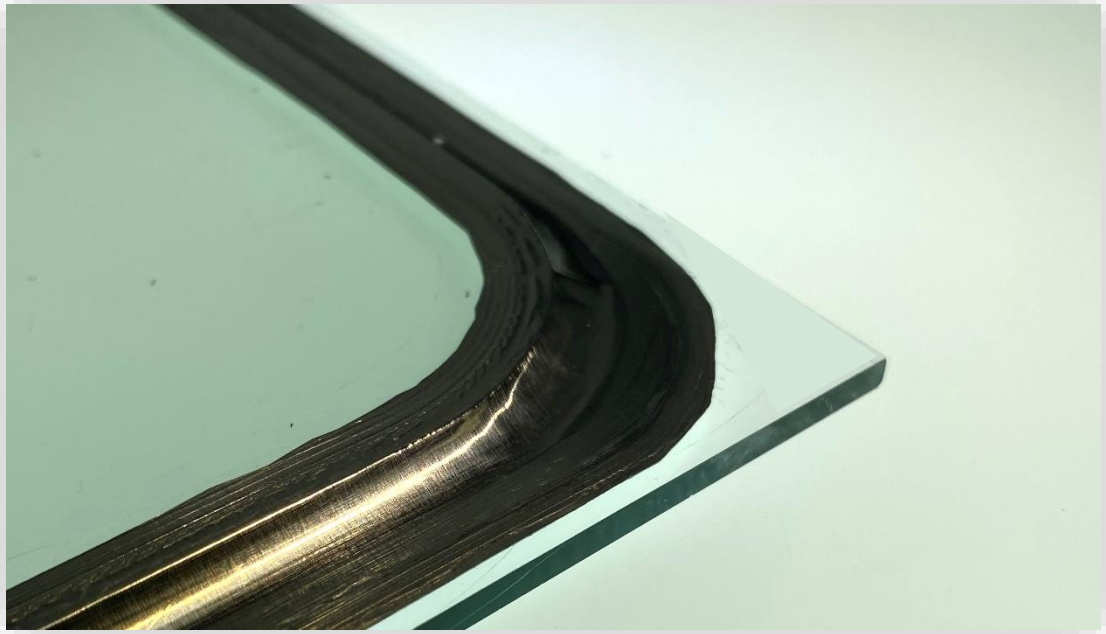
Vacuum Glass for R-10 *Whole* Windows



Performing Organization: V-Glass, Inc.
PI Name and Title: Chris Kubicek, CTO
PI Tel and/or Email: 262.374.2089 | ckubicek@v-glass.com
Project # DE-SC0017841

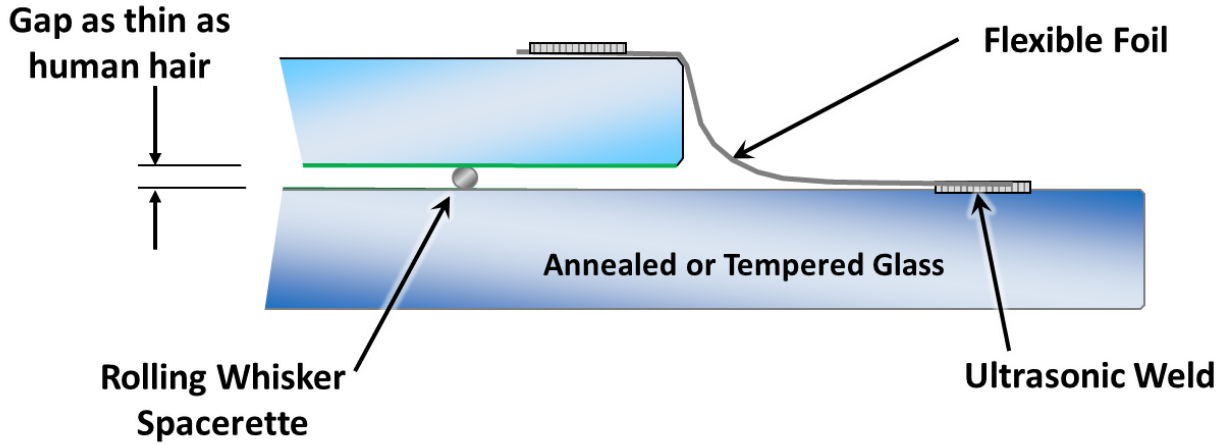
Project Summary

Objective and outcome

V-Glass has proven performance and durability of oven-free manufacturing platform to achieve low-cost vacuum insulating glass (VIG).

V-Glass alone has developed technology to drive widespread adoption of affordable $R_{ww}10$ windows.

V-Glass is unique



Team and Partners

University of Sydney (Subawardee)
Edison Welding Institute (Subawardee)
University of Waterloo (Subawardee)
Lawrence Berkeley National Lab
National Renewable Energy Lab
Anonymous Glass Industry Manufacturer

Stats

Performance Period: 8/27/2020 – 8/27/2023

DOE budget: $1,150K, Cost Share: $1,150K

Milestone 1: 70% prototype yield ✓

Milestone 2: Medium Size, 28”x40” capability ✓

Milestone 3: Cost analysis showing pathway to competitive pricing

Problem

Buildings account for 39.1% of total U.S. primary energy use and 75% of total U.S. electricity use. Compared with existing glazing technology, the replacement with V-Glass will reduce up to 40% of the energy used to condition the building.

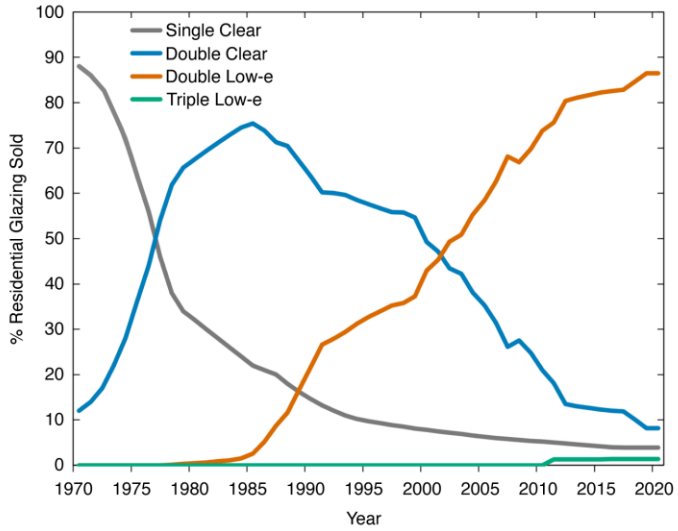
Windows are the single largest source of energy loss in buildings – 45% of buildings energy loss is through today's windows. To ensure our planet's survival, the energy efficiency of buildings must improve exponentially.

To date, consumer acceptance of highly insulated vacuum glass is very slow due to its excessive manufacturing costs.

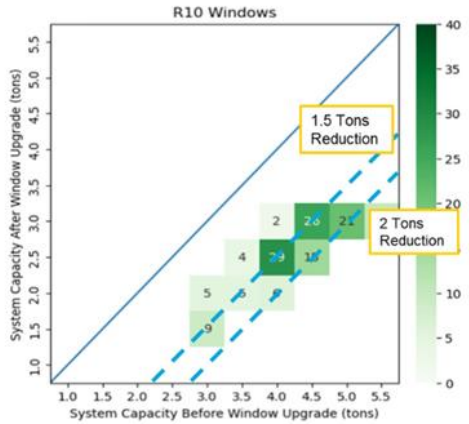
Providing consumers with cost effective V-Glass will accelerate the adoption toward decarbonization. *V-Glass technology is the path to supply low-cost vacuum insulating glass (VIG)*.

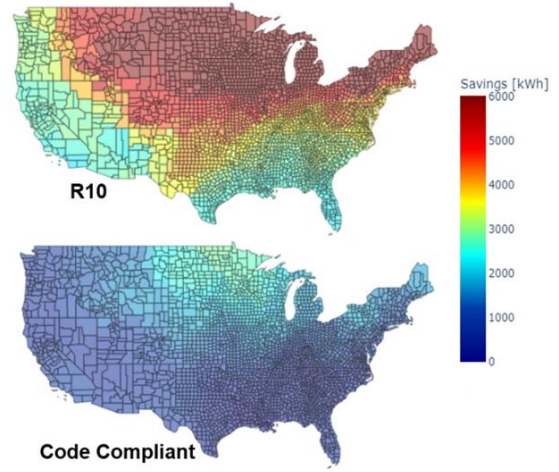
Adoption of highly insulated VIG's enables high efficiency heat pumps to provide adequate heating in northern climates.

R-10 enables decarbonization and net-zero buildings.

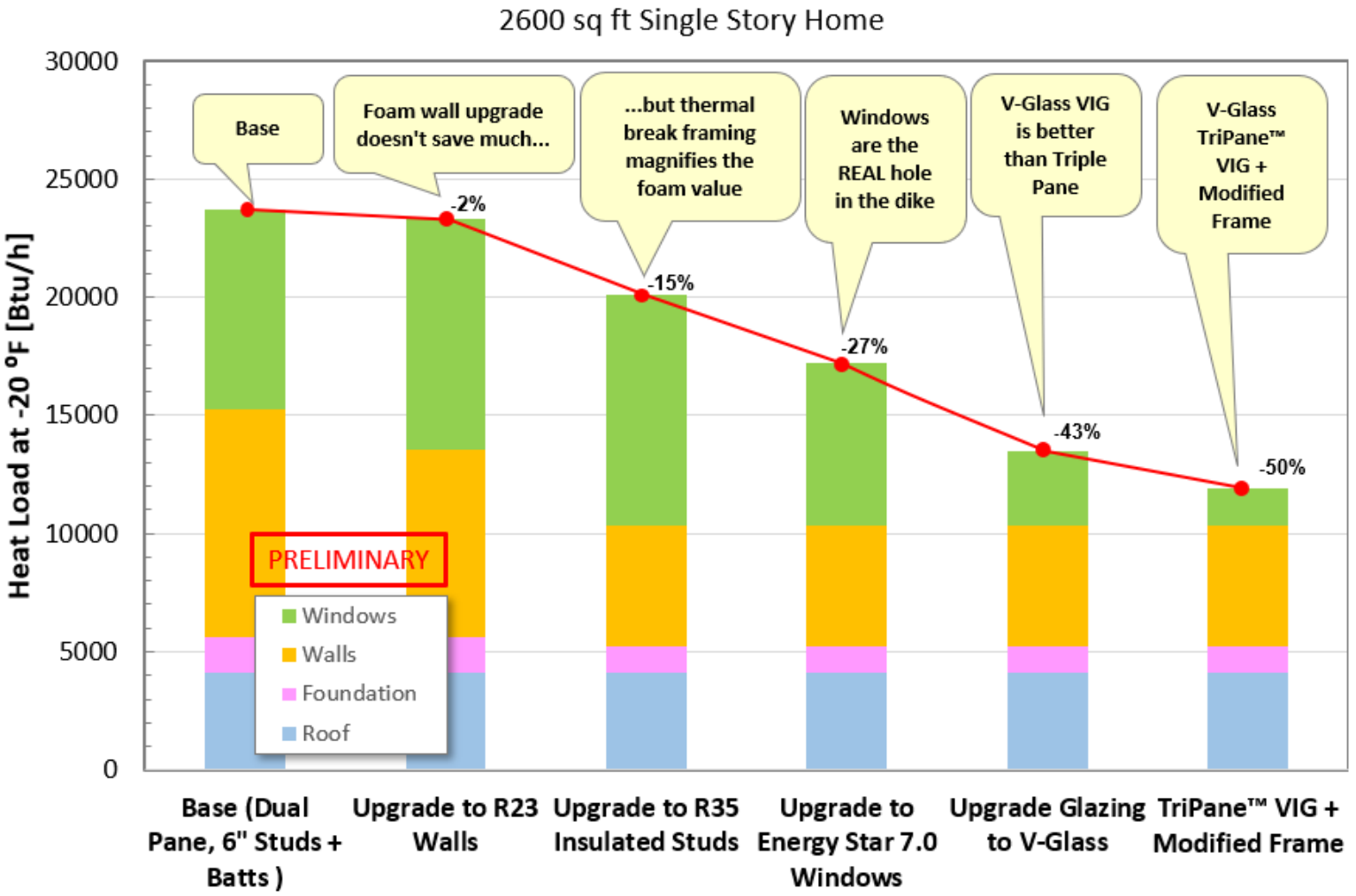


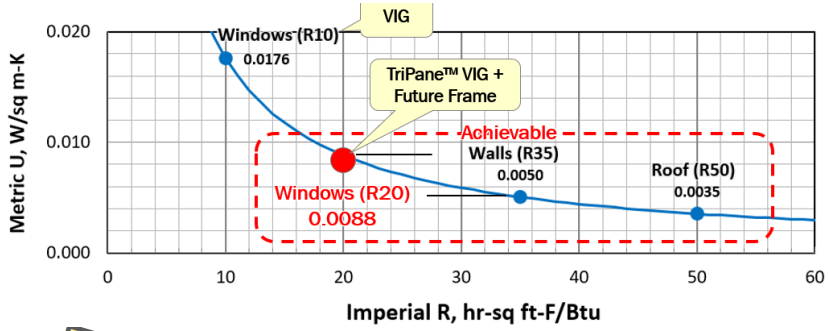
Annual Energy Savings





Case Study: V-Glass Showcase Home in Wisconsin

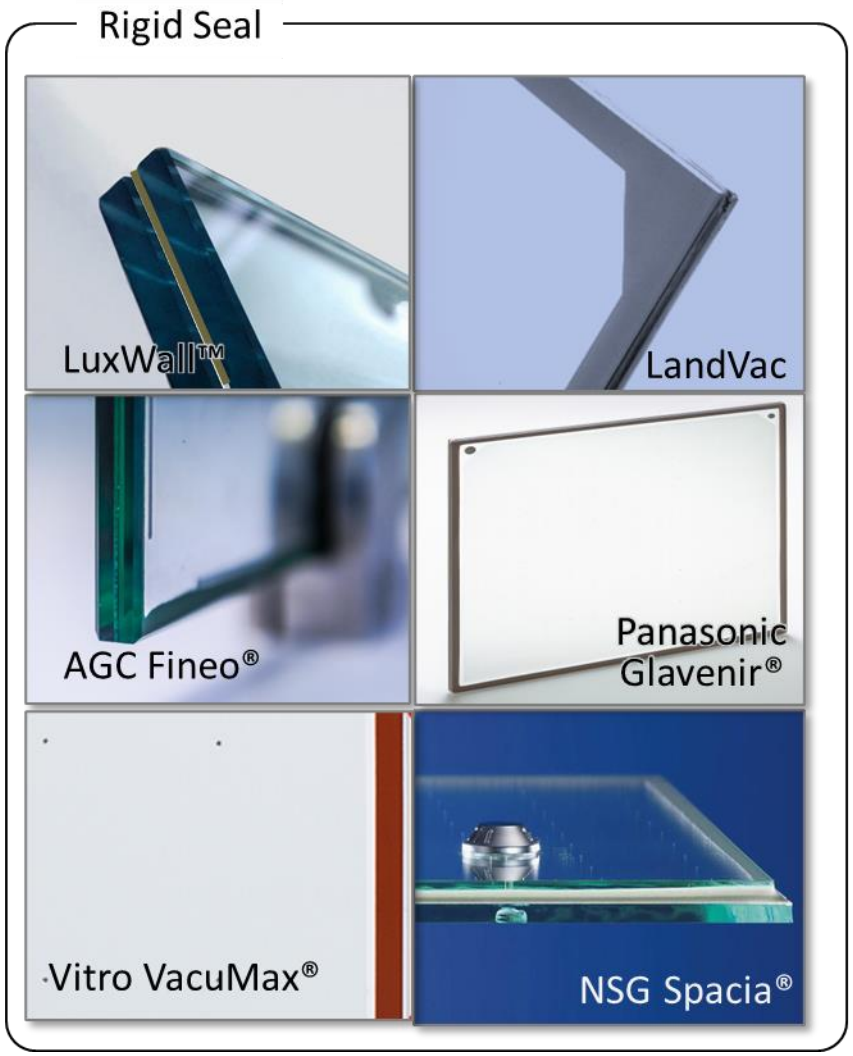




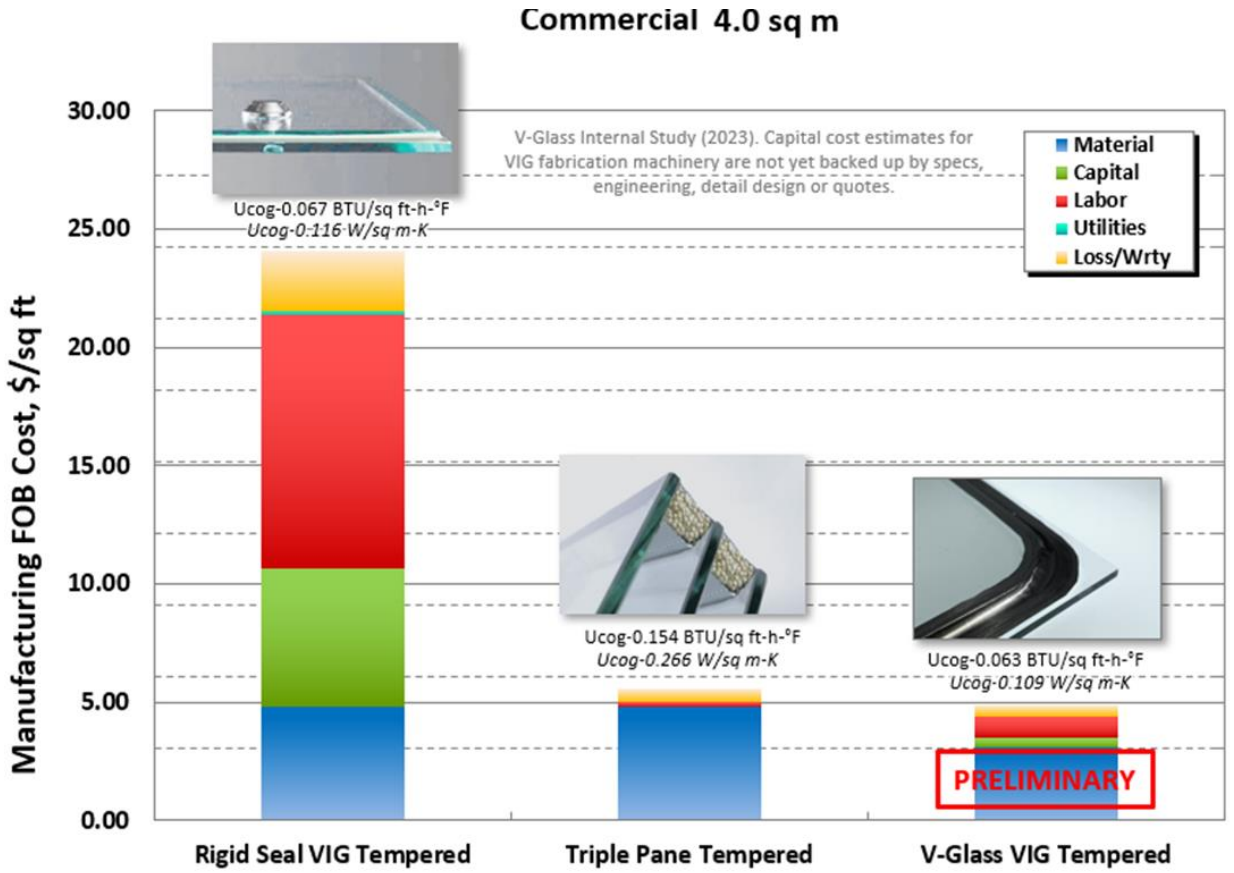
R10 enables decarbonization

Alignment and Impact:

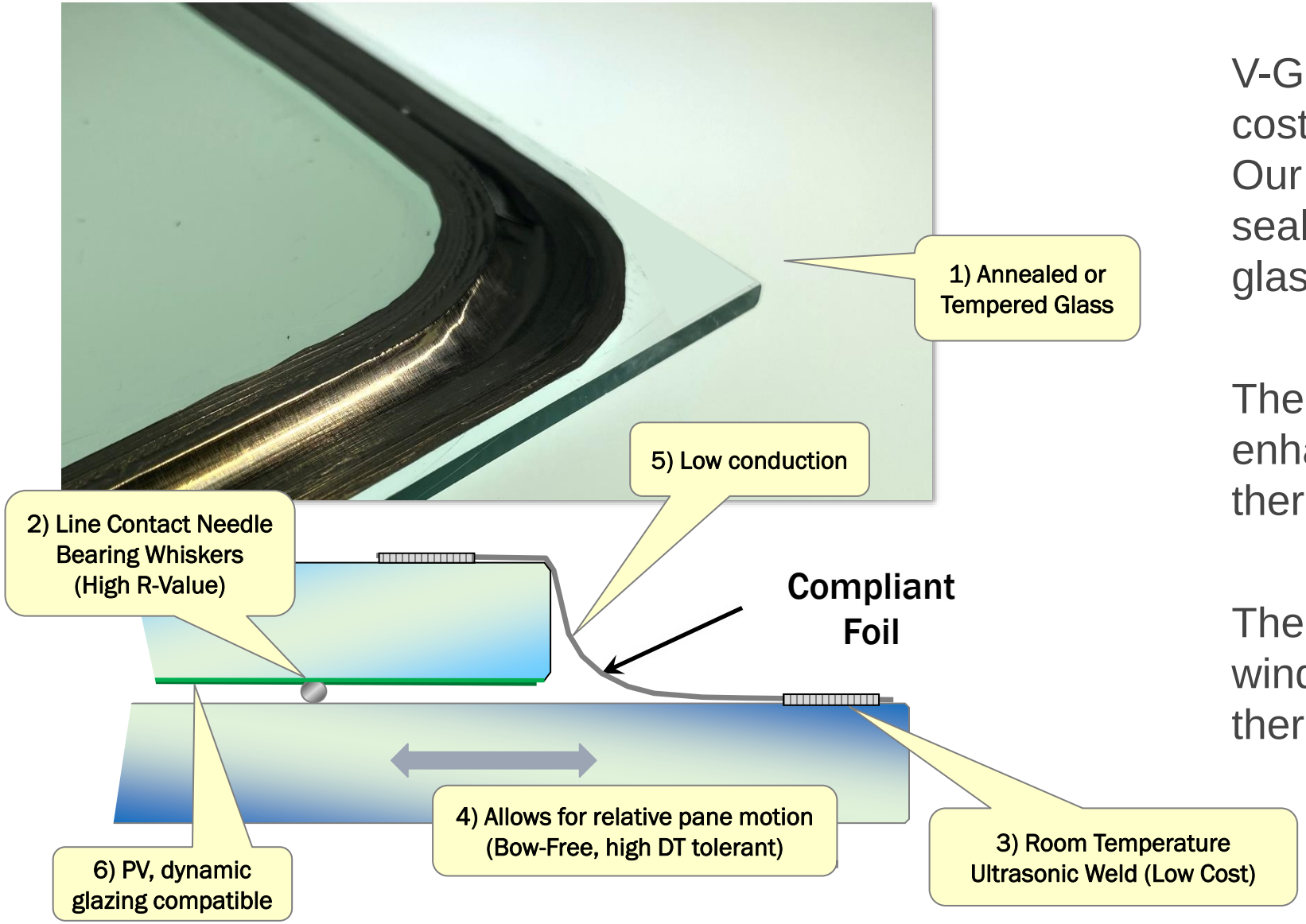
Competitive landscape



Current VIG manufacturing processes are <u>oven-based</u>, inherently costly, with large carbon & energy footprints.



Approach: V-Glass is Different

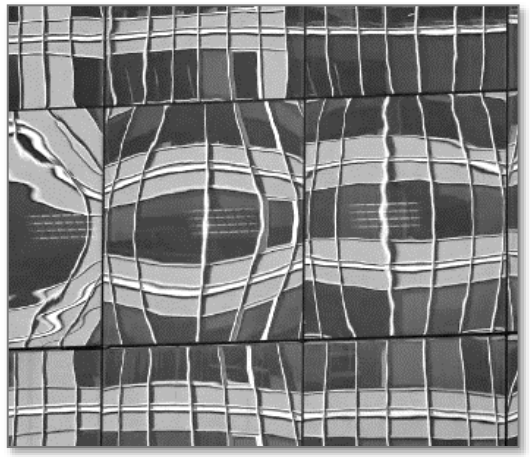


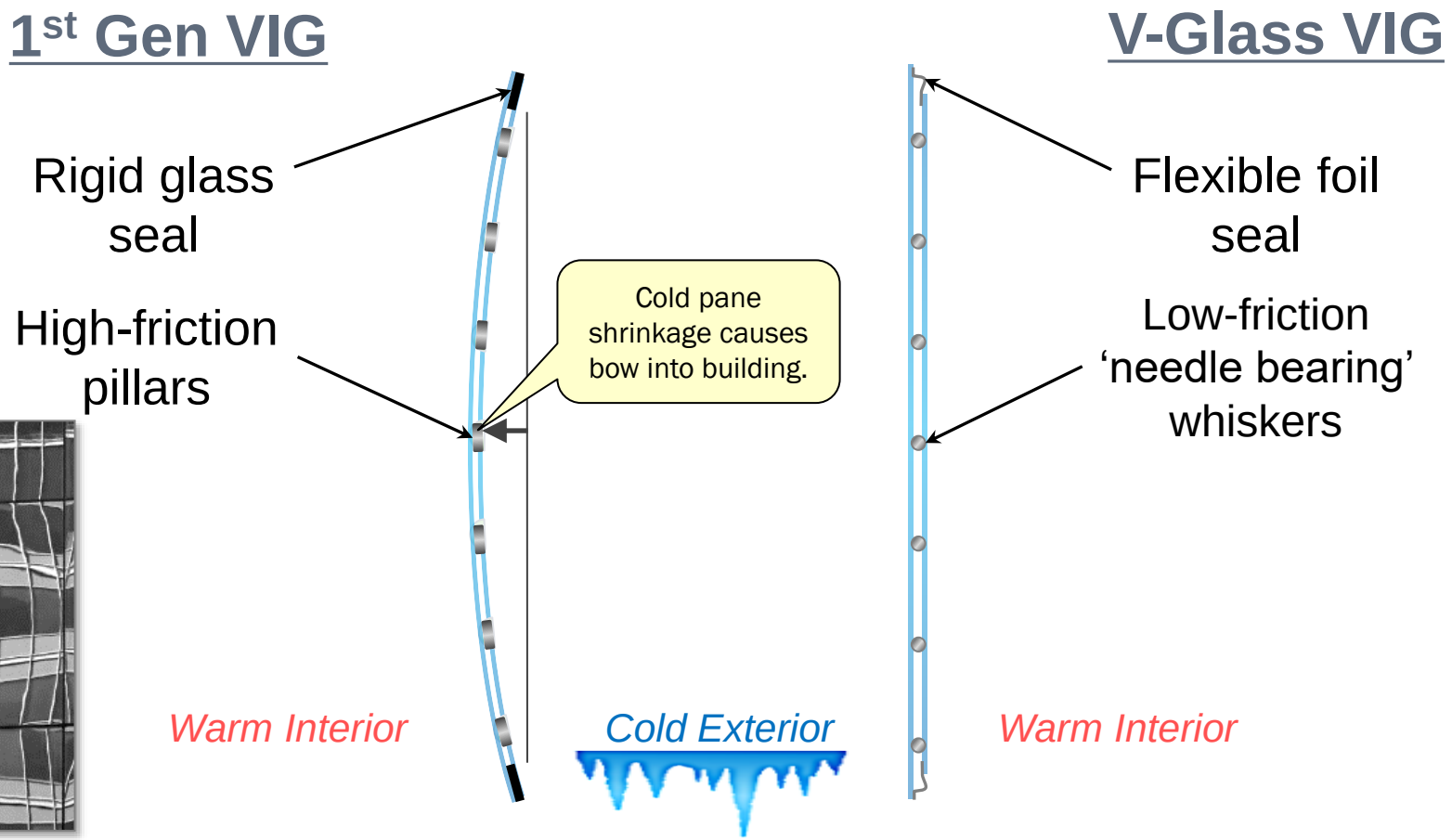
V-Glass technology enables low-cost vacuum insulating glass (VIG). Our unique solution uses a metal foil seal diffusion bonded to standard glass in a room temperature factory.

The foil seal and whiskers provide enhanced durability by allowing for thermal expansion.

The foil provides for higher overall window insulation due to higher thermal resistant perimeter sealing.

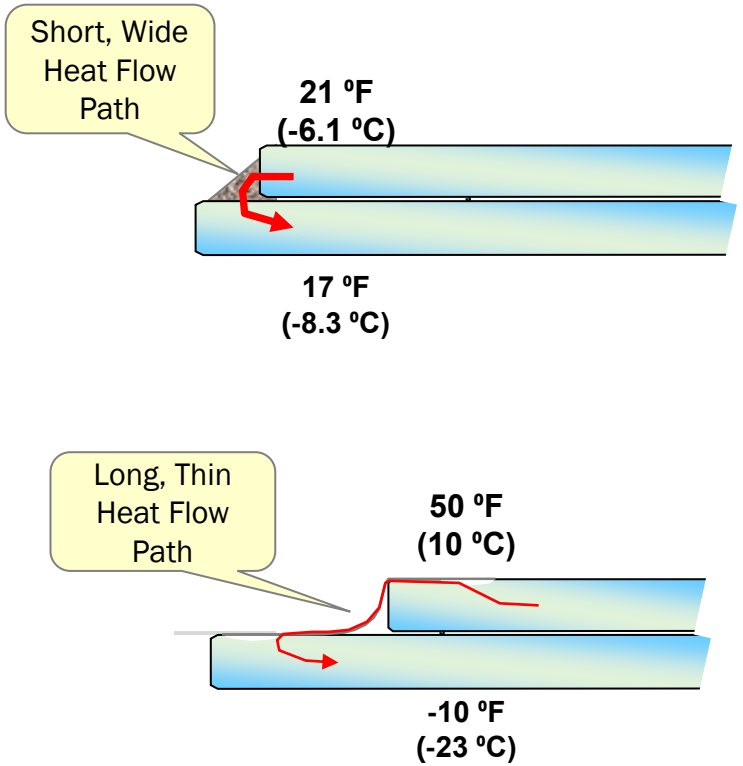
Our Low Friction, Bow-Free VIG

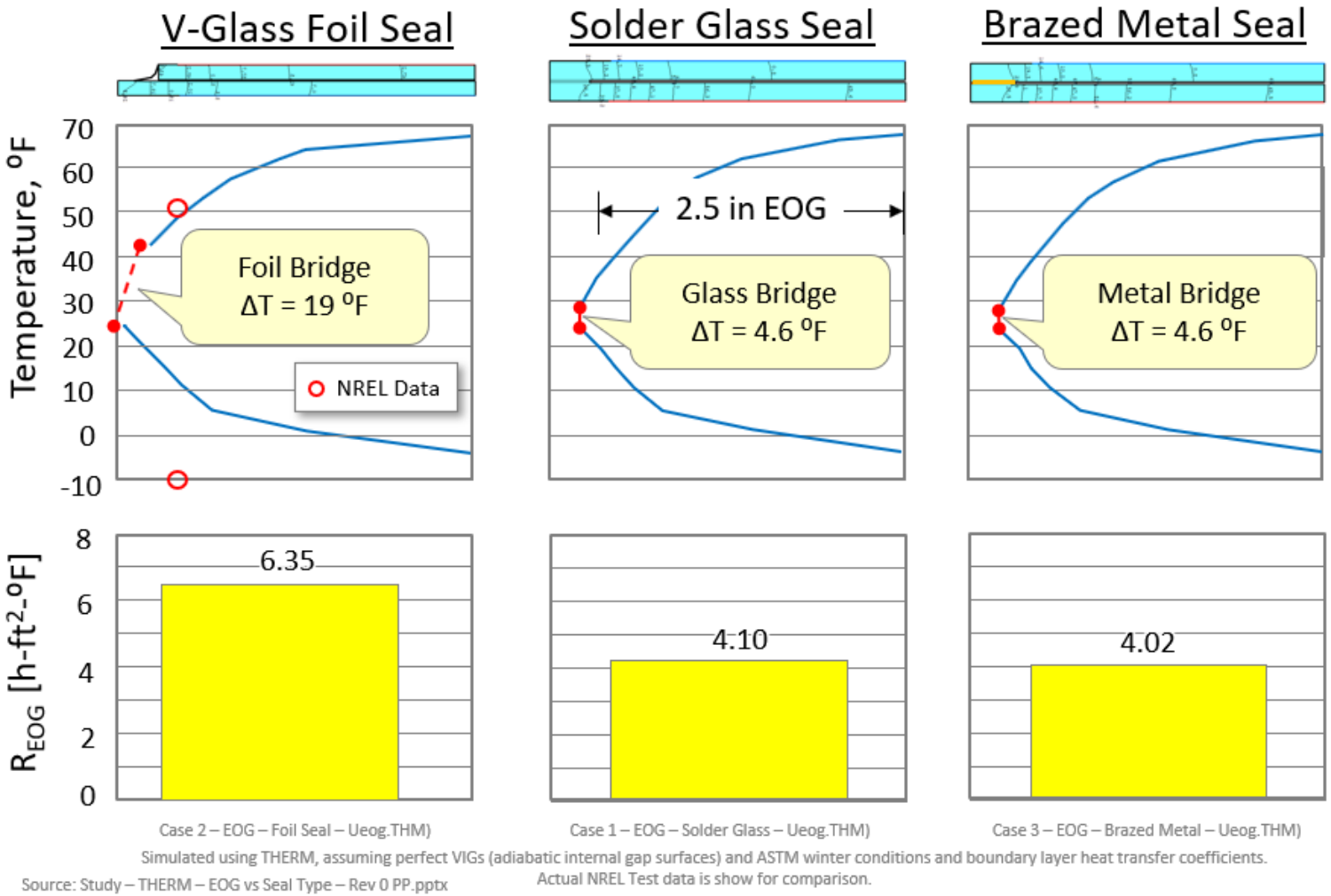




Our flexible foil seal and whisker spacerettes work together to eliminate bowing.

Relative Edge Loss Comparison

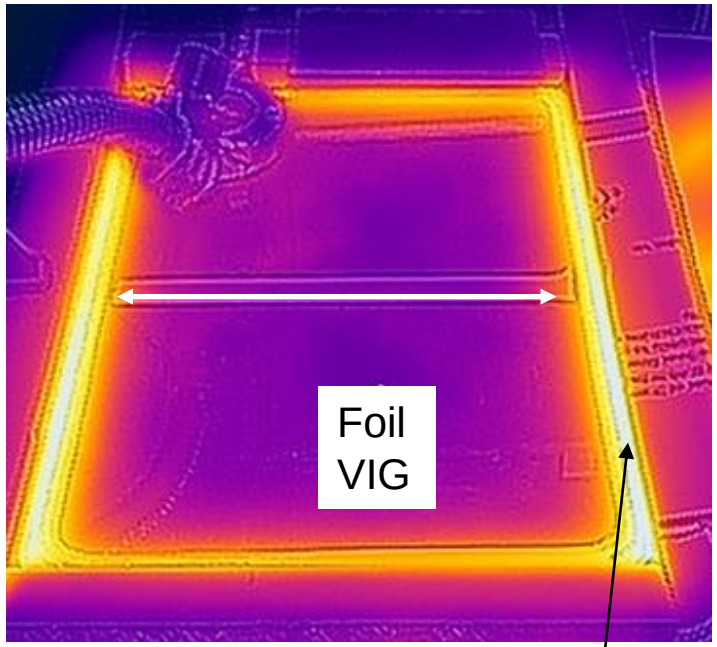




Simulated using THERM, assuming perfect VIGs (adiabatic internal gap surfaces) and ASTM winter conditions and boundary layer heat transfer coefficients.
Actual NREL Test data is show for comparison.

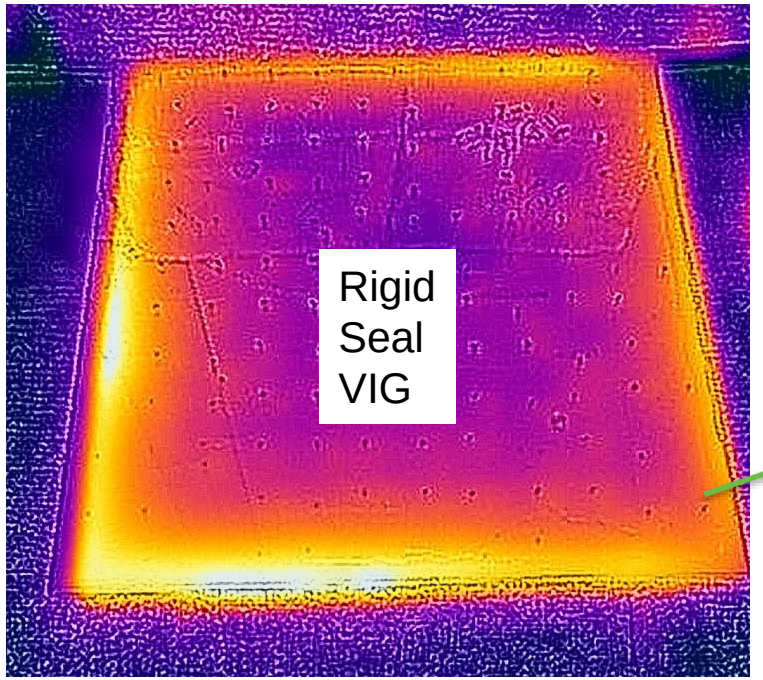
Source: Study – THERM – EOG vs Seal Type – Rev 0 PP.pptx

Foil VIG's: Warm edge; higher performance



Uniform temp on ambient side

Reduced heat flow on edge

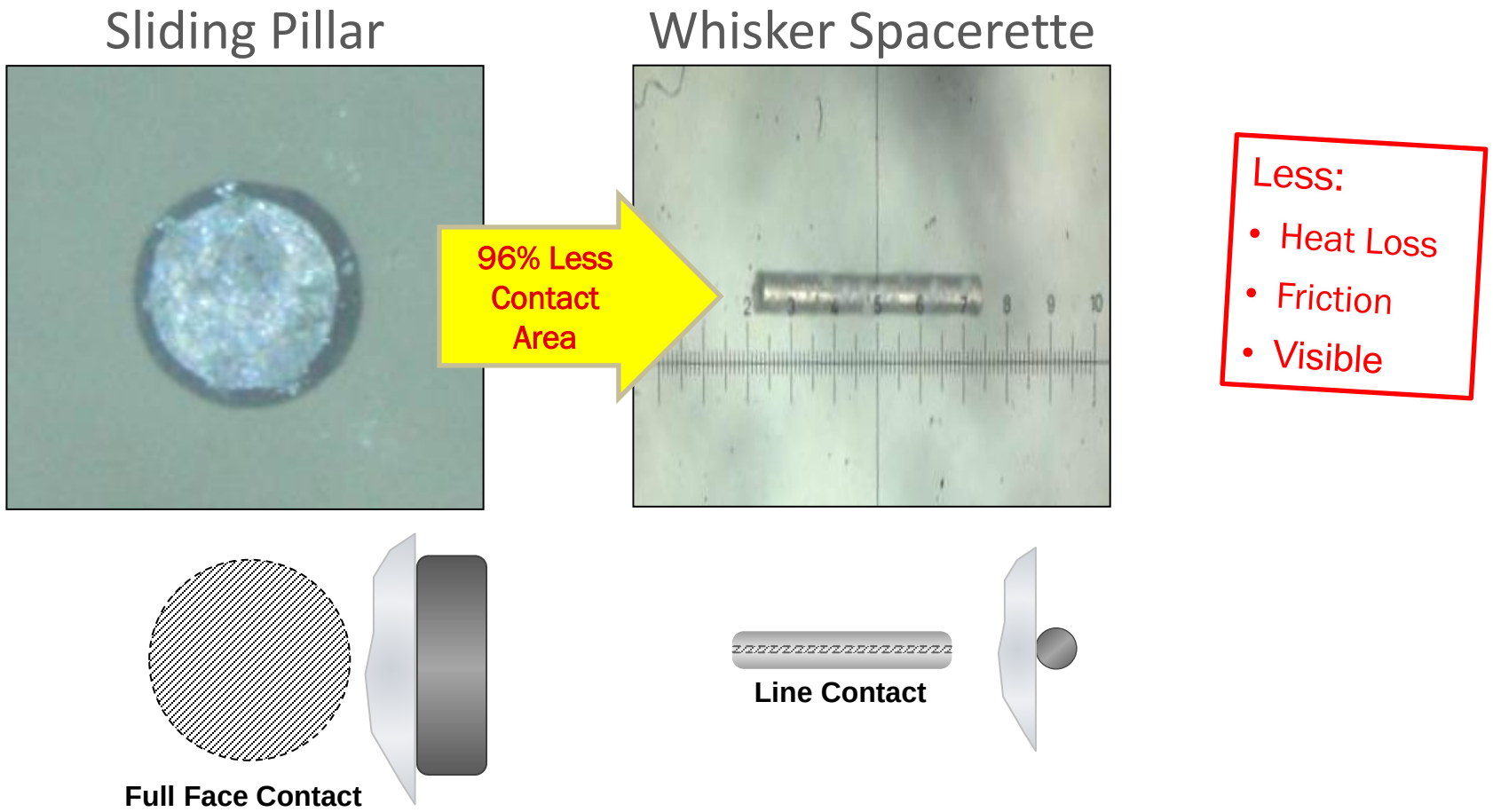


Non-uniform temp on ambient side

'Sloppy' or 'Frosty' edges

A low conductive edge provides better whole window performance.

Approach: Whisker Spacerette, higher performance



Our whiskers & warm edge allow V-Glass to achieve $R_{ww}10$ performance using annealed glass.

*to achieve $R_{ww}10$ using pillars, 1st Gen VIGs must use tempered glass (costly, oven-based process).

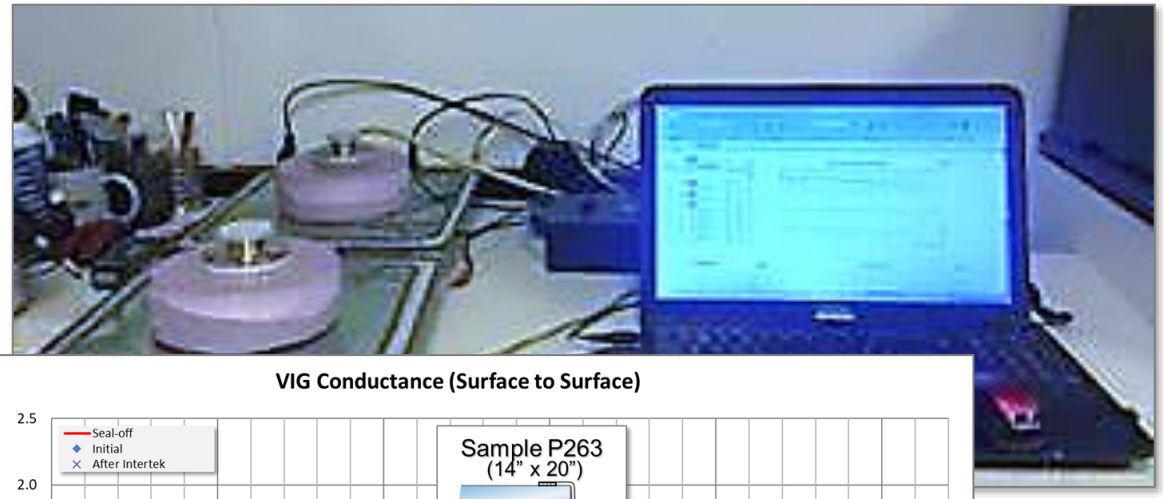
VIG Competitive Analysis

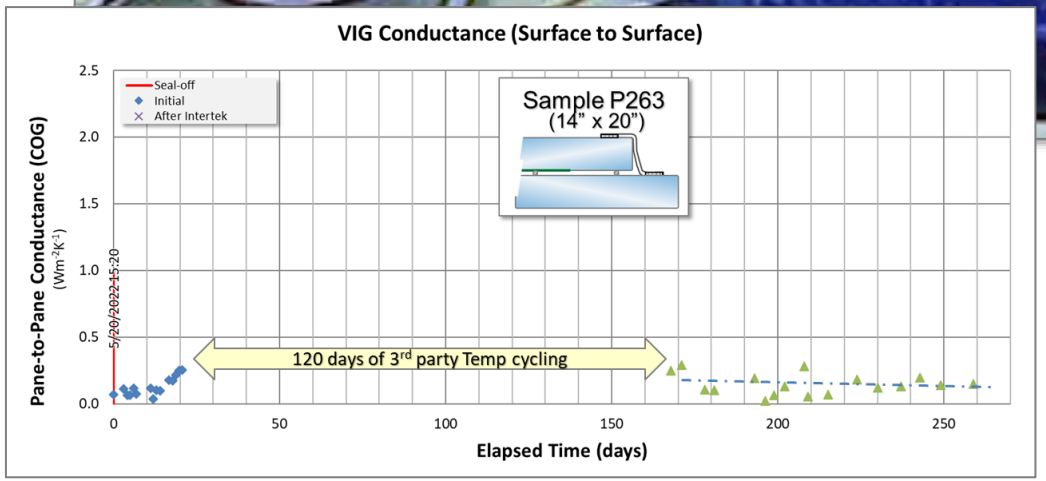
	Annealed* R_{COG}	Tempered R_{COG}	Calculated Whole Window	Seal Type	Visible Port	Primary Markets	Notes
V-Glass	R16	R16+	R13	Flexible Foil	For now	USA	DOE Funding & Lab Support
NSG/Pilkington Spacia®	R-5.7		*R5*	Rigid Glass	YES	Global	1st commercial VIG product
ASG Fineo®	R-8.1		*R7*	Rigid Glass	NO	EU by license	JV with Panasonic
Panasonic Glavenir®	R8.1	R11.6	*R8.5*	Rigid Glass	NO for annealed	Asia & Europe	Leverage TV technology
Vitro (LandGlass) VacuMax®		R14.3	*R8*	Rigid Metal	YES	USA by license	Plan to build U.S. plant
LuxWall®		R12+	*R9*	Rigid Glass	YES	USA	Pilot Plant Phase

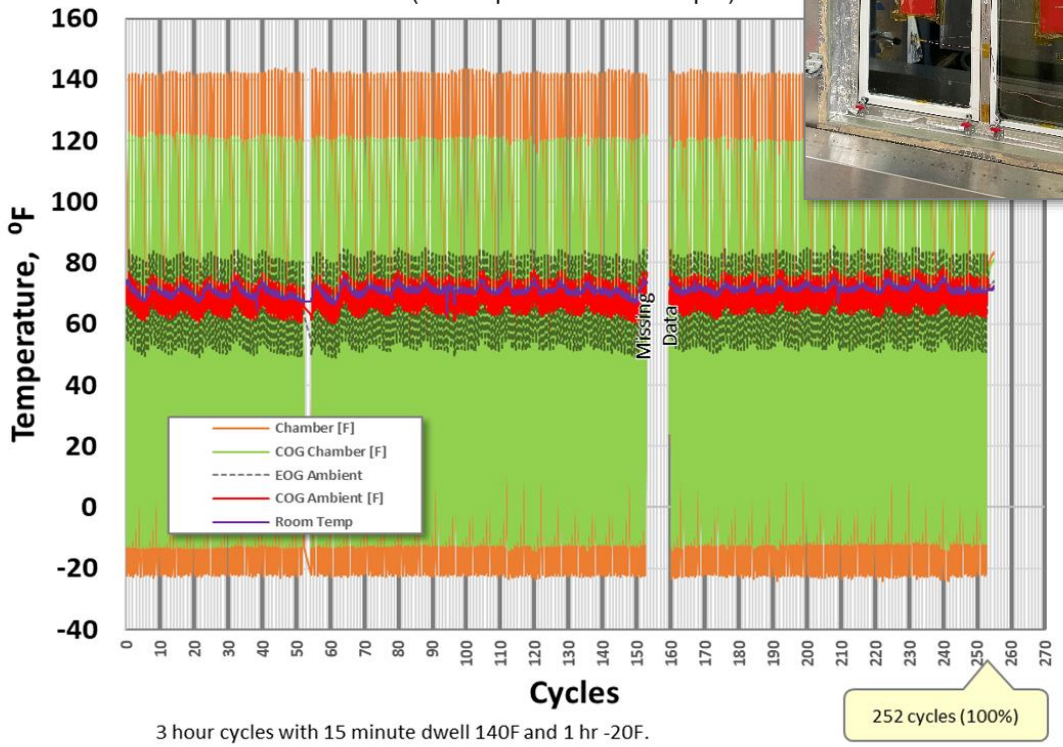
*Annealed glass is 80% of US Residential Market

V-Glass's superior thermal performance and lowest cost, will drive VIG adoption.

Progress: Hermeticity & Durability







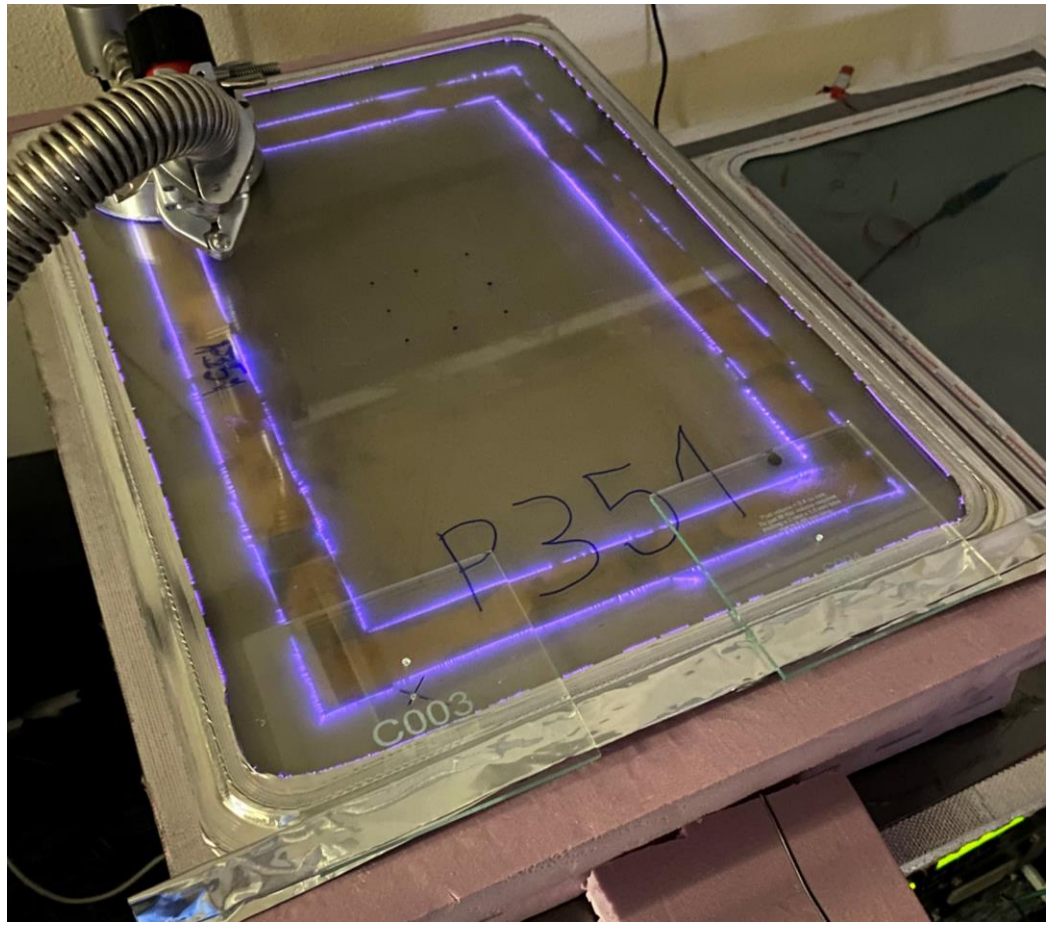
3 hour cycles with 15 minute dwell 140F and 1 hr -20F.

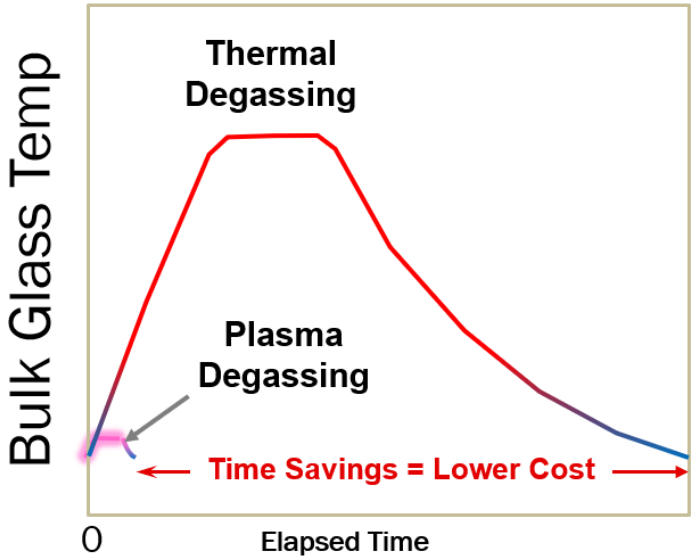
Tracking R-Value measurements over time is best indicator of VIG life.

Extreme ΔT Test

No bow detected – Flexible Foil Seal provides compliance to isolate stresses.

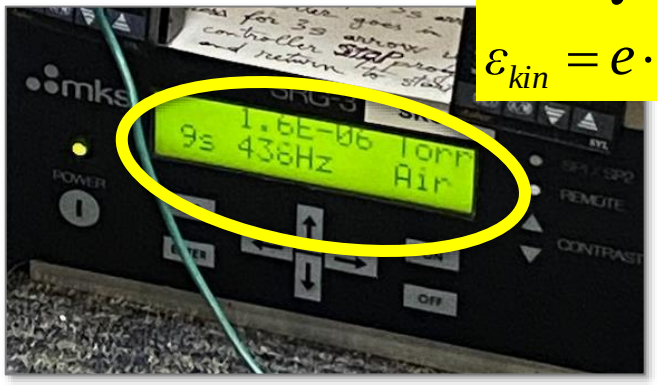
Vacuum Plasma Kinetics





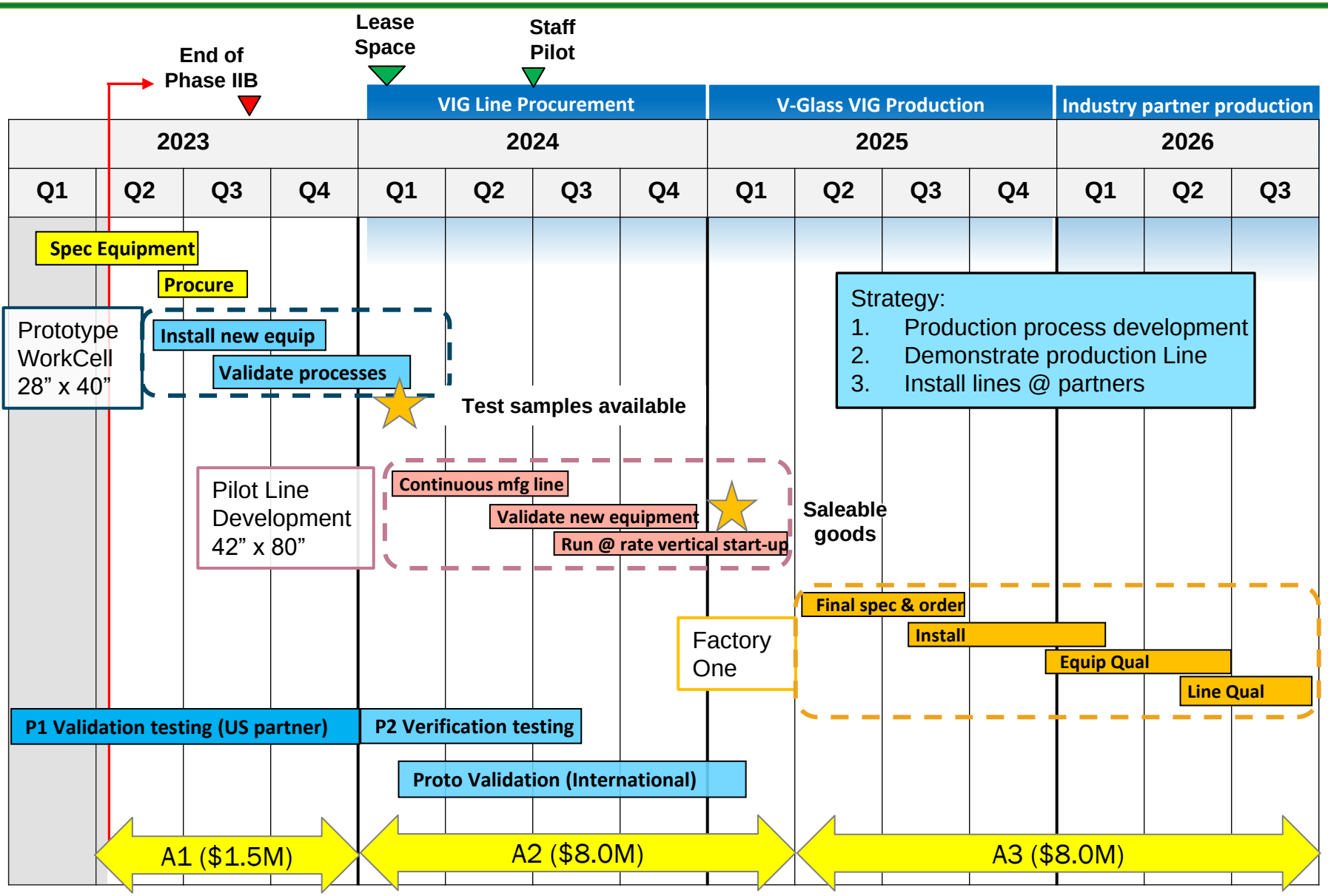
$$\varepsilon_{kin} = \int e \cdot E \cdot dl \geq \varepsilon_{ex}$$

$$\varepsilon_{kin} = e \cdot E \cdot \lambda \geq \varepsilon_{ex}$$

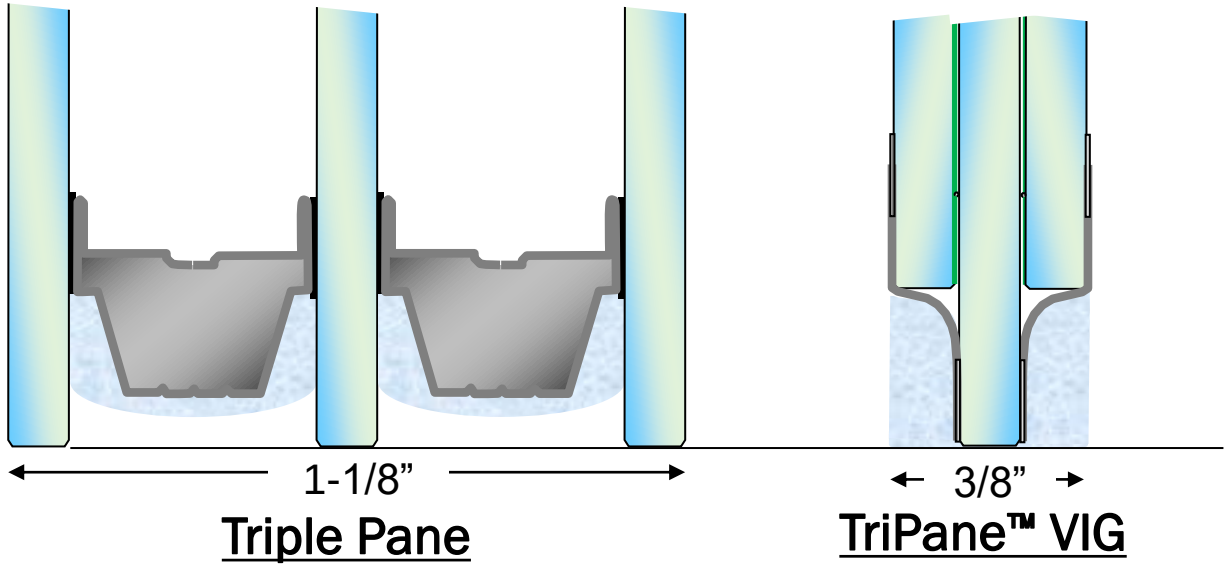


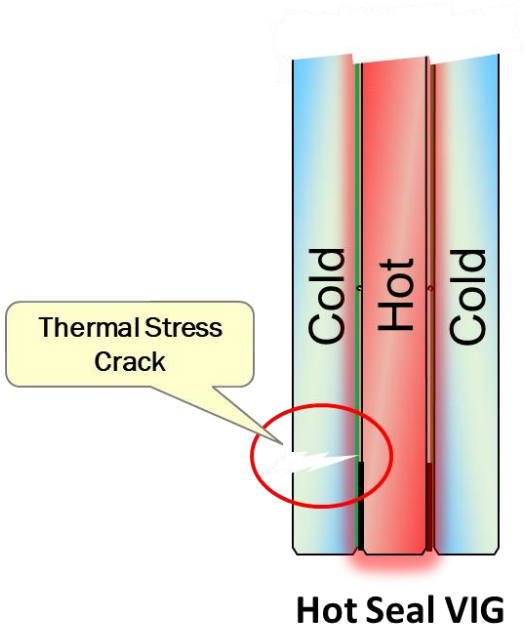
Gap pressure below pump capability proves plasma created dangling bonds (as if a getter).

Future Work: V-Glass Commercialization Plan



TriPane™ VIG





- HVIG (R_{COG} 18) makes little economic sense
- Replace HVIG with TriPane VIG (R_{COG} 31)
  - Oven-free process is required
- R_{ww}20 Whole Window becomes achievable

Thank You

Performing Organization(s): V-Glass, Inc.
PI Name and Title: Chris Kubicek, CTO
PI Tel and/or Email: 262.374.2089 | ckubicek@v-glass.com
Project # DE-SC0017841

REFERENCE SLIDES

Project Execution

	FY2021				FY2022				FY2023			
Planned budget	$1,150,000				$1,150,000							
Spent budget	$1,150,000				$1,150,000							
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Past Work												
Q1 Milestone: Envelope Production Reliability												
Q2 Milestone: Gas Balance Model Development												
Q3 Milestone: Plasma cleaning development												
Q4 Milestone: NREL Test #1; 14x20												
Q1 Milestone: Size & Rate Scaleup												
Current/Future Work												
Q3 Milestone: NREL Test #3: 28x40												
Q4 Milestone: Plasma Cleaning Scaleup												
Insert more Milestones as needed												

- COVID delayed critical equipment delivery from Australia ~ 12months

Team

Peter Petit: Founder | President

- 40 years of innovation experience; including 25 years managing R&D and IP
- Driven new product investment process for world class firms
- Named inventor on 18 patents
- BS/MSME degrees from Marquette University.

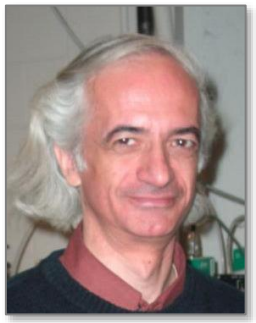
Chris Kubicek, Chief Technology Officer

- 20 years of R&D & commercialization
- At SC Johnson, directed 12 centers of excellence teams and glass R&D
- Named inventor on +100 patents
- Manufacturing and technology integration experience
- BS/MSME University of Wisconsin - Madison

Michael Petit: CEO | CFO

- 30 year career in business, finance and technology
- Past EVP & President at PRA Group (NASDAQ:PRAA)
- BSME from the University of Illinois
- MBA from The University of Texas at Austin

Team



Dr. Sorin Manolache: Plasma Kinetics Molecular Chemist

- Vacuum stability and VIG life
- Degassing process development
- PhD Chemical Engineering Gh. Asachi Polytechnical Institute, Iasi, Romania

Dr. Cenk Kocer: Univ Sydney, Subawardee

- VIG Group Leader
- Member, ISO VIG Standards Development Task Force
- PhD Physics, University of Sydney

David Cooper (Founder, FCS)

- Founder of Fenestration Consulting Services, Madison, WI
- 14 years at Guardian (12 yrs in VIG development)
- Named inventor on 3 VIG process patents
- BSChE Michigan State University (1983)

EERE/BTO goals

(Not a template slide – for informational purposes only)

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