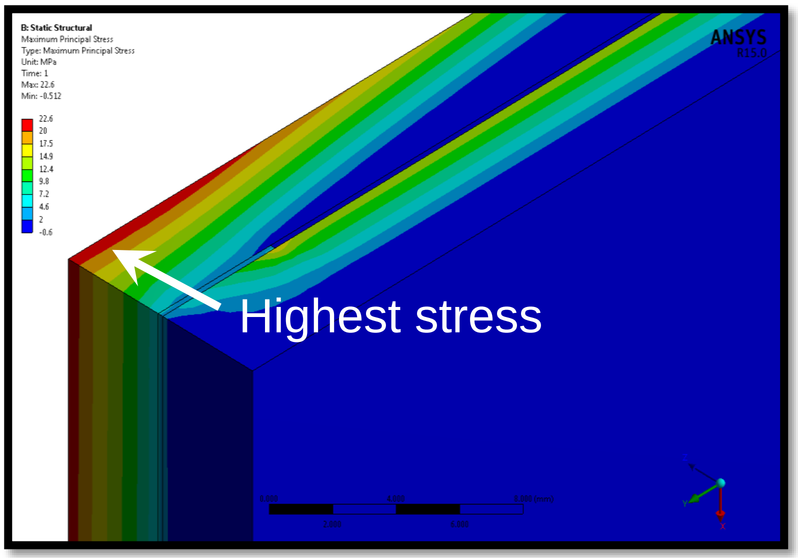
- Reduces mechanical stresses to improve yield
- Lowers capital equipment requirements
- Increases production throughput

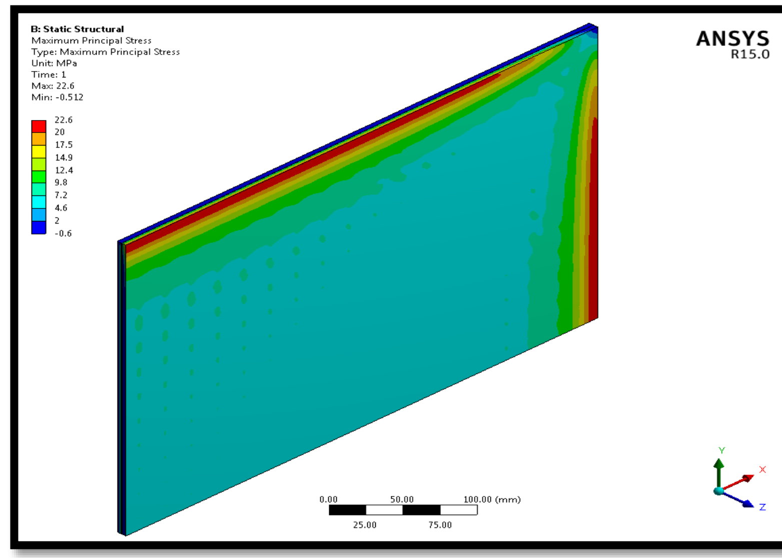
Distinctive Characteristics:

The manufacturing process focus reduces cost and eliminates the barriers that prevent smaller manufacturers from entering into the market.



Approach – FEA Model-based Design





- Maximum tensile stresses are within design criteria with a safety factor of 1.8
- Both flex and rigid edge seals are viable designs

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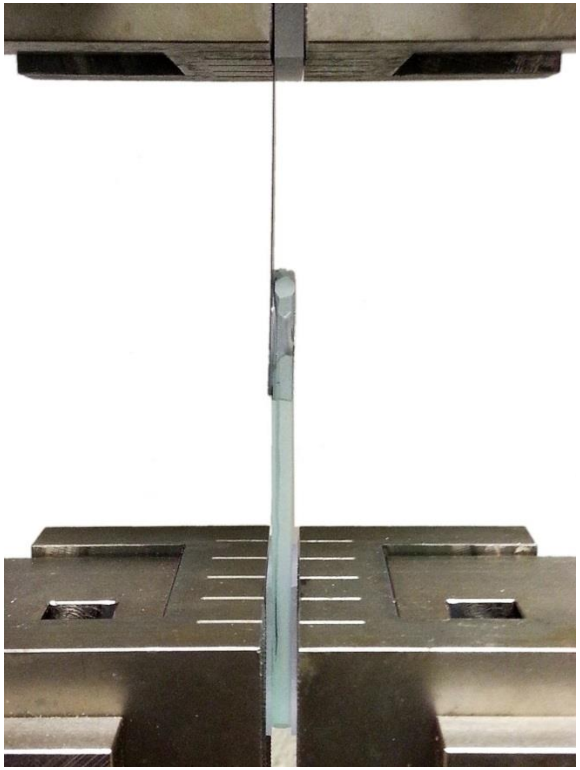
Approach – Experimental Selection of Edge Seal Materials

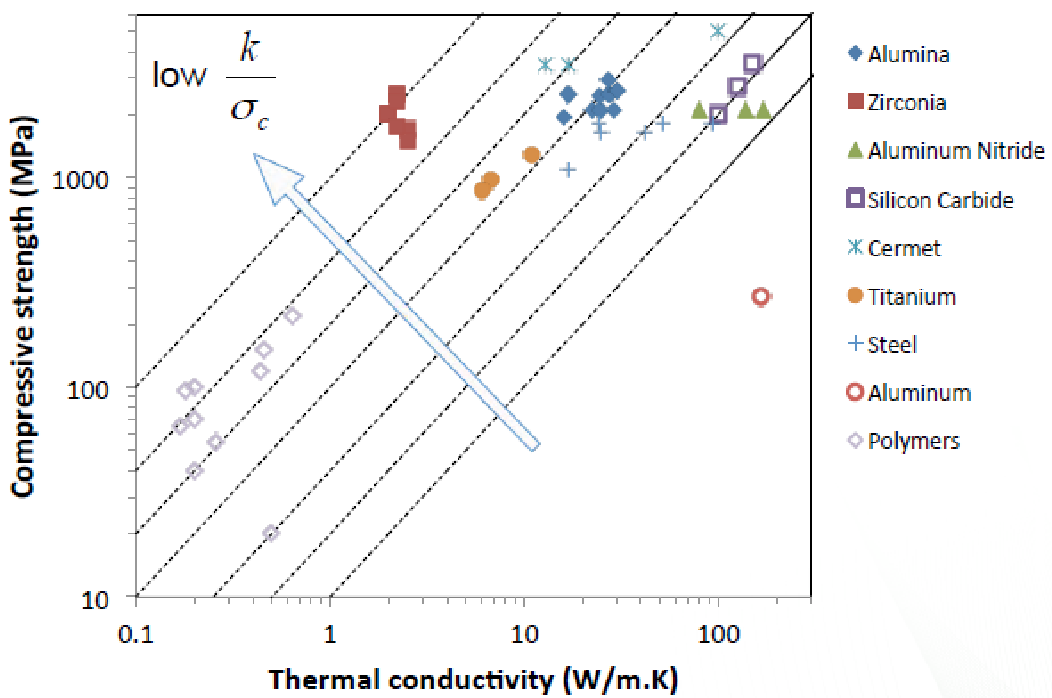
Lap-shear Test Results Summary

Bond Type	Results
Glass-to-Glass	Successful with maximum Shear Strength of 2.8 MPa and 2.1 MPa for two different frits
Glass-to-Metal 1	Successful with maximum Shear Strength of 2.5 MPa and 2.2 MPa for two different frits
Glass-to-Metal 2	Successful with maximum Shear Strength of 3.4 MPa with one frit and failure in glass with second frit
Glass-to-Metal 3	Unsuccessful with debonding at surface coating interface
Glass-to-Meta 4	Unsuccessful with no bond formed or heavy glass cracking for all samples



Approach – Model-based Pillar Materials Identification

Candidate materials: performance

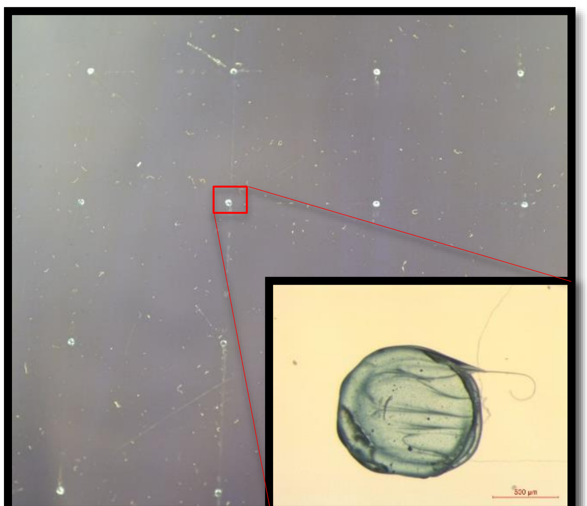


Polymers can perform as well as or better than many ceramics and metals.

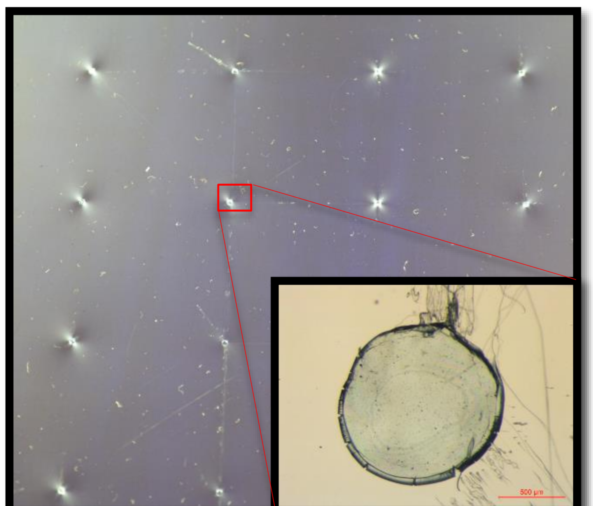
Approach – Evaluation of Additive Manufacturing

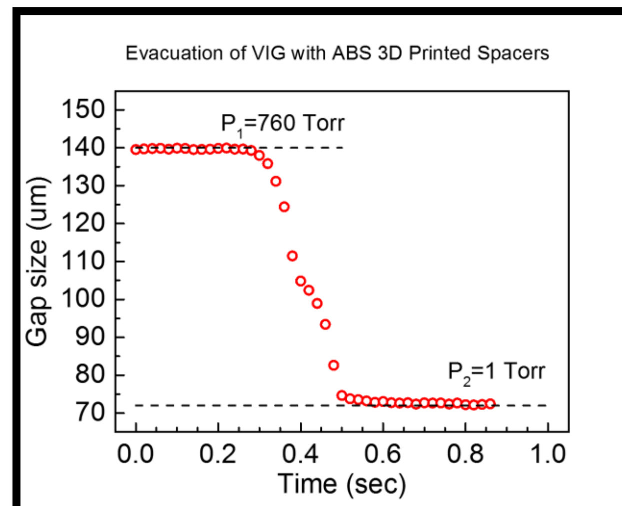
- ABS pillars (Diameter: 1mm) printed directly on glass
- Pictures taken under polarizing filters show stress after evacuation
- Pillar shows a cracked edge under vacuum
- Spacing between inner surfaces reduced by ~1/2

760 Torr



1 Torr

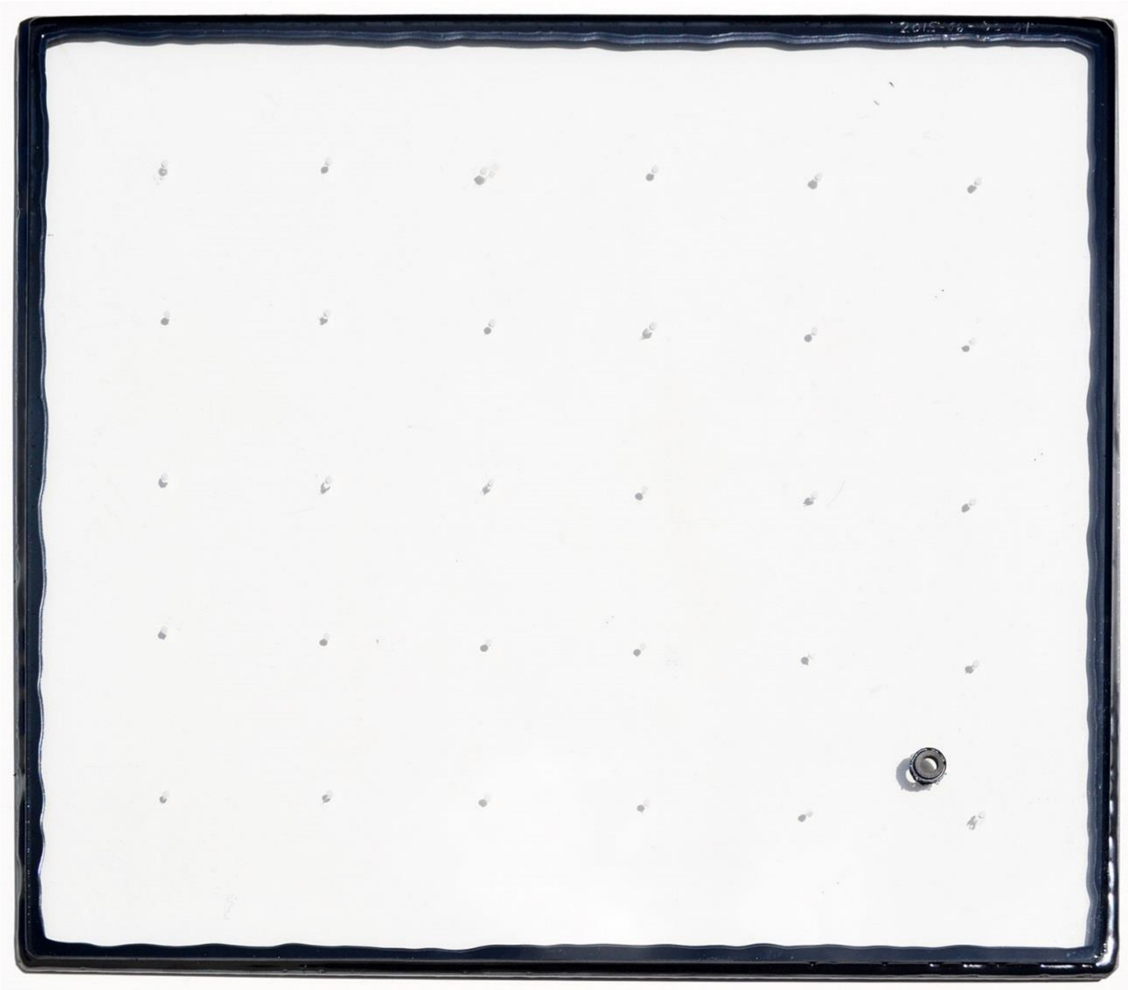




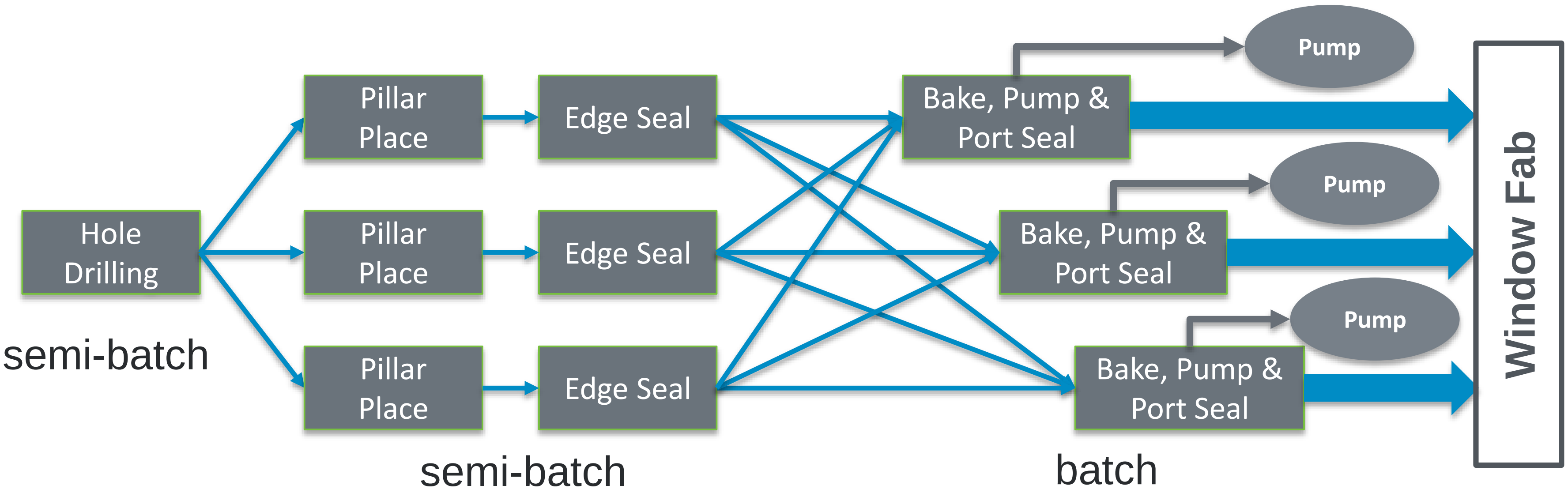
Approach – Prototype Fabrication

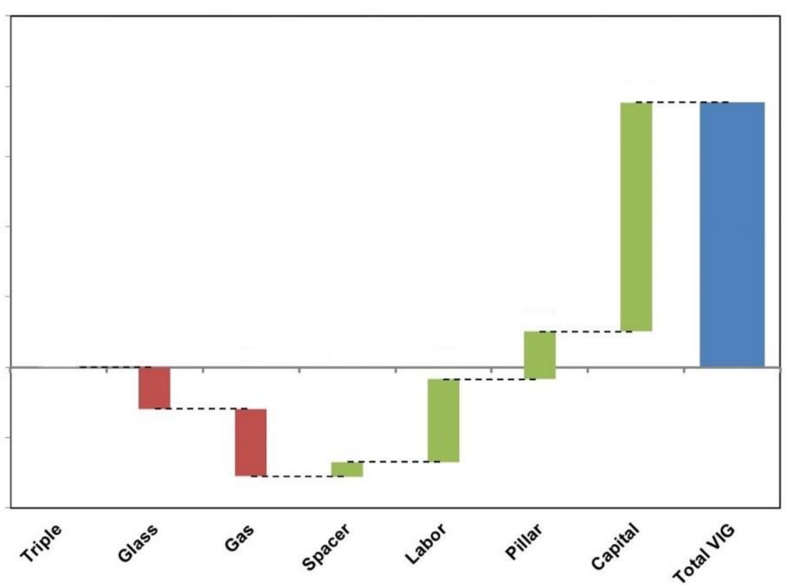
Prototype VIG

- 9" x 10" unit
- Glass-to-glass seal successfully applied and fired
- Cylindrical zirconia spacers
- Evacuated to target vacuum and sealed



Approach – Process Design and Incremental Cost Analysis





- Production rate: 60%
- Capital cost: $2.2MM
- Installed cost: >$13/ft^2

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Progress and Accomplishments

Accomplishments:

Technical metrics of the project were reached or are achievable

✓ VIG design meets performance goals of DOE roadmap

- ✓ At least one material and process for the edge seal
- ✓ At least one material and process for pillars
- ✓ Small area prototypes fabricated using identified materials

✗ Materials and design for low-cost evacuation process does not meet cost goals of DOE roadmap

✗ A process evaluation showed the capital and fabrication costs exceeded both the window manufacturer's expectations and the market acceptance threshold

✓ Alternate high-performance window designs and fabrication processes were identified that can meet the performance and cost targets

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Progress and Accomplishments

Market Impact:

- Market research guided the technical work
  - Discussions and interviews with window manufacturers
  - Critical acceptance criteria for market acceptance established

	IGU Characteristics			*Fabrication*		
Technology	***Performance***	***Weight (Lb/ft^2)***	***Width***	***Capital Cost ($MM)***	***Fabrication Cost ($\$/ft^2$)***	***Installed Cost ($\$/ft^2$)***
Double IG						
Triple IG						
HPW IGU #1						
HPW IGU #2						
HPW IGU #3						
HPW IGU #4						

High-performance window, insulated glazing unit technology #1 and #2 are VIG designs from BP1. Technology #3 and #4 are candidates proposed for BP2.

Progress and Accomplishments

Awards/Recognition:

- No awards or recognition to report

Lessons Learned:

- High performance windows will play an important role in energy savings
- Value exists in market for an alternate window design to the standard triple IGU
- The role of each step in the supply chain must be considered, and these needs, acceptance criteria, and constraints must be met
- Flexibility in the performance / cost relationship is important to achieve increased adoption rate and market penetration

Project Integration and Collaboration

Project Integration: The project team includes technology partners and manufacturing equipment providers. PPG supplies both glass and toll-produces IGUs. PPG has a vast certified fabricator network for both residential and commercial glazings.

Partners, Subcontractors, and Collaborators:

- **PPG Industries, Inc**. is the world's largest coatings company, and a supplier of flat glass, fiber glass, and specialty materials.
- **Gyrotron Technologies, Inc**. provides advanced thermal process heating solutions using high-frequency microwave beam technology.
- **GED Integrated Solutions** is a global system solution provider to the window and door industry.
- **Oak Ridge National Lab** helps to ensure America's security and prosperity by addressing its energy, environmental, and nuclear challenges.

Communications: No presentation to report

Next Steps and Future Plans

Next Steps and Future Plans:

- Budget Period 1 Continuation Review completed
- PPG recommended a redirection to pursue an alternate high-performance window IGU design that meets both the performance and cost goals

REFERENCE SLIDES

Project Budget

Project Budget:
BP1: $966,340 ($634,281 Federal, $322,059 Cost Share)
BP2: $970,230 ($637,003 Federal, $333,227 Cost Share)
BP3: $571,153 ($378,716 Federal, $192,437 Cost Share)
Total: $2,507,723 ($1,650,000 Federal, $857,723 Cost Share)
Variances: None
Cost to Date: All BP1 funds spent
Additional Funding: None

Budget History					
10/01/2014 – FY 2015		FY 2016 Spent and Remaining		FY 2017 – 9/30/2017	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$475,545	$247,168	$158,736 $496,870	$74,891 $259,921	$518,848	$265,743

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Project Plan and Schedule

- Budget Period completed within planned duration
- Three-month (estimated) redirection period underway
- New SOPO proposed to DOE
- Same duration BP2, abbreviated BP3

Project Schedule												
Project Start: 10/01/2014		Completed Work										
Projected End: 09/30/2017		Active Task (in progress work)										
		Milestone/Deliverable (Originally Planned) use for missed										
		Milestone/Deliverable (Actual) use when met on time										
	FY2015				FY2016				FY2017			
Major Milestones	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												
Edge Seal and Pillars Are Feasible: 12/31/2015												
BP1 Continuation Process/Redirection												
Current/Future Work												
Demo Edge Seal and Pillars in VIG: 12/31/2016												
Prototype VIG Built: 09/30/2017												