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

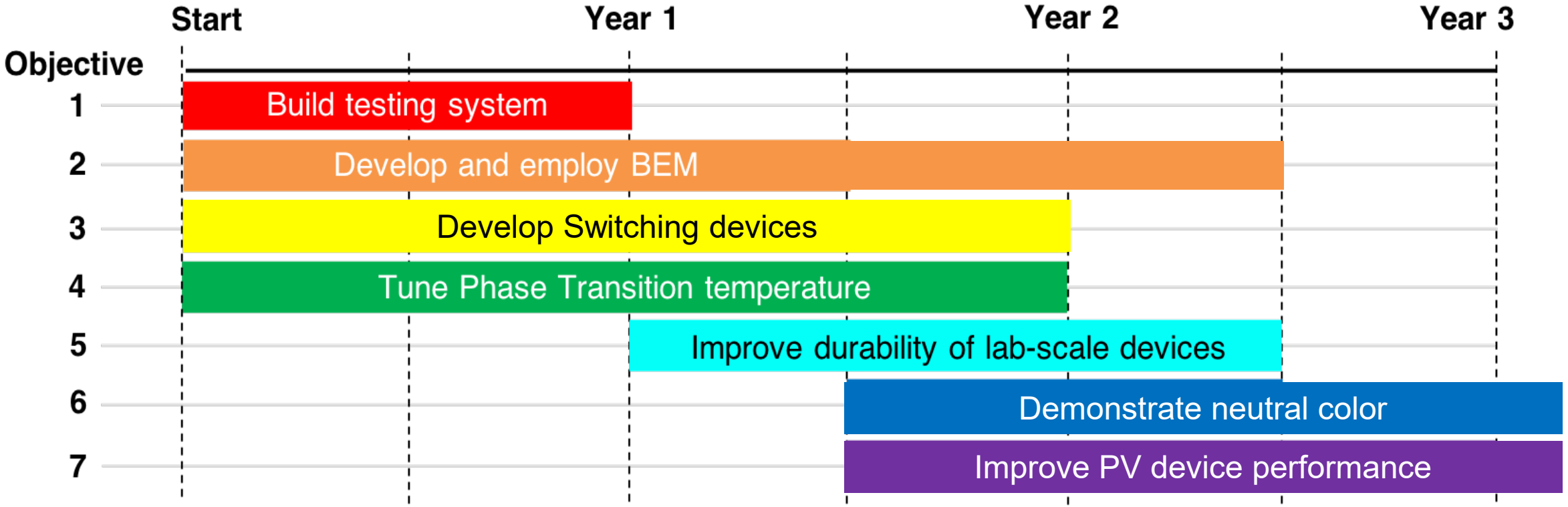
Project Budget: Within planned budget within 5% throughout the project.

Variances: Project extended to 2022 with no additional funds

Cost to Date: $2,010,551.00

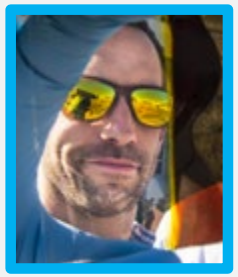
Budget History					
FY 2020 (past)		FY 2021 (current)		FY 2022 (planned)	
DOE	Cost-share	DOE	Cost-share	DOE	Cost-share
$785736	$78574	$599815	$59982	$136236	$13624

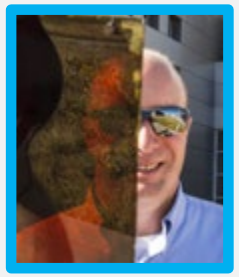
Project Plan and Schedule



The Team

Largest commercial glazing manufacturer in the US


Lance Wheeler


Rob Tenent


Charles Boyer


Mike Sheppy


Matt Bergers

NREL

Viracon/Apogee

Colorado School of Mines

University of Wisconsin-Stout

Test System


David Moore

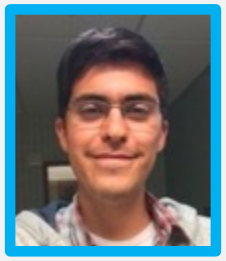

Mirzo Mirzokarmov

BEM


Jangyhun Kim


Vincent Wheeler

Tune Phase


Bryan Rosales


David Moore

Device Development


David Moore

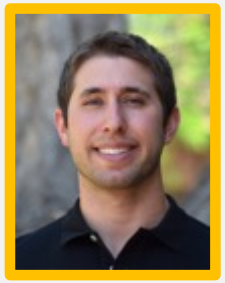

Mirzo Mirzokarmov


Colin Wolden


Owen Hildreth


Emily Warren


Kevin Prince


Steven DiGregorio

Manhattan 2025

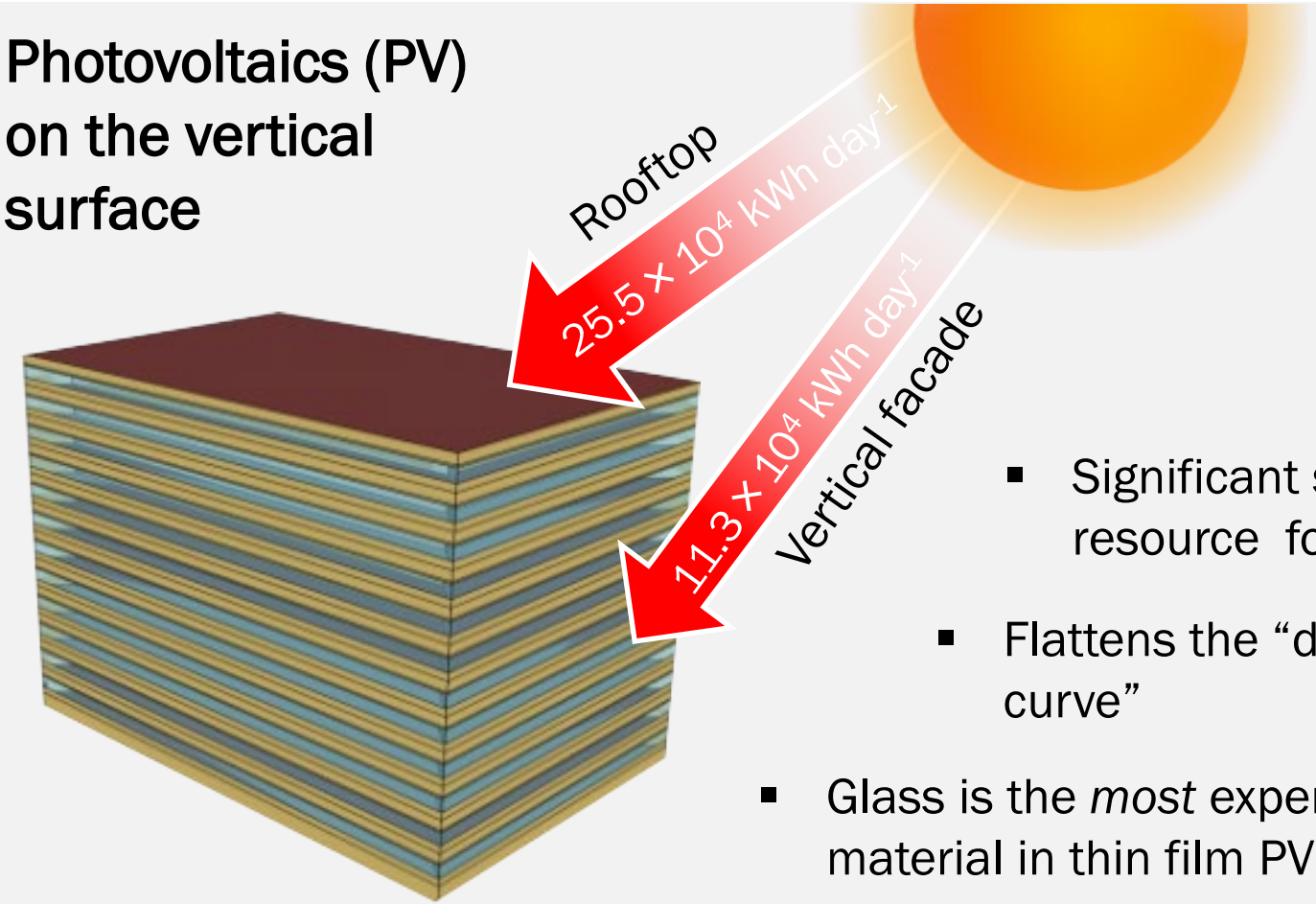
Challenge: How do we make architectural beauty more efficient?

There are 43×10^9 ft^2 (4×10^9 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?

nytimes.com

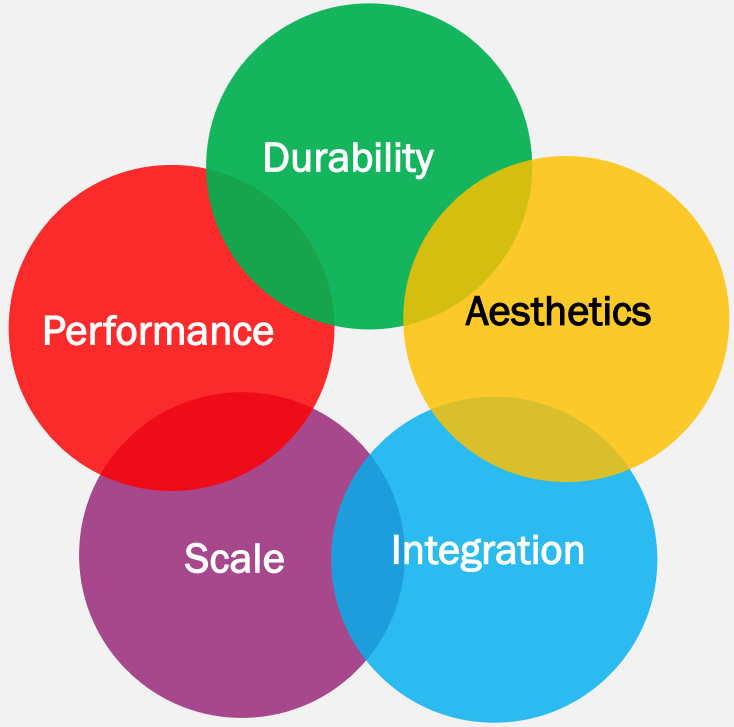
Approach - Energy *conversion* instead of mitigation

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

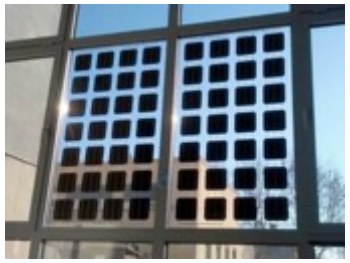
Challenges with PV windows



*Based on prototype large office building in Denver (pvwatts.nrel.gov)

Approach: Perovskites are the next big thing in PV

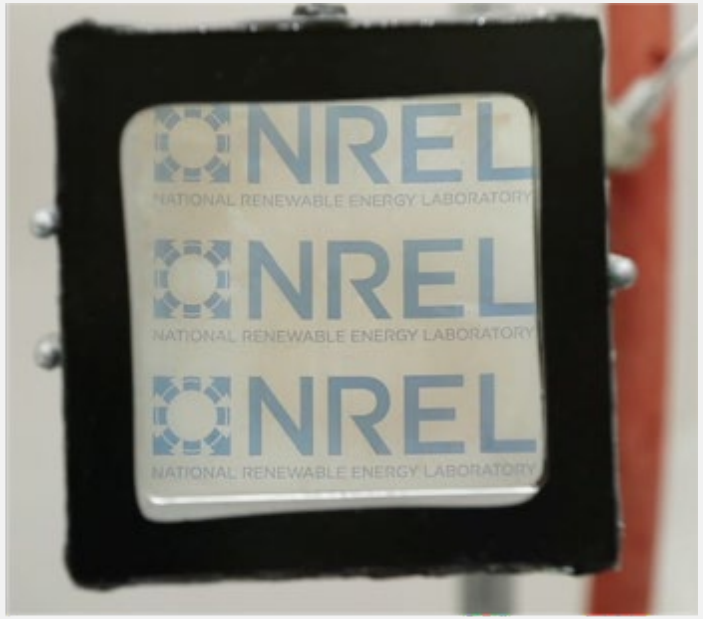
Segmented



Semitransparent

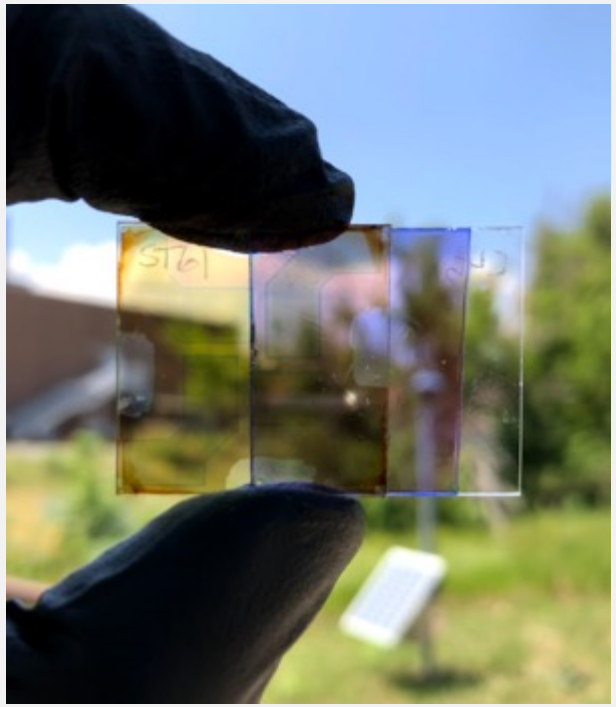
Approach: Two Perovskite Technologies & Modeling

SwitchGlaze™ – the world's first switchable PV window



Early-stage R&D

Neutral-color static PV windows

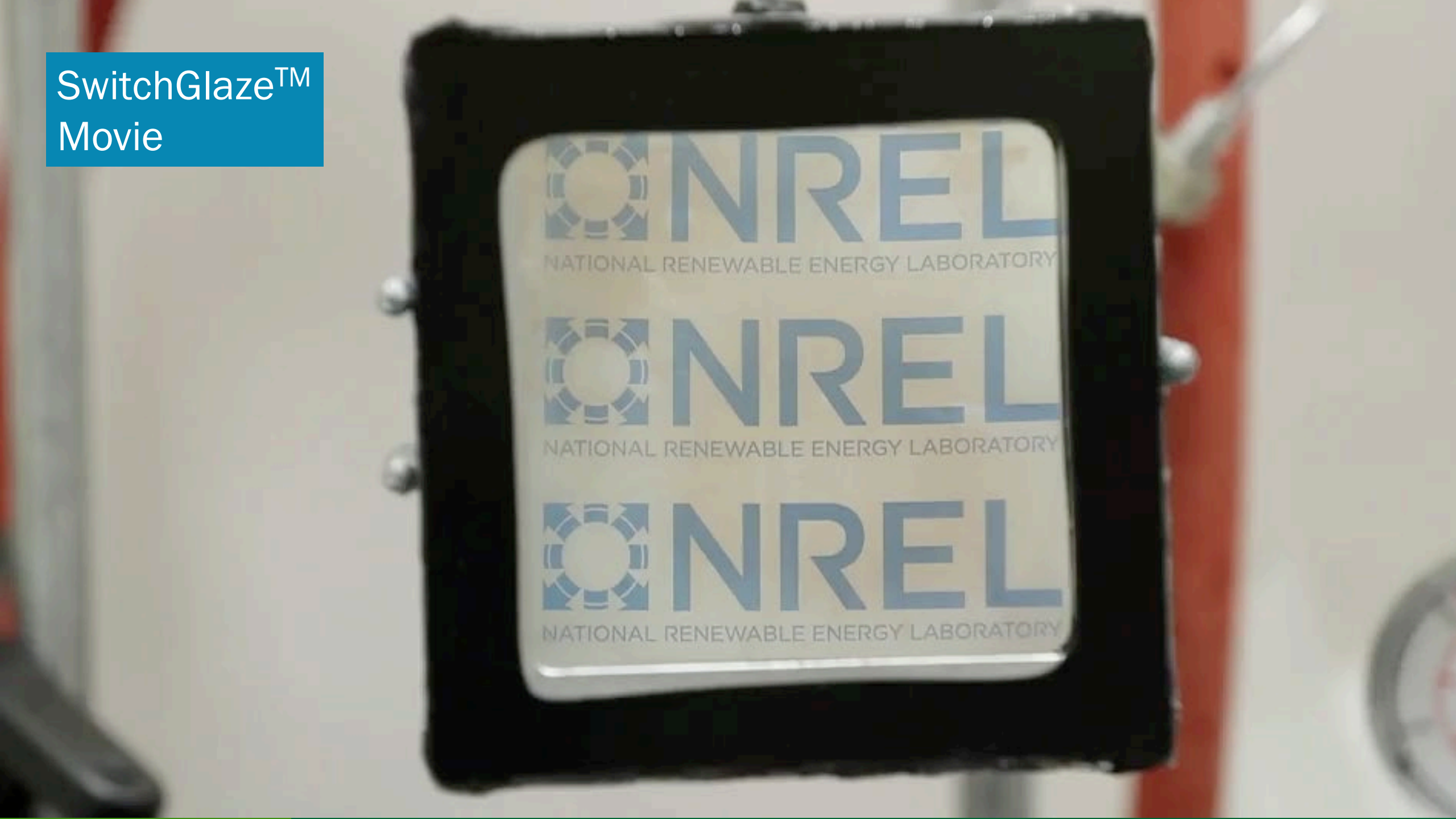


Early-stage R&D

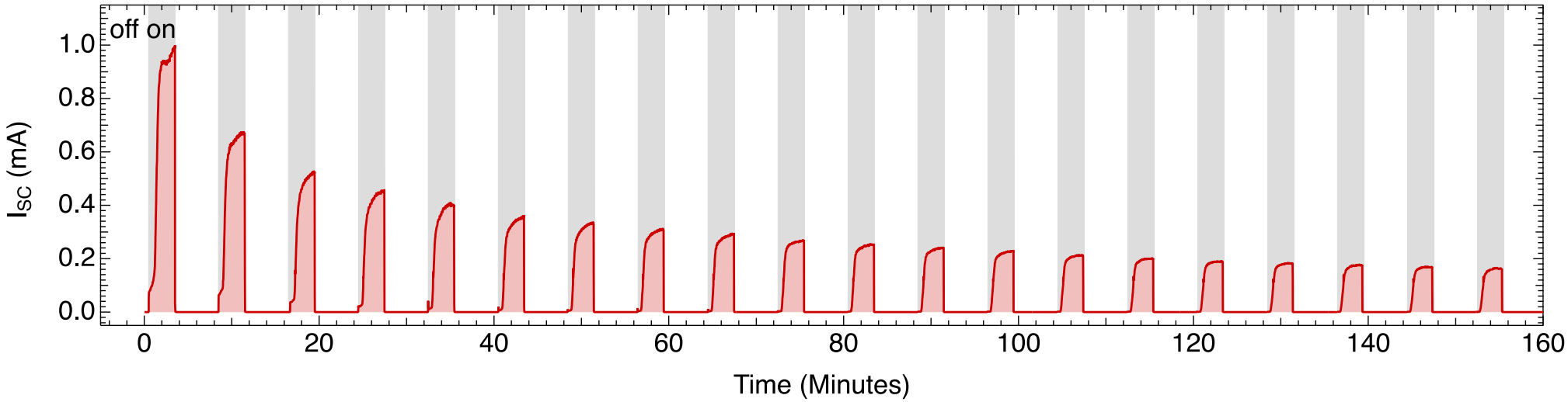
Building Energy Modeling

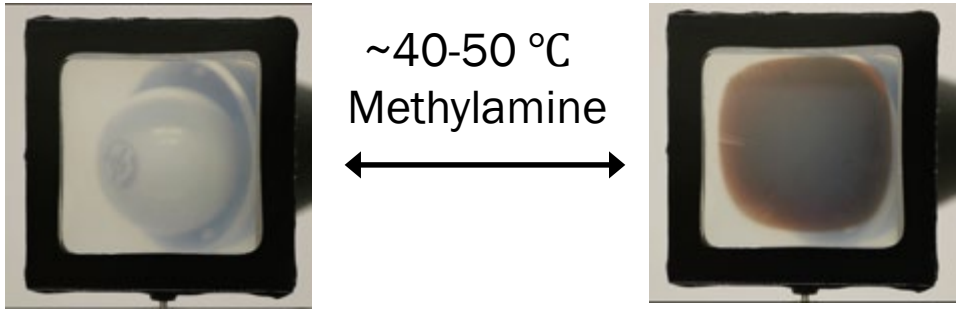
Large-scale energy simulations to determine savings find optimum properties

SwitchGlaze™ Movie



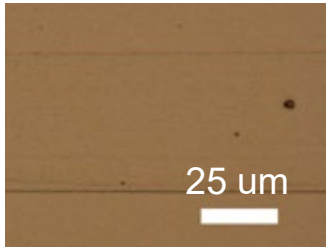
Background: Previous cycle stability was poor, T_{switch} too high



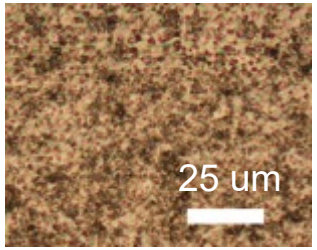


~40-50 ℃
Methylamine

Initial film

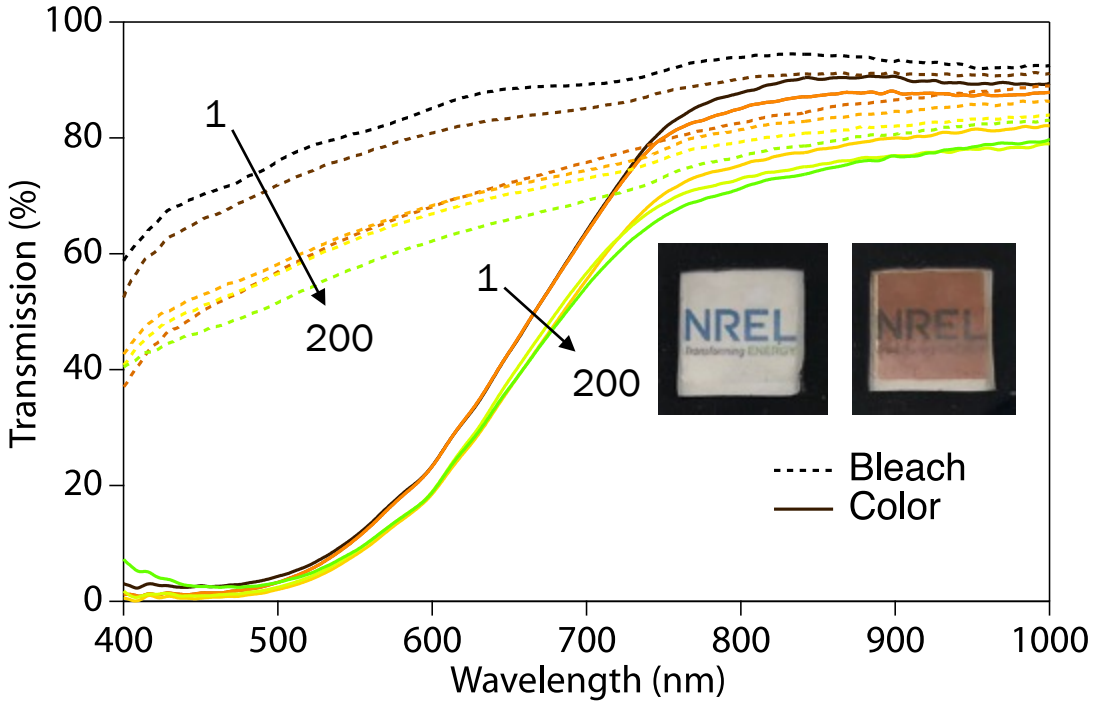


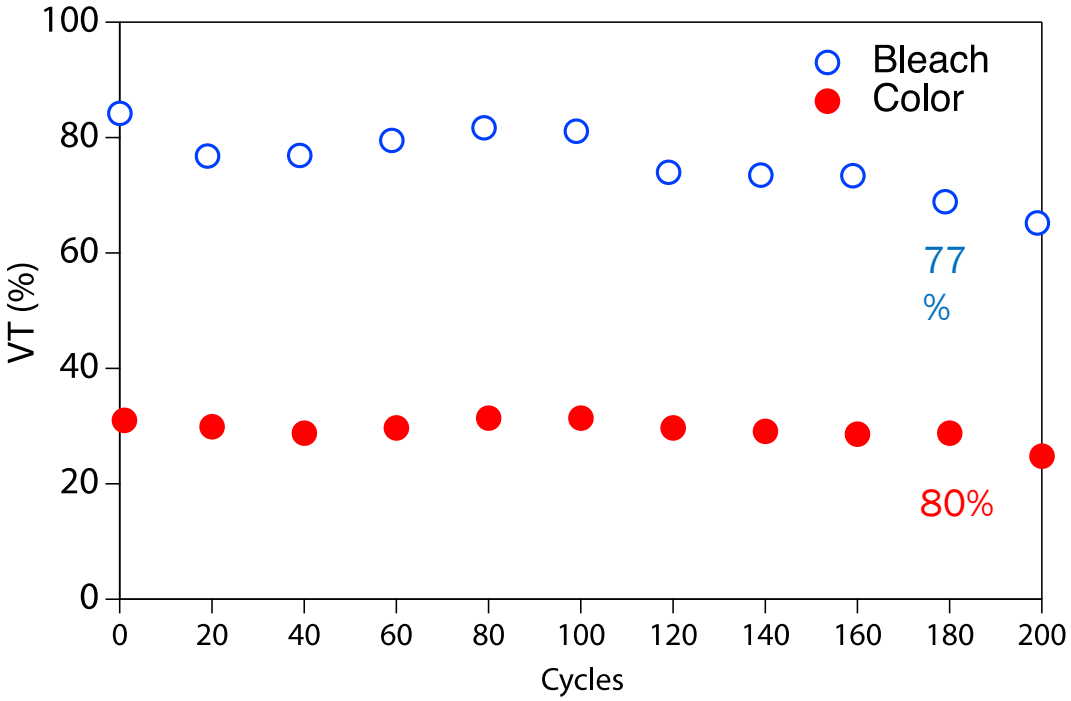
After 20 cycles

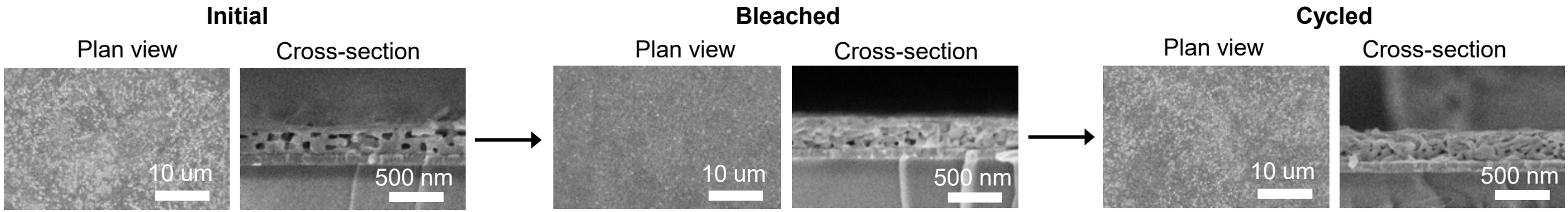


Wheeler, Lance M., et al. “Switchable Photovoltaic Windows Enabled by Reversible Photothermal Complex Dissociation from Methylammonium Lead Iodide.” *Nature Communications* 8, no. 1 (2017): 1722.

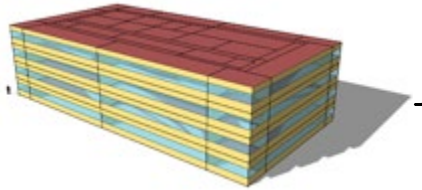
Progress: Our new chemistry solves mechanical degradation





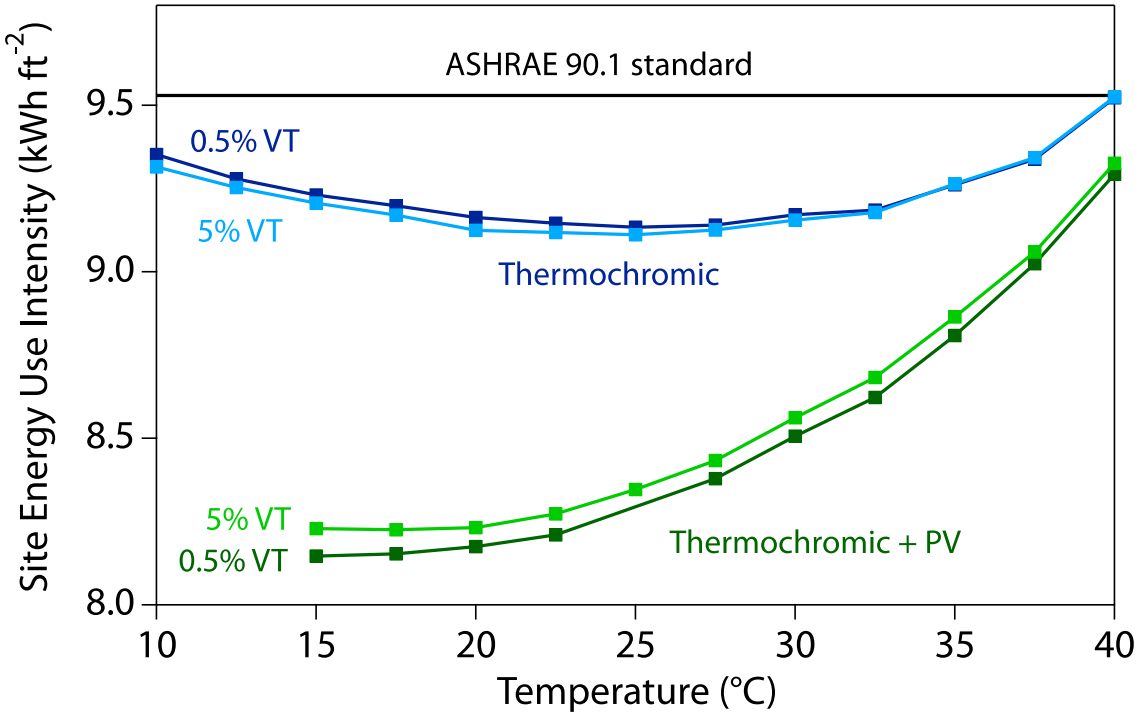


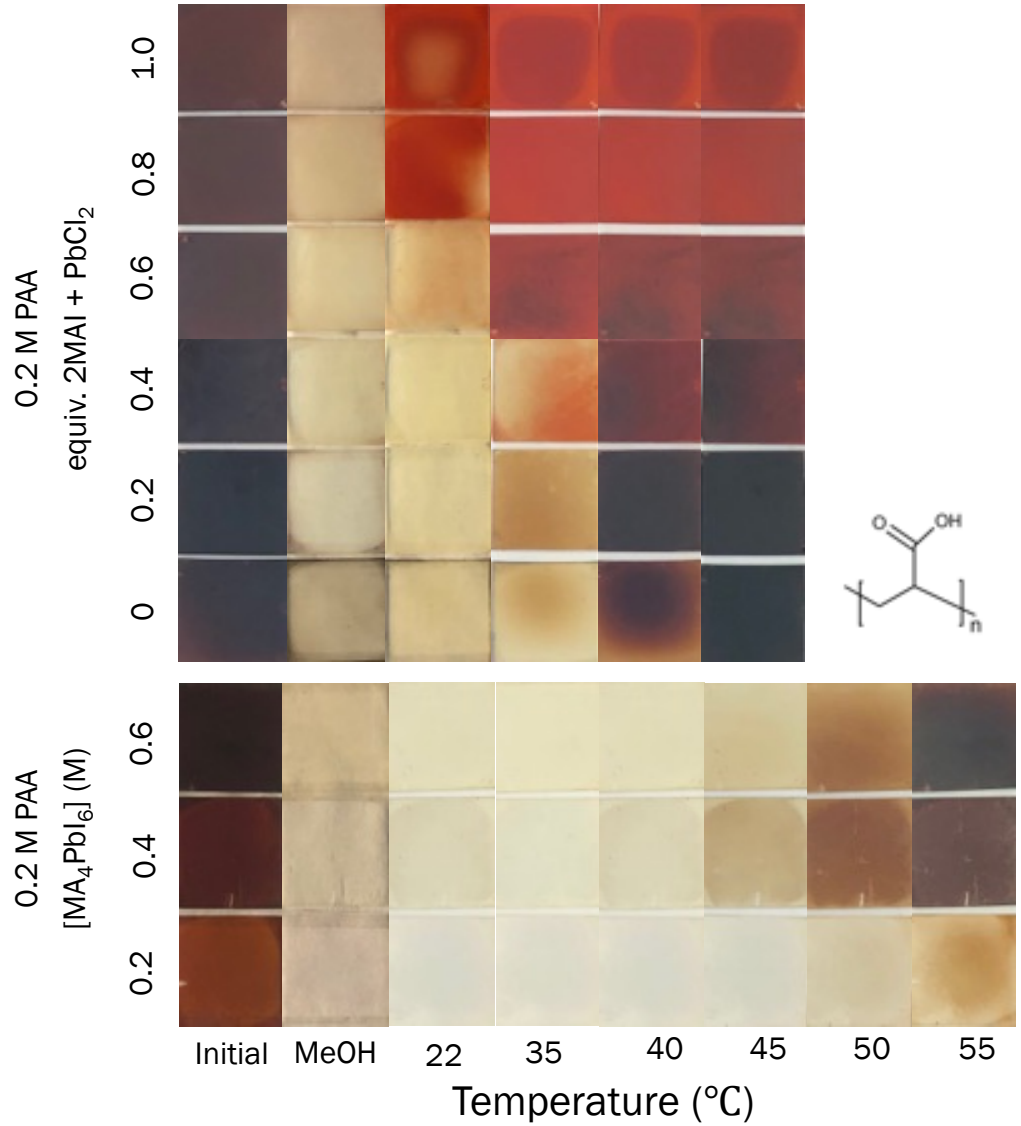
Progress: We determined and demonstrated optimal T_{Switch}



New York
Medium office
12 floors

Modeling + Material Science



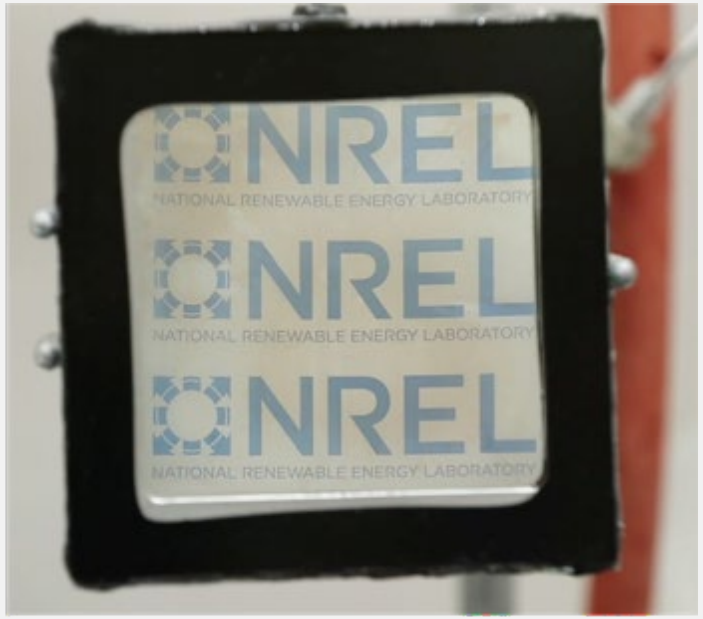


Rosales, Bryan A.,…Lance M. Wheeler. *Nature Communications* 11, no. 1 (2020): 5234.

Rosales, Bryan A.,…Lance M. Wheeler. *Submitted* (2021)

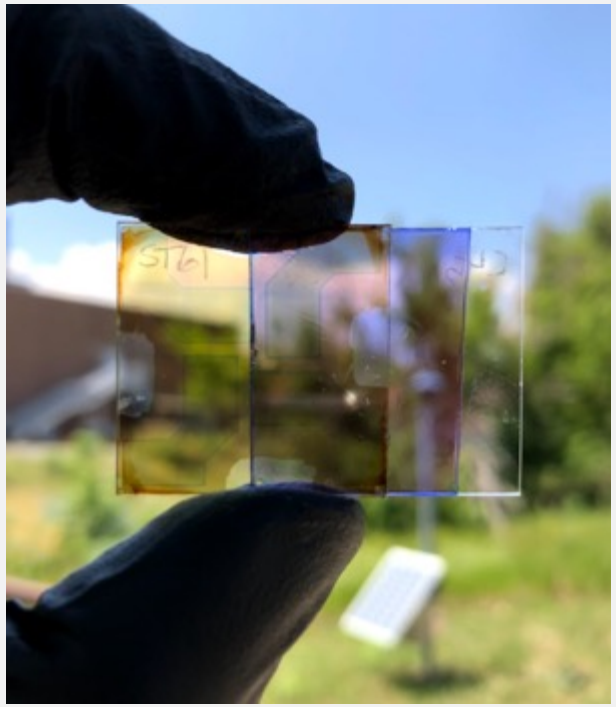
Approach: Two Perovskite Technologies & Modeling

SwitchGlaze™ – the world's first switchable PV window



Early-stage R&D

Neutral-color static PV windows



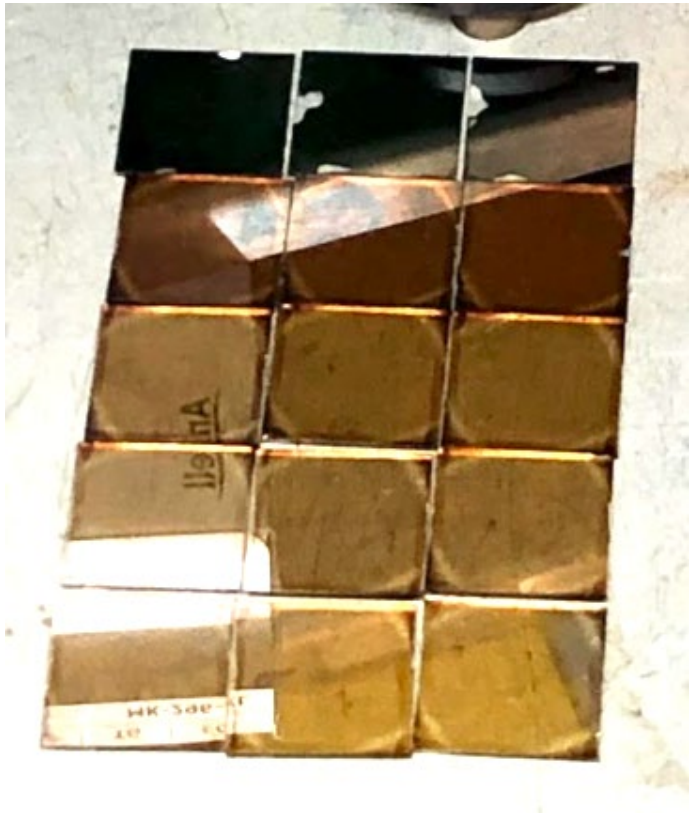
Early-stage R&D

Building Energy Modeling

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 show-stopper for most applications." – *Matt Bergers, Viracon*



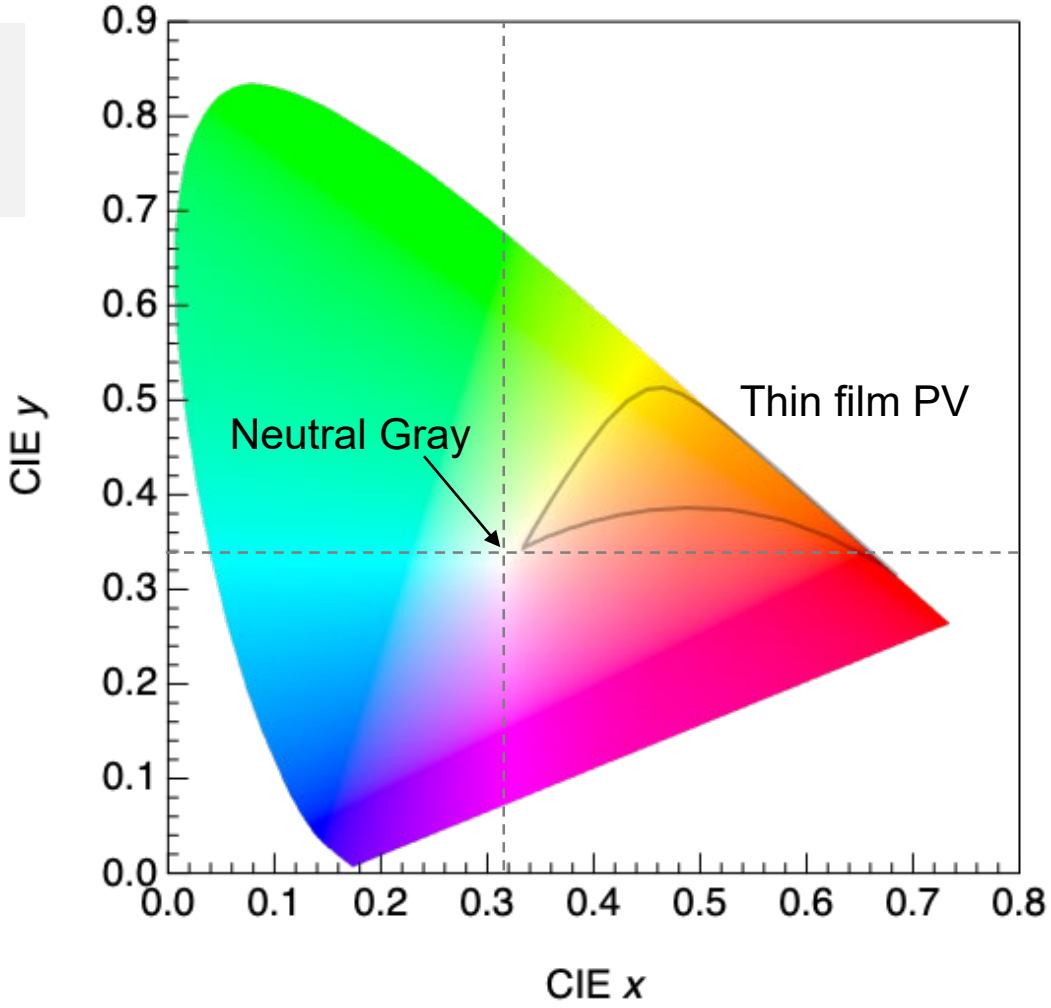
550 nm

130 nm

65 nm

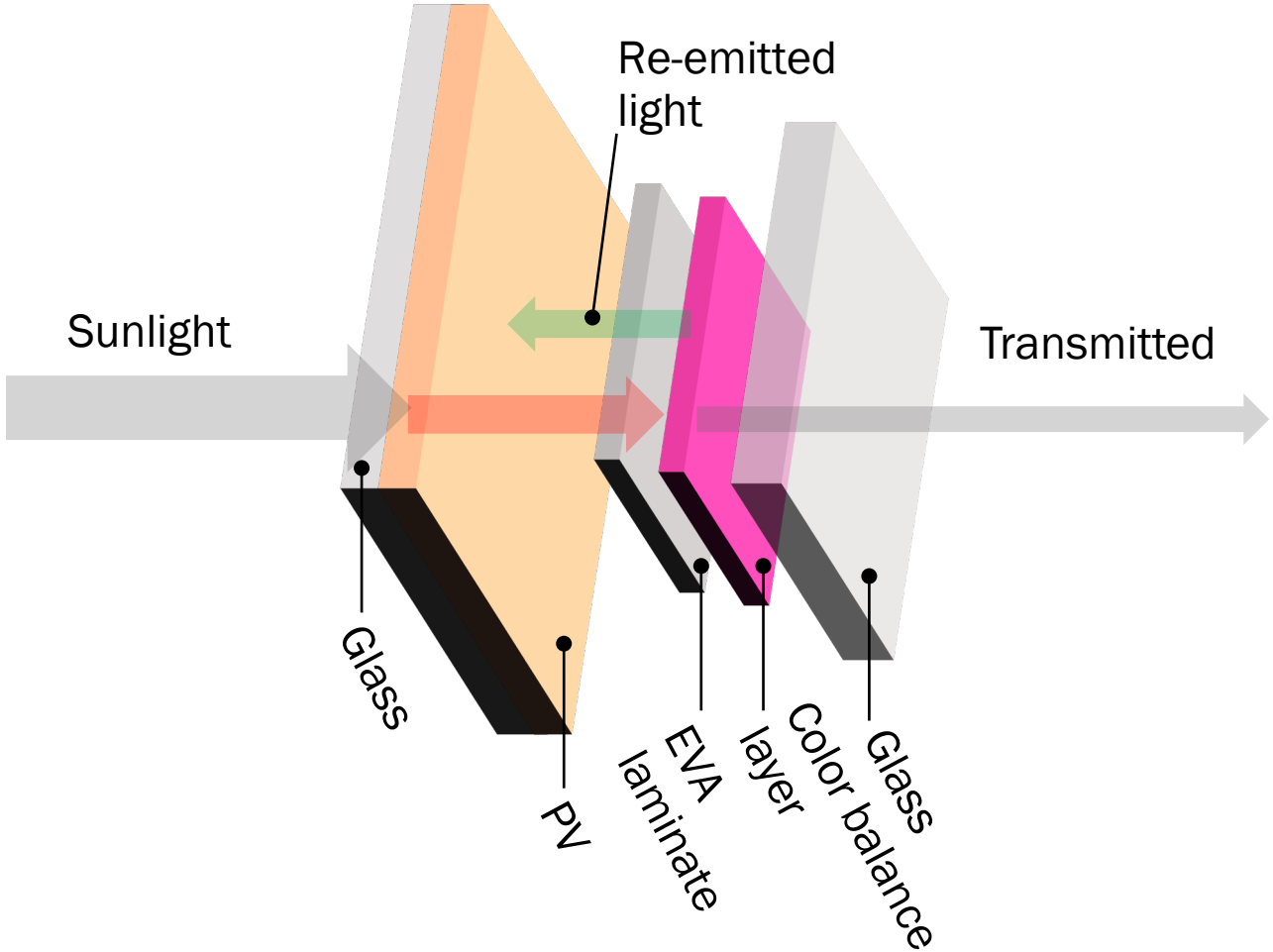
40 nm

25 nm



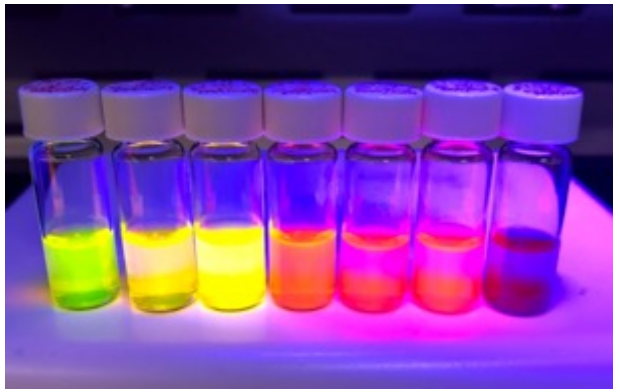
Wheeler, L. M., and V. M. Wheeler *ACS Energy Letters* 4, no. 9 (2019): 2130–36.

Progress: Downshifting color balance laminate



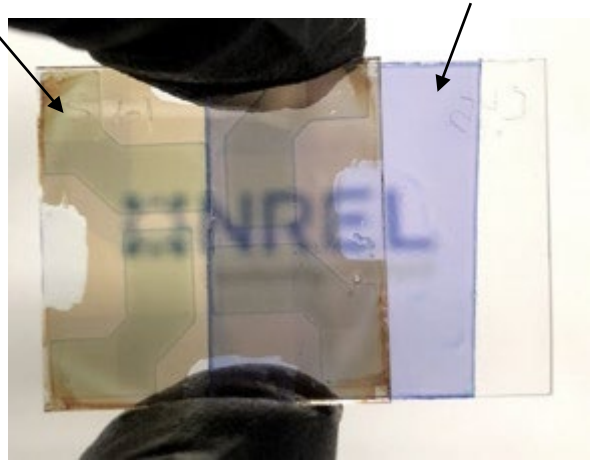
*Compatible with current laminate fabrication

UV illumination (QY = 65-100%)

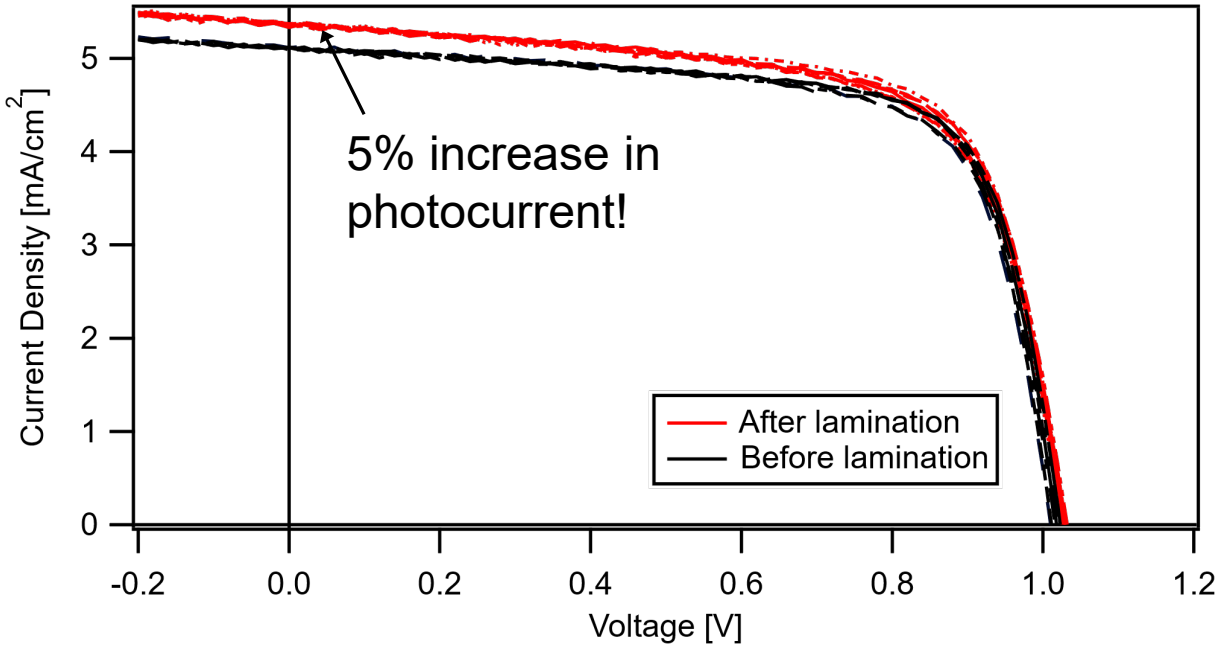


PV window

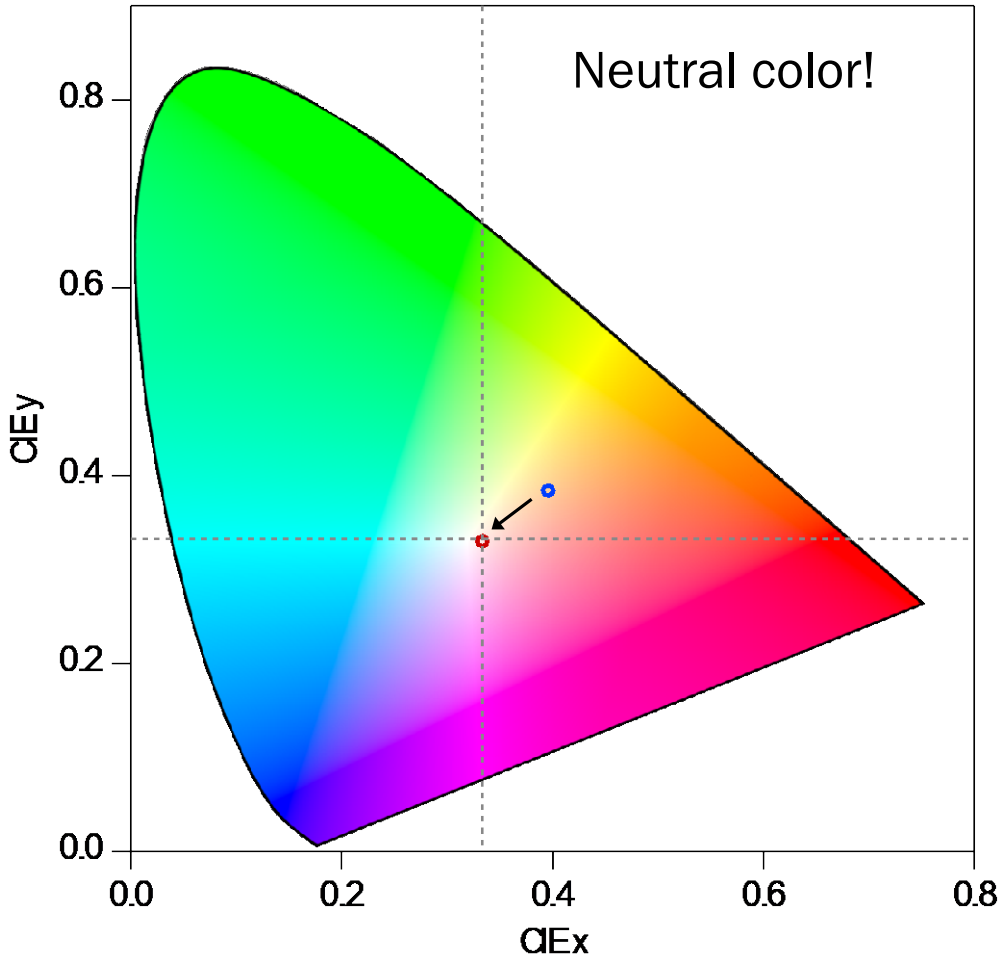
Color balance layer



Progress: A static *color-neutral* perovskite window



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



Approach: Two Perovskite Technologies & Modeling

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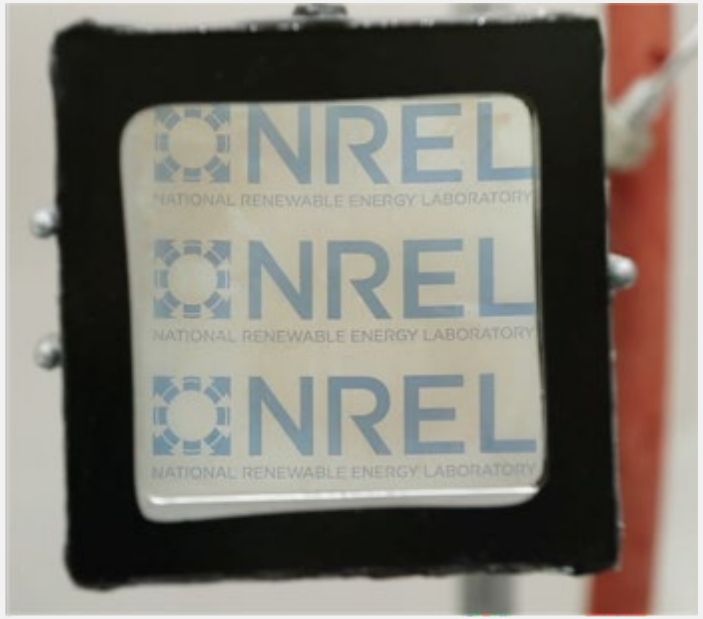
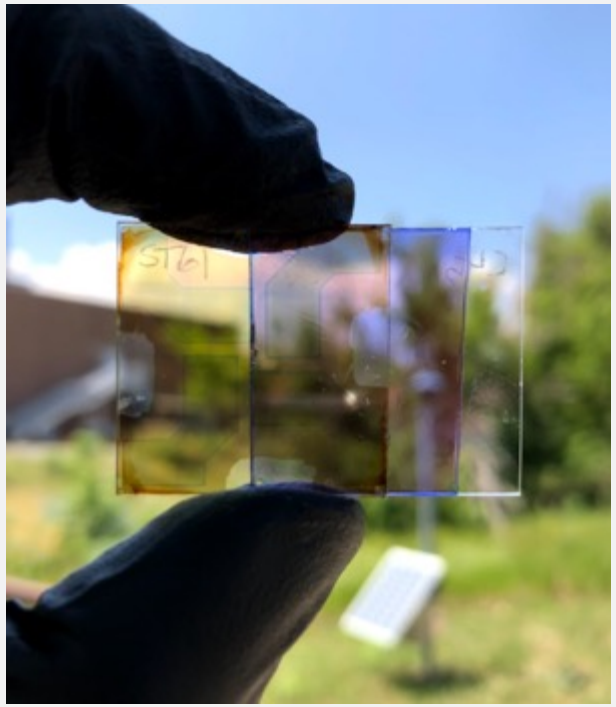


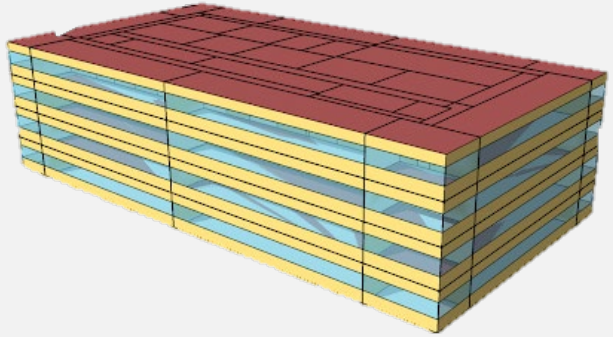
Early-stage R&D

Neutral-color static PV windows



Early-stage R&D

Building Energy Modeling



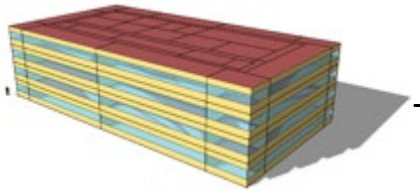
Large-scale energy simulations to determine savings find optimum properties

Impact: More PV glass = higher building performance

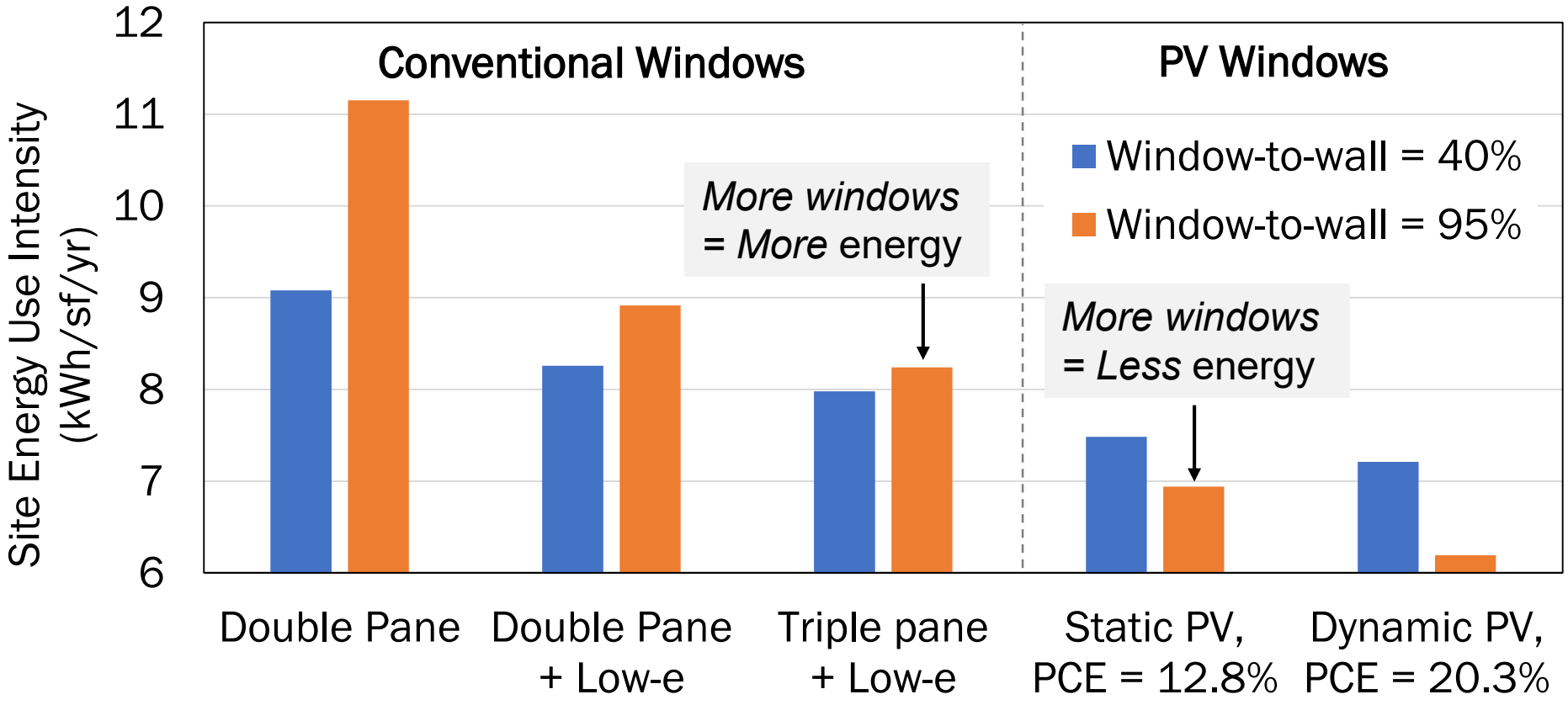
Window PV & optical properties

Developed for project

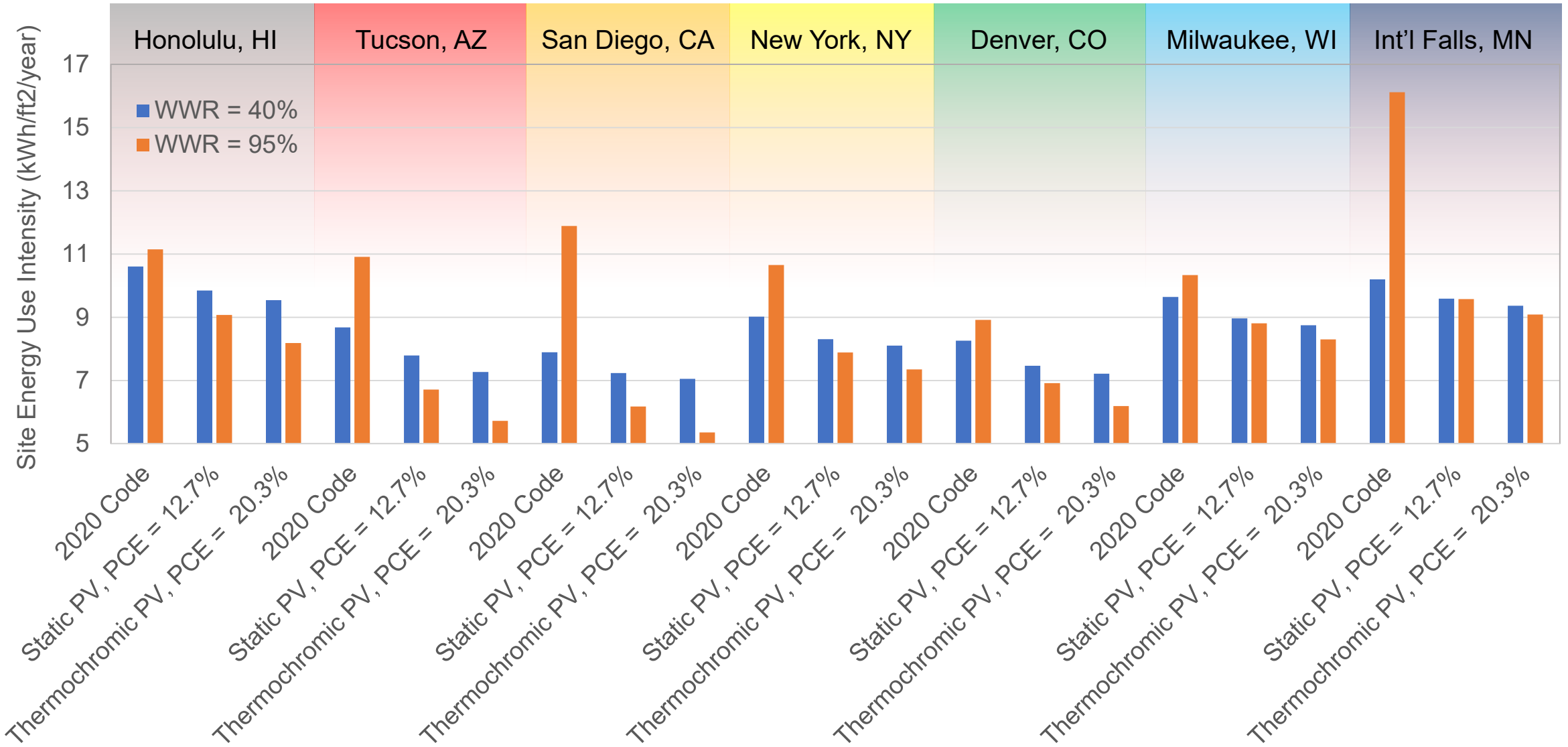
Measures Developed for project



Denver, CO
Medium office
12 floors



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

R&D100 award submitted for SwitchGlaze. Letters of support from Viracon, Pilkington, Walter and Wolf, and Architectural Solar Association

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

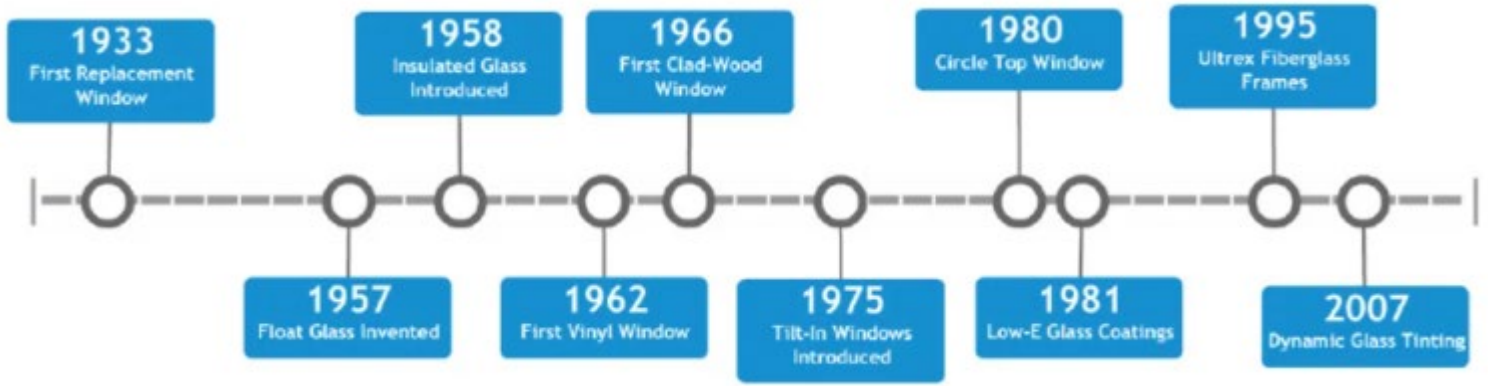
Technical

- 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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