Switchable and Color-Neutral Photovoltaic Windows

National Renewable Energy Laboratory
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Project Summary

Combining high thermal performance, switchability, and energy generation into a unified durable window platform

Timeline:
Start date: October 1, 2019
Planned end date: December 31st, 2021

Key Milestones:
▪ Exceed 2000 switching cycles in switchable PV window
▪ Achieve color Neutrality in static PV window.

Budget:
Total Project $ to Date:
• DOE: $2,010k
• Cost Share: $201k

Total Project $:
• DOE: $2,225k
• Cost Share: $225k

Key Partners:
Viracon
Colorado School of Mines
University of Wisconsin - Stout

Project Outcome:
Improved durability, switching temperature, and aesthetics in perovskite-based PV windows
**Project Budget**: Within planned budget within 5% throughout the project.

**Variances**: Project extended to 2022 with no additional funds

**Cost to Date**: $2,010,551.00

<table>
<thead>
<tr>
<th></th>
<th>FY 2020 (past)</th>
<th>FY 2021 (current)</th>
<th>FY 2022 (planned)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DOE</td>
<td>$785736</td>
<td>$78574</td>
<td>$136236</td>
</tr>
<tr>
<td>Cost-share</td>
<td>$78574</td>
<td>$5998215</td>
<td>$13624</td>
</tr>
</tbody>
</table>
Project Plan and Schedule

Objective

1. Build testing system
2. Develop and employ BEM
3. Develop Switching devices
4. Tune Phase Transition temperature
5. Improve durability of lab-scale devices
6. Demonstrate neutral color
7. Improve PV device performance
The Team

Test System
- David Moore
- Mirzo Mirzokarmov

BEM
- Jangyhun Kim
- Vincent Wheeler

BEM Device Development
- David Moore
- Mirzo Mirzokarmov

Tune Phase
- Bryan Rosales

Colleges:
- NREL
- Viracon/Apogee
- Colorado School of Mines
- University of Wisconsin-Stout

Largest commercial glazing manufacturer in the US
Challenge: How do we make architectural beauty more efficient?

There are $43 \times 10^9$ ft$^2$ ($4 \times 10^9$ m$^2$) of windows in the US. The architectural trend points to even more glass in the future. Commercial buildings account for 35% of electricity consumed in the U.S. and generate 16 percent of all CO$_2$ emissions. Though thermal properties are improving, we are long way from the performance of the opaque façade. How do we reconcile demand for more glass with the need for more efficient buildings?
Approach - Energy conversion instead of mitigation

Photovoltaics (PV) on the vertical surface

- Significant solar resource for PV
- Flattens the “duck curve”
- Glass is the most expensive material in thin film PV

Challenges with PV windows

- Durability
- Aesthetics
- Performance
- Scale
- Integration

*Based on prototype large office building in Denver (pvwatts.nrel.gov)
Approach: Perovskites are the next big thing in PV
Approach: Two Perovskite Technologies & Modeling

**SwitchGlaze™** – the world’s first switchable PV window

Neutral-color static PV windows

Building Energy Modeling

Early-stage R&D

Early-stage R&D

Large-scale energy simulations to determine savings find optimum properties
Background: Previous cycle stability was poor, $T_{\text{switch}}$ too high

Progress: Our new chemistry solves mechanical degradation

Initial

Plan view
Cross-section

Bleached

Plan view
Cross-section

Cycled

Plan view
Cross-section

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Transmission (%) vs. Wavelength (nm)

- **Bleach**: Dotted line
- **Color**: Solid line

![Graph showing transmission (%) vs. wavelength for Bleach and Color](image)

- **Initial**: Transmission at 10 um and 500 nm is shown.
- **Bleach**: Transmission at 10 um and 500 nm is shown.
- **Cycled**: Transmission at 10 um and 500 nm is shown.

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VT (%) vs. Cycles

- **Bleach**: Blue circles
- **Color**: Red circles

![Graph showing VT (%) vs. cycles for Bleach and Color](image)

- **Initial**: VT at 77% is shown.
- **Bleach**: VT at 80% is shown.
- **Cycled**: VT at 80% is shown.

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**NREL**

**Plan view**

- 10 um scale
- 500 nm scale

**Cross-section**

- 10 um scale
- 500 nm scale
Progress: We determined and demonstrated optimal $T_{\text{Switch}}$

Modeling + Material Science


Approach: Two Perovskite Technologies & Modeling

SwitchGlaze™ – the world’s first switchable PV window

Neutral-color static PV windows

Building Energy Modeling

Early-stage R&D

Early-stage R&D

Large-scale energy simulations to determine savings find optimum properties
Near-term impact: color neutralization

“Aesthetics trump performance for architectural applications...The brown appearance would be a showstopper for most applications.” – Matt Bergers, Viracon

Progress: Downshifting color balance laminate

*Compatible with current laminate fabrication

UV illumination (QY = 65-100%)
Progress: A static color-neutral perovskite window

- 30% Visible Transmittance
- 4% power conversion efficiency
- Neutral color!

5% increase in photocurrent!
**Approach: Two Perovskite Technologies & Modeling**

**SwitchGlaze™** – the world’s first switchable PV window

Neutral-color static PV windows

Building Energy Modeling

Early-stage R&D

Early-stage R&D

Large-scale energy simulations to determine savings and find optimum properties
Impact: More PV glass = higher building performance

- Window PV & optical properties

Developed for project

Measures Developed for project

- Denver, CO Medium office 12 floors

Site Energy Use Intensity (kWh/sf/yr)

<table>
<thead>
<tr>
<th>Window Type</th>
<th>Energy Use Intensity (kWh/sf/yr)</th>
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</thead>
<tbody>
<tr>
<td>Conventional Windows</td>
<td></td>
</tr>
<tr>
<td>Double Pane</td>
<td>12</td>
</tr>
<tr>
<td>Double Pane + Low-e</td>
<td>11</td>
</tr>
<tr>
<td>Triple pane + Low-e</td>
<td>9</td>
</tr>
<tr>
<td>PV Windows</td>
<td></td>
</tr>
<tr>
<td>Static PV, PCE = 12.8%</td>
<td>6</td>
</tr>
<tr>
<td>Dynamic PV, PCE = 20.3%</td>
<td>4</td>
</tr>
</tbody>
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More windows = More energy

More windows = Less energy
Impact: Savings around the country
Impact: Many metrics of success

Patents/Trademark
- 10 submitted patents
- 1 issued patent
- 5 more records of invention
- 1 Trademark on SwitchGlaze™

Publications
- 3 led by this project
  (1 in Nature Commun.)
- 5 more in process
- >5 supporting other projects

Invited Talks
- 4 invited talks to academia and industry

Mentorship
- 2 PhD students supported
- 1 Postdoc supported
- 5 interns supported
Stakeholder Engagement


Started working NREL/ASA working group to tackle challenges in BIPV.

Invited seminars for ASA, Vitro, IGMA, NFRC.

Start-up company bought a license option agreement for SwitchGlaze IP.
Remaining project work

Though FY22 Q1

Technical
- Publish Building Energy Modeling study
- Make PV/thermochromic window software available to public
- Improve switching durability
- Demonstrate record performance from color-balanced PV window.

Beyond

Technical
- Improve performance using device architecture engineering
- Extend durability to building lifecycle scales

Deployment
- PV window deployment studies (performance, CommStock, urban heat island effects?)

Glazing breakthrough timeline
Thank You

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