Vacuum Glass for R-10 Windows

Performing Organization: V-Glass LLC
PI Name and Title: Peter Petit, CTO
PI Tel and/or Email: 262.347.8404 | peter.petit@swingresearch.com
**Project Summary**

**Timeline:**
- Start date: 8/27/2018
- Planned end date: 8/26/2020

**Key Milestones**
1. Demo R-10 capable foil-sealed glazing | Aug 2019
2. Demo 50-yr life potential | Jul 2020
3. Identify roadmap to competitive mfg cost | Aug 2020

**Budget:**

*Total Project $ to Date (3/31/19):*
- DOE: $166,531
- Cost Share: $0

*Total Project $:
- DOE: $1,007,593
- Cost Share: $0

**Key Partners:**

<table>
<thead>
<tr>
<th>University of Sydney (Subawardee)</th>
</tr>
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<tbody>
<tr>
<td>Edison Welding Institute (Subawardee)</td>
</tr>
<tr>
<td>Lawrence Berkeley National Lab</td>
</tr>
<tr>
<td>National Renewable Energy Lab</td>
</tr>
<tr>
<td>Anonymous Glass Industry Manufacturer</td>
</tr>
</tbody>
</table>

**Project Outcome:**

V-Glass continues to develop its oven-free manufacturing platform to achieve low-cost vacuum insulating glass (VIG).

After identifying our small welder as the barrier to improved vacuum life, a new, larger welder has been ordered that will increase weld speed by almost 3X, with more upside potential.

Failure to clearly demonstrate feasibility of using a flat bar welder for rapid foil-to-glass welding led to selecting a rotary seam welder similar to the current one, but larger, more robust, and faster.

Please note this data may be provided in later slides, take the time to make sure it matches. This is a summary slide, please don’t spend a large amount of time presenting this slide. 45 minutes
Team

Peter Petit: Founder | CTO
- 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.

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

Fred Krumberger: VP Business Development & Strategy
- 30-year executive leadership and international business development
- Past President, Netpeak Energy and Algoma Door
- BS Industrial Engineering from Northwestern University
- MBA from the University of Chicago
Team

Shields Bergstrom: Seal Weld Process Scientist
- Welding process development
- Weld parameter mapping
- BS Physics, Stanford University

Dr. Sorin Manolache: Plasma Kinetics Scientist
- Vacuum stability and VIG life
- Degassing process development
- PhD Chemical Engineerin Gh. Asachi Polytechnical Institute, Iasi, Romania

Dr. Cenk Kocer: USyd Subawardee PI
- VIG Group Leader
- Member, ISO VIG Standards Development Task Force
- PhD Physics, University of Sydney
Team

V-Glass currently collaborates with these world-class institutions.
Team: University of Sydney Pioneered VIG

1892  Almost one century  1988

Round Vacuum Flask  
James Dewar

Flat Vacuum Glass  
Richard Collins & Jack Tang  
University of Sydney

• **Program Goal**: Market Entry by 2023-2025

• **Barriers**:
  a) VIG manufacturing cost is at least 4X higher than dual pane IG.
  b) energy is cheap, hurting incentive to invest more in windows.

• **Evidence**: After two decades of commercial sales, penetration of VIG into the global IG market is only 10%.

• **Root Cause**: Current VIG manufacturing processes are oven-based, inherently slow, and a barrier to further cost reduction.
Oven-based VIG platforms cannot break through the “glass floor” at about $12/sq ft.

<table>
<thead>
<tr>
<th>‘80s</th>
<th>‘90s</th>
<th>2000’s</th>
<th>2010’s</th>
<th>2020’s</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven-based (Solderglass) Manufacturing Platform (University of Sydney)</td>
<td>NSG/Pilkington</td>
<td>AGC/Panasonic</td>
<td>Guardian</td>
<td></td>
</tr>
</tbody>
</table>

Manufacturing Cost of Dual Pane Argon IG is about $3/sq ft

“Glass Floor” is about $12/sq ft

Mfg Cost Legend

- Oven-based
Challenge: Manufacturing Cost

In contrast, dual pane IG production rate is 1 unit every 30 seconds.
As an alternative to the oven-based manufacturing platforms, V-Glass is developing a new oven-free platform to eliminate:

- process bottlenecks (barriers to high throughput),
- high energy demand and increased capital outlay for ovens.
Challenge: Manufacturing Cost

<table>
<thead>
<tr>
<th>Year</th>
<th>Mfg Cost Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘80s</td>
<td>O Oven-based</td>
</tr>
<tr>
<td>‘90s</td>
<td>X Oven-Free</td>
</tr>
<tr>
<td>2000’s</td>
<td>NSG/Pilkington</td>
</tr>
<tr>
<td>2010’s</td>
<td>AGC/Panasonic</td>
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<tr>
<td>2020’s</td>
<td>Guardian</td>
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</tbody>
</table>

Oven-based (Solderglass) Manufacturing Platform (University of Sydney)

Oven-Free Manufacturing Platform (V-Glass)

<table>
<thead>
<tr>
<th>Year</th>
<th>Mfg Cost</th>
<th>Manufacturing</th>
<th>Cost, $/sq-ft</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘80s</td>
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<tr>
<td>‘90s</td>
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<td>2010’s</td>
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<tr>
<td>2020’s</td>
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</tbody>
</table>

- “Glass Floor” is $12/sq ft (est.)
- Manufacturing Cost of Dual Pane Argon IG is about $3/sq ft

V-Glass intends to break the “glass floor” by developing an oven-free platform.
The final foil-to-foil seal will be made using a non-ultrasonic weld. Welding will still be done at room temperature without preheating. Low current draw will not damage glass.
V-Glass is the only company in the world pursuing a “mismatched” seal (analogous to a 1917 Houskeeper seal, a design for joining two materials of different Coefficient of Thermal Expansion, or CTE).

Our mismatched seal was validated by cyclic thermal testing at NREL (2018 under NSF funding), exceeding 50 years equivalent life without delamination or fatigue.
The whisker spacerette enables VIGs to attain R-10 performance using annealed glass (75% of residential market). Otherwise, to achieve R-10 using pillars, panes would need to be tempered (a costly, oven-based process).
Approach: In-situ Plasma Degassing

Research on atmospheric pressure plasma degassing was funded by NSF.
### Impact: Windows Roadmap (most recent draft)

<table>
<thead>
<tr>
<th>Building Sector</th>
<th>Performance</th>
<th>Installed Price Premium</th>
<th>Primary Energy Savings (quads)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Highly Insulating Windows</strong></td>
<td></td>
<td></td>
<td>2030</td>
</tr>
<tr>
<td>Residential</td>
<td>13 R-value</td>
<td>2.9 $/ft² window area</td>
<td>1.28</td>
</tr>
<tr>
<td>Commercial</td>
<td>10</td>
<td>8.5</td>
<td>0.93</td>
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<tr>
<td><strong>Dynamic Windows</strong></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Residential</td>
<td>0.05/0.65 SHGC (active/inactive)</td>
<td>2.9 $/ft² window area</td>
<td>1.35</td>
</tr>
<tr>
<td>Commercial</td>
<td>15</td>
<td>1.56</td>
<td>1.64</td>
</tr>
<tr>
<td><strong>Daylighting</strong></td>
<td>Commercial</td>
<td>40% Lighting energy savings</td>
<td>13 $/ft² window area</td>
</tr>
</tbody>
</table>

V-Glass is targeting R-10 window and an installed price premium of $0 (assuming new construction).
Projected 2030 primary energy savings is more than all the solar energy generated in the U.S. in 2017.
V-Glass™ VIG manufacturing cost could be 75% less than oven-based VIGs.
Cumulative grant funds to date: $2.88 million

Technology is still considered “too early stage” by venture capitalists.
## Remaining Project Work

<table>
<thead>
<tr>
<th>Year 1</th>
<th>2018</th>
<th>2019</th>
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<tbody>
<tr>
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<td>N</td>
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<td>J</td>
<td>J</td>
<td>A</td>
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</table>

**V-Glass**
- **Welder Pivot Decision**
  - Current Welder Stud size too small
- **Specify and Procure New Sonotrodes**
  - Lab Testing Results Early April
- **Procure New Weld Head**
- **Automation**
- **Make VIGs for USyd U-Testing**
- **Ship Welder to USyd**

**EWI**
- **Study feasibility of rapid bar welder**
  - Not infeasible, but very difficult. Establishes a limit at radius = h.
  - **Non-linear FEA of Foil Stack at Weld Nip**

**University of Sydney**
- **Make glass-sealed whisker VIG and verify to be R10-Capable**
  - R-10 potential verified
- **Sonotrode FEA Study**
  - **Non-Linear FEA**
  - **Foiled VIG R-10**
- **P1: Foil-Sealed R-10 VIG Perf. Goal Met**

Note: EWI indicates the Evolution of Wire Interface, and the University of Sydney's ongoing project work in the field of energy efficiency and renewable energy.
Stakeholder Engagement

Insulating Glass Supply Chain
Stakeholder Engagement

Confidential discussions have been held with most of the largest IG makers and window makers in our key global markets.

One U.S. firm is evaluating our VIGs to consider entering a Joint Development Agreement.
V-Glass was an invited speaker at the First International Vacuum Glass Conference in Qingdao, China, July 26, 2018. Major IG and VIG makers in Asia-Pacific market were in attendance.
Remaining Project Work (Year 1)

University of Sydney

- Make glass-sealed whisker VIG and verify to be R10-Capable

EWI

- Study feasibility of rapid bar welder
- Non-linear FEA of Foil Stack at Weld Nip
- Sonotrode FEA Study
- Non-Linear FEA
- Measure R-value

V-Glass

- Welder Pivot Decision
- Specify and Procure New Sonotrodes
- Procure New Weld Head
- Automation

2018

S O N D J F M

2019

A M J J A

- Manufacture’s Lab Testing Results Early April
- Make VIGs for USyd U-Testing
- Ship Welder to USyd

P1: Foil-Sealed R-10 VIG Perf. Goal Met

Forecast
## Remaining Project Work (Year 2)

<table>
<thead>
<tr>
<th>Year 2</th>
<th>2019</th>
<th>2020</th>
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<tr>
<td><strong>V-Glass</strong></td>
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<tr>
<td>Lab-Scale Welding Yield and Reliability Improvement</td>
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<tr>
<td>VIG Life Extension</td>
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<td><strong>P2: Forecast 50-Yr R-10 Window</strong></td>
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<tr>
<td>Commercial Equipment Spec and Manufacturing Cost Forecast</td>
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<td><strong>P3: Forecast Mfg Cost</strong></td>
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<tr>
<td>Final Report</td>
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| **University of Sydney** | | | | | | | | | | | | |
| Make foil welds and VIGs for Testing | | | | | | | | | | | | |
| Seal Leakage Rate Measurement/Improvement | | | | | | | | | | | | |
| **Self-pumping VIG Development** | | | | | | | | | | | | |
| Final Report | | | | | | | | | | | | |
Thank You

V-Glass LLC

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Michael Petit, CEO
757-619-9843
mjpetit@aol.com
REFERENCE SLIDES
Project Budget

Project Budget: $1,007,593

Variances: Task 2a, Non-linear FEA, was added. Work was started by and adder to EWI, and will be completed with the USyd subaward.

Cost to Date: 30%

Additional Funding: Other funding provided by V-Glass and a $100K grant from the State of Wisconsin SBIR Advance program.

<table>
<thead>
<tr>
<th>Budget History</th>
<th>8/27/18 – FY 2018 (past)</th>
<th>FY 2019 (current)</th>
<th>FY 2020 – 8-26/20 (planned)</th>
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<tbody>
<tr>
<td>DOE Cost-share</td>
<td>$166,531</td>
<td>$508,000</td>
<td>$333,062</td>
</tr>
<tr>
<td>DOE Cost-share</td>
<td>$0</td>
<td>$0</td>
<td>$0</td>
</tr>
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Project Plan and Schedule

Project Start: 8/27/2018  Project End: 8/26/2020

Current Status (4/1/2019):

- Glass-sealed VIG demonstrated R-10 capability using whisker spacerettes. On track to achieve **Milestone P1** by end of Yr 1.
- Design/Build of new weld system (part of Parallel Effort) is on track to accept new weld head in May.
- USyd is evaluating leakage rate of single-weld samples using improved protocol.
- EWI rapid bar welder feasibility study was inconclusive. Pursing improved-speed seam welder (alternate).
- Non-linear FEA (Task 2a) has been added, and is providing useful insights.
- Pivot: Change from offset-pane seal design to offset-free seal to reduce risk and increase seal reliability.