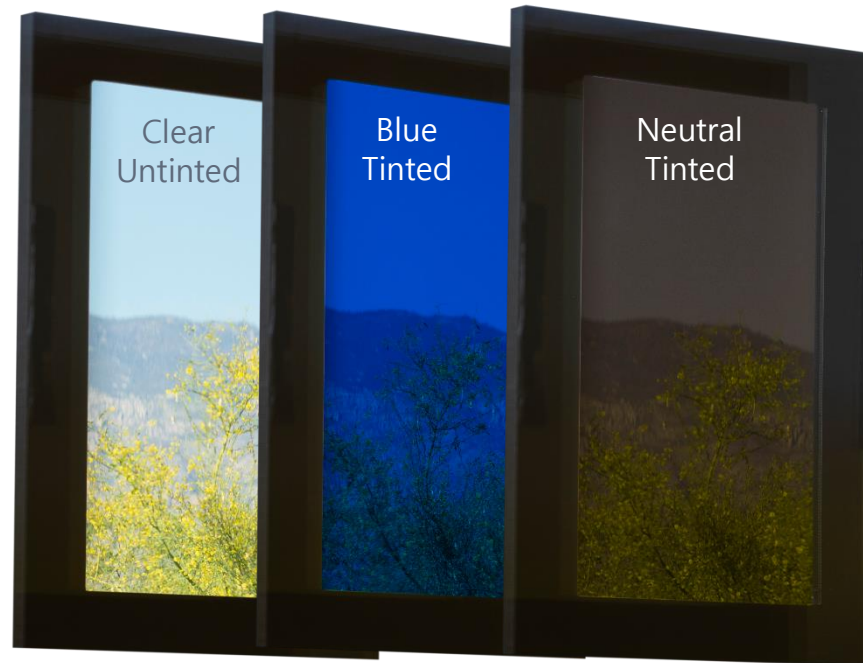


Low-Cost Dynamic Glazing with Custom Colors



Performing Organization: Polyceed, Inc. dba Glass Dyenamics
PI Name and Title: Anoop Agrawal, CTO
PI Tel and/or Email: 520 230 2140, anoop@dyenamics.com
Project #: NREL SUB-2022-10374

Project Summary

The start: Low Cost, Proven Durability

1. **Low cost:** Device simplicity, low capex due to the use of standard glass process equipment.
2. **Durability:** Demonstrated highly durable dye-based EC products with liquid electrolytes which cycle > 150k times over 5,000 hours under ASTM E2141 exposure conditions.

Objective: Color & Manufacturing Optimization

1. Increased product marketability with neutral color dyes, and
2. Increase manufacturing readiness with solid electrolyte chemistry

Team and Partners

1. Glass Dynamics
2. NREL

Key Milestones / Demonstrations

1. Solid electrolyte devices
2. Neutral coloring devices

Problem: Windows are sponsible for ~20% of total energy use

Problem:

Buildings account for ~40% of our total energy use

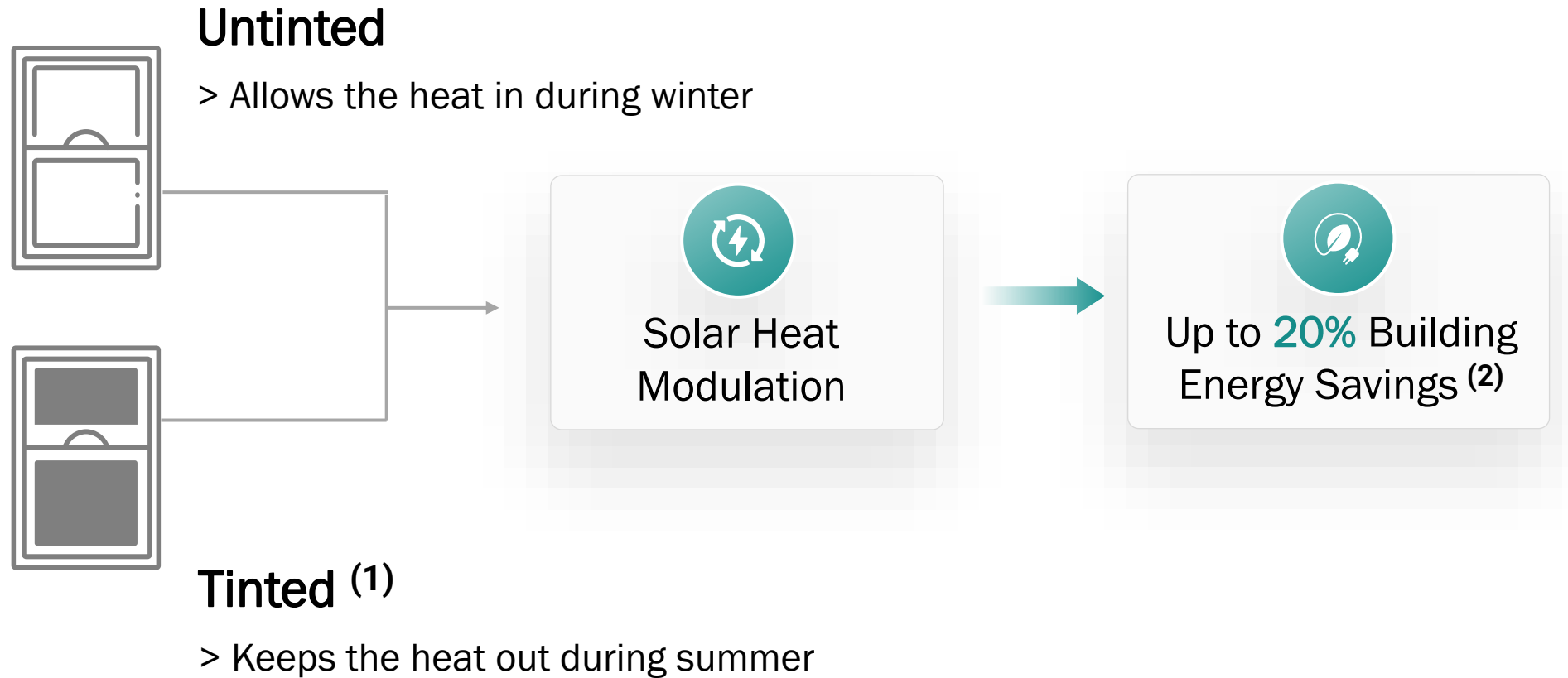
- 35% of our carbon emissions

Windows influence up to 50% of building energy use

- Heating
- Cooling
- Lighting

Solution: Dynamic glass can modulate solar heat > 50%

Dynamic glass tints and untints upon application of an electric charge

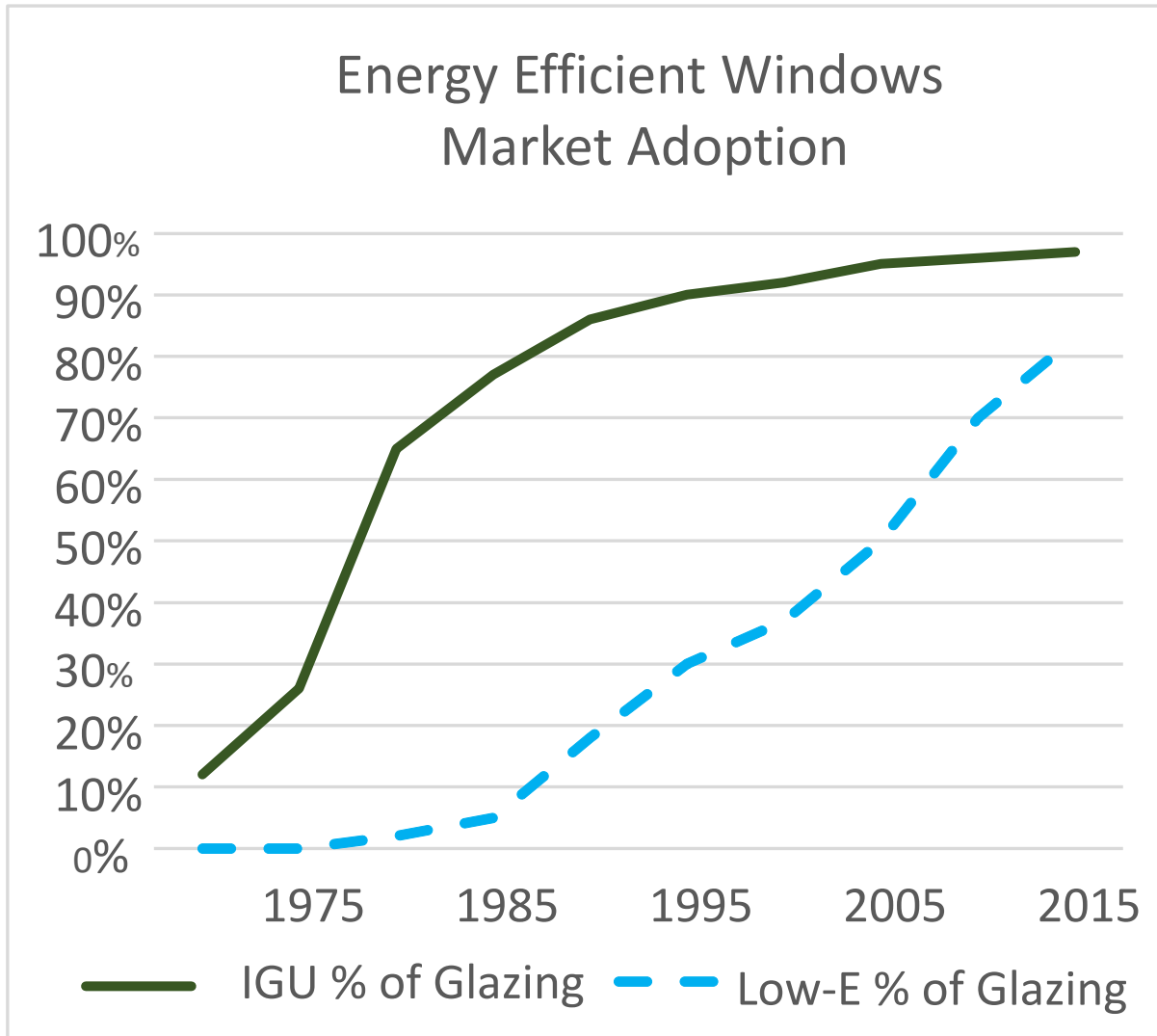


(1) Intermediate tint states available

(2) U.S. Department of Energy, Pathway to Zero Energy Windows. April 2022

Energy Efficient Glass Market: Proven climate impact & adoption

Energy Efficient Windows
Market Adoption



2B sqft/yr low-e glass sales¹:

- Static, energy efficient low emissivity glass (“Low-E”) R&D began in the mid-1970’s in response to the 1973 oil embargo
- 50% commercial / 50% residential
- 50% new build / 50% remodel
- Contributed to 40% building energy reduction

(1) Ducker Frontier Market Research Report ‘22

Existing Dynamic Glass Solutions: Metal oxide systems

Three companies have commercialized dynamic architectural windows:



- 99% visible light blockage
 - Up to 100,000+ cycles with minimal degradation
 - Passed ASTM E2141
-
- **Challenge: Demonstrating economics suitable for mass adoption**

Existing Dynamic Glass Solutions: Dye systems

Two companies have commercialized dynamic mirrors and aircraft windows:



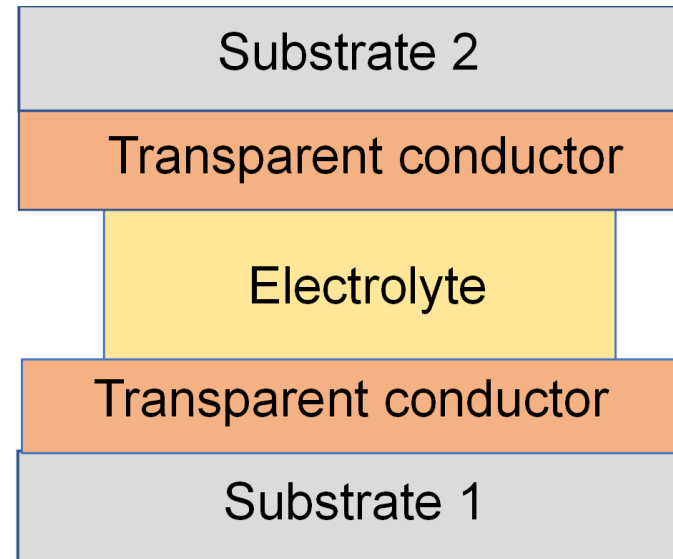
- 99.99% visible light blockage¹
 - 500,000 cycles with minimal degradation²
 - Robust economics and scalability: 40M products sold annually, 30% EBITDA margins
-
- **Challenge: Demonstrating durability to ASTM E2141 standard**

1. [*https://www.mobilityengineeringtech.com/component/content/article/adt/pub/features/articles/27502](https://www.mobilityengineeringtech.com/component/content/article/adt/pub/features/articles/27502)

2. Data generated by AJJER LLC

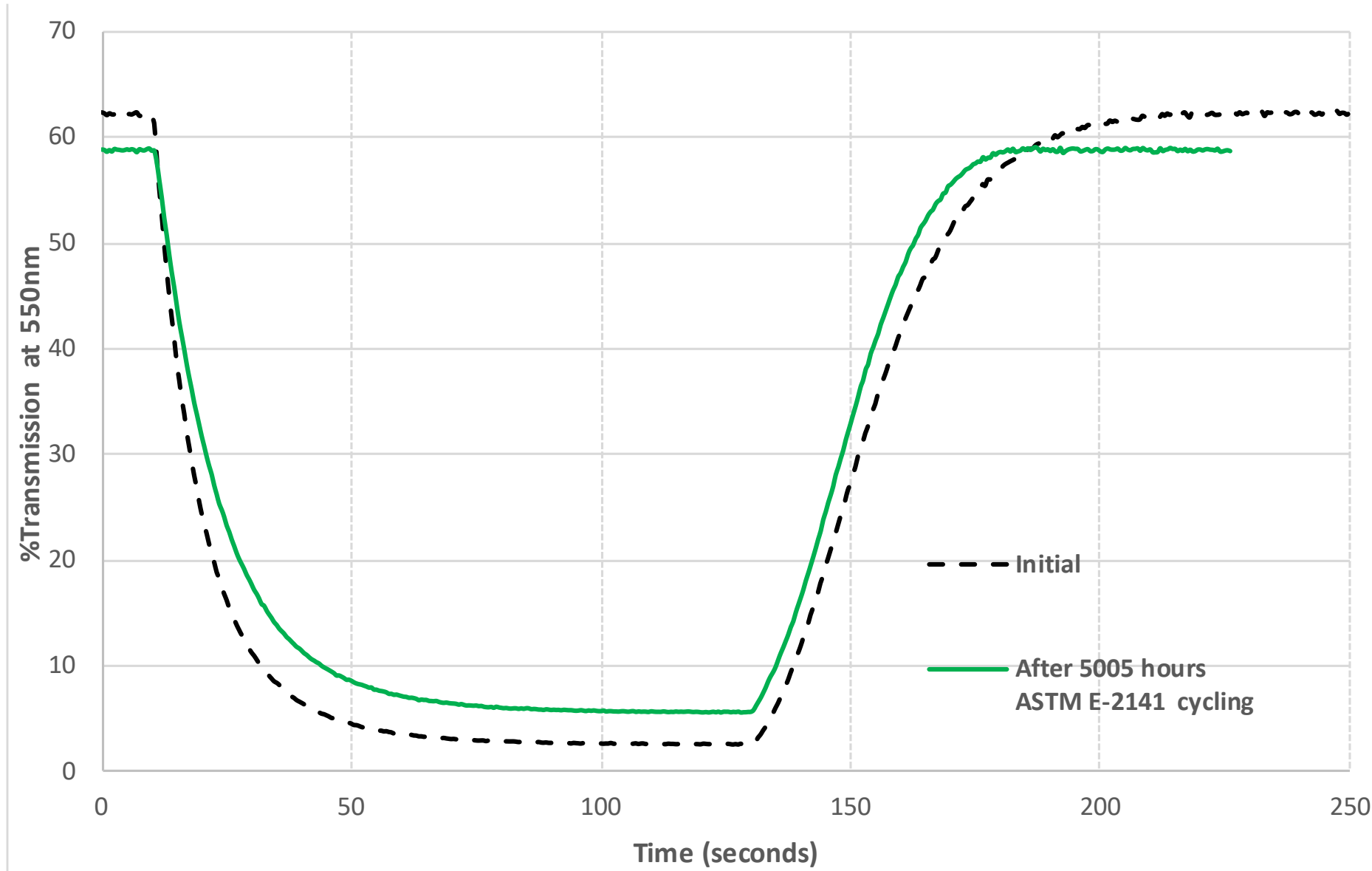
Glass Dyenamics Solution: Dye systems that can pass ASTM

Glass Dyenamics collaborated with the DOE to develop UV-durable organic dye-based EC technology (BENEFIT 2018)



- Emphasis placed on low toxicity electrolytic materials and device recyclability
- Multilayer “Transparent Conductor” solutions avoided to keep attractive economics
- Size scalability addressed by modifying electrolytic properties

BENEFIT 2018 Results: 150k Cycles under ASTM E2141 conditions



- Tests on 13 x 9cm² EC cells

Glass Dynamics Confidential

Glass before and after 150,150 cycles, 5005 hours (ASTM E2141)



Glass Dynamics Solution: UV-stable Dyes

Projections show that BENEFIT 2018 program success can lead to favorable product economics:

1. 90% /sqft capex reduction
2. 75% /sqft COGS reduction
3. Custom colors with NIR blockage without changing the manufacturing process.

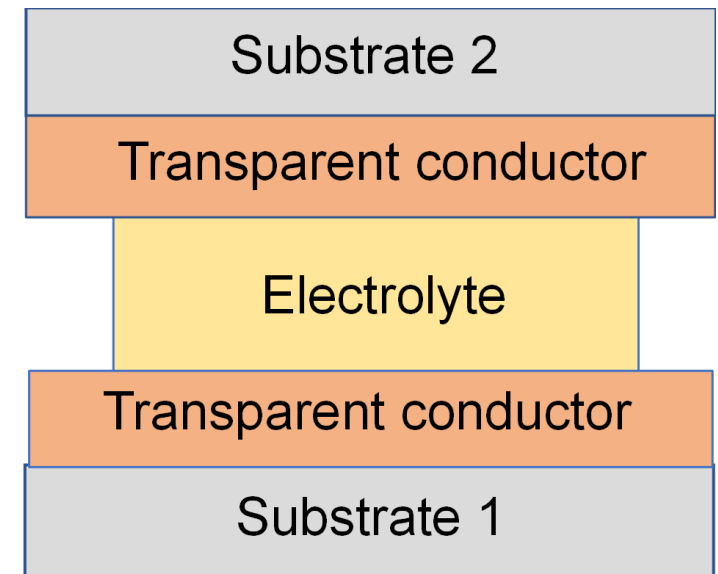


Current Program w/NREL Color & Manufacturing Optimization

The objective of the current program is to increase commercial viability of the products developed under BENEFIT 2018:

Two objectives:

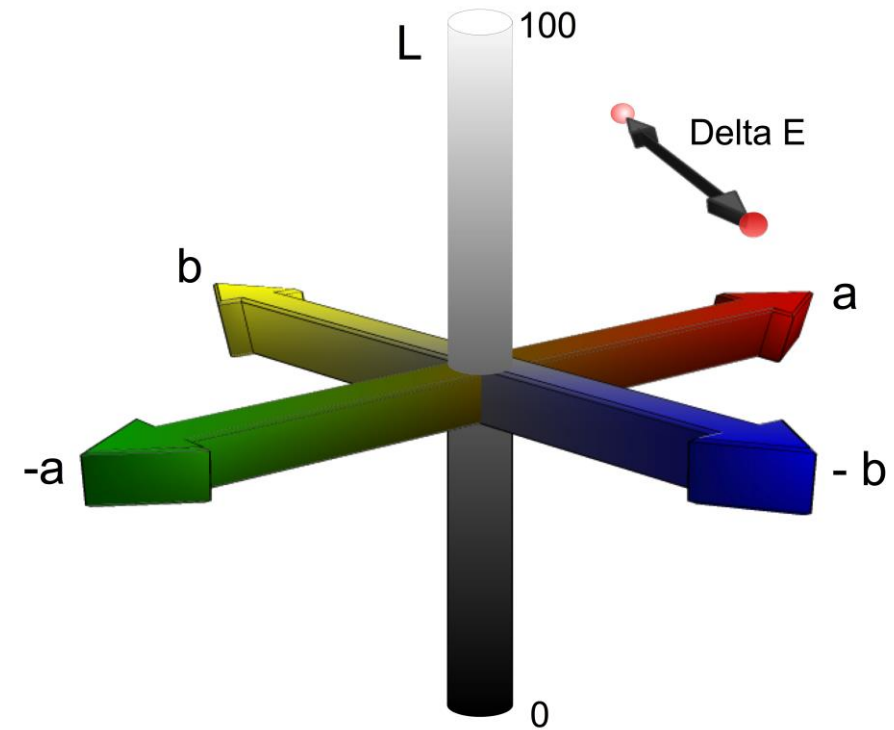
1. Increased product marketability with neutral color dyes, and
2. Increase manufacturing readiness, eliminate hydrostatic pressure with solid electrolyte chemistry



For each development to demonstrate cyclic durability
at 90C for 2,000 to 5,000 times and
Submit cells to NREL for ASTM E2141 testing

Objective 1: Neutral Color

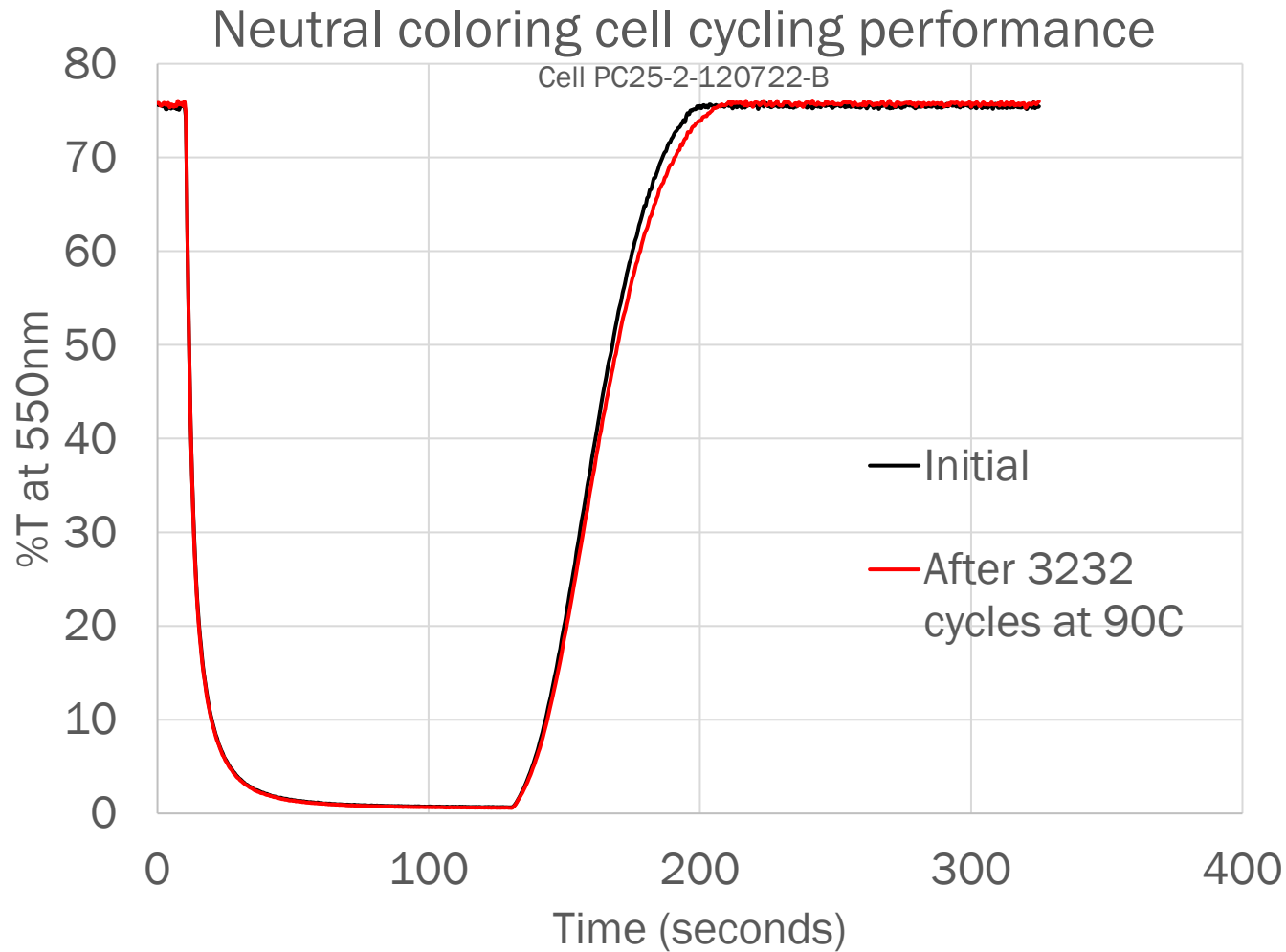
- Demonstrate devices that color to a more neutral color characterized by $c^* < 15$
- Demonstrate preliminary durability by cycling the devices at 90C between 2000 and 5000 cycles



$$c^* = \sqrt{a^2 + b^2}$$

Large value of c^* represents increasing blue, red, green or a yellow color

Objective 1 Results Achieved: Neutral Color



c* (bleached)

Initial	14.6
After cycling	14.8



c* (colored)

Initial	13.8
After cycling	12.1

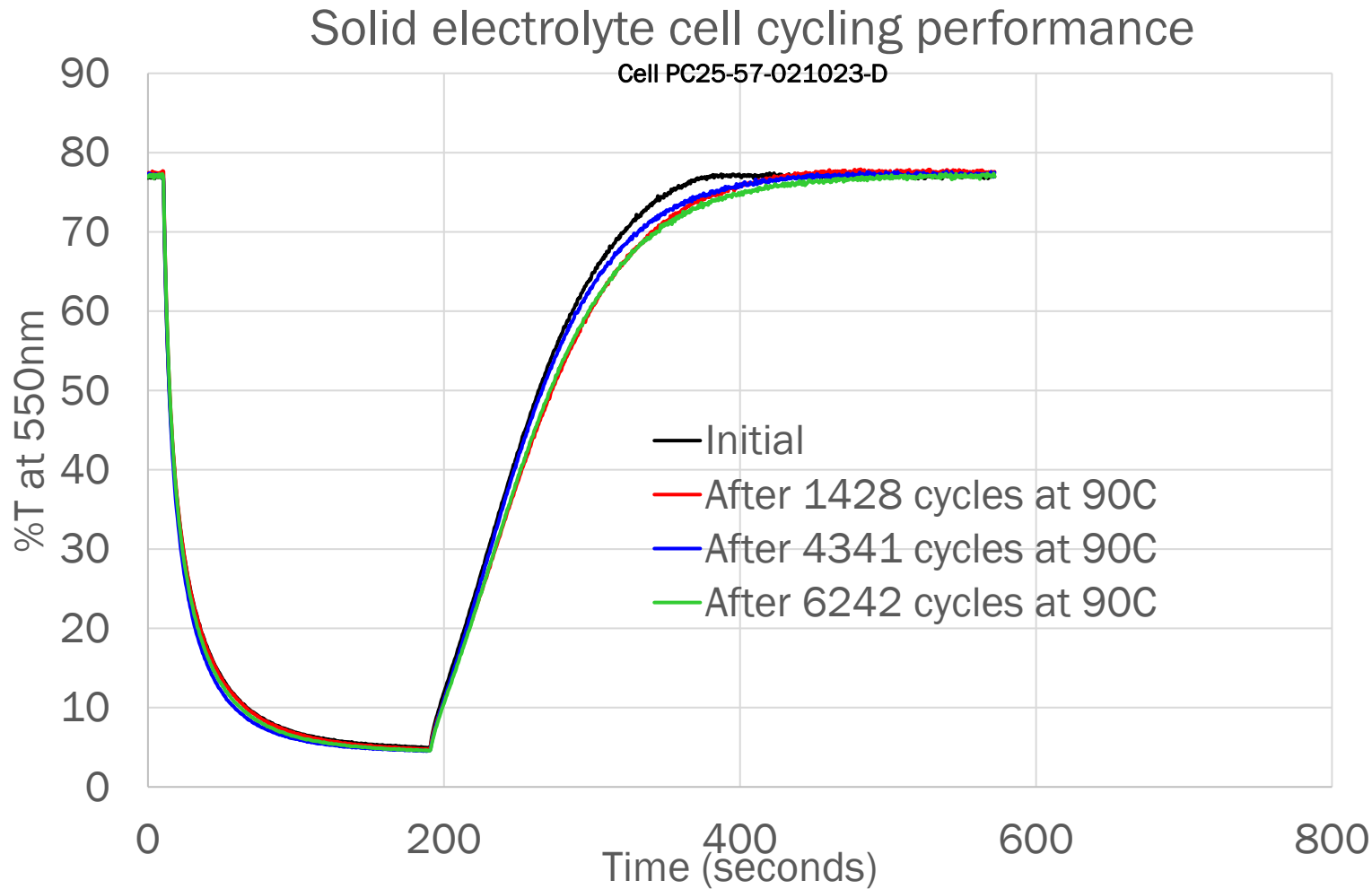
Cells have been submitted to NREL for ASTM Testing

Remaining Task: Final Report

Objective 2: Solid Electrolyte

- Demonstrate devices where the electrolyte is solid, rather than a liquid or a viscous liquid
- Demonstrate preliminary durability by cycling the devices at 90C for 2,000 and 5,000 cycles

Objective 2 Results Achieved: Solid Electrolyte



Remaining Task: Final Report



Cells have been submitted to NREL for ASTM Testing

Progress & Future Work

We have met both the program's major milestones

These devices will be cycled at NREL for 250-1,000 hours of exposure, to measure performance gap if any

Remaining program tasks:

Final Technical Report

Technical plans beyond the Project focus

Preparation for commercial scaleup in the next 12 months

Emerging superior low-cost product in the dynamic glass industry

Installation



GLASS DYNAMICS

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Thank You

Performing Organization(s): Glass Dyenamics Inc dba Glass Dyenamics

PI Name and Title: Anoop Agrawal, CTO

PI Tel and/or Email: 520 230 2140, anoop@dyenamics.com

Project # NREL SUB-2022-10374

Project Execution

	2022-23			
Planned Budget	\$ 381,000			
Spent Budget	\$ 348,014	91%		
Past Work	Q1	Q2	Q3	Q4
Milestone 1: Report on cycling performance of solid electrolyte devices at 90C			◆	
Milestone 2: Report on cycling performance of neutral coloring devices at 90C		◆		
Current and future work				
Submission of devices to NREL for testing			◆	
Final Report			◆	