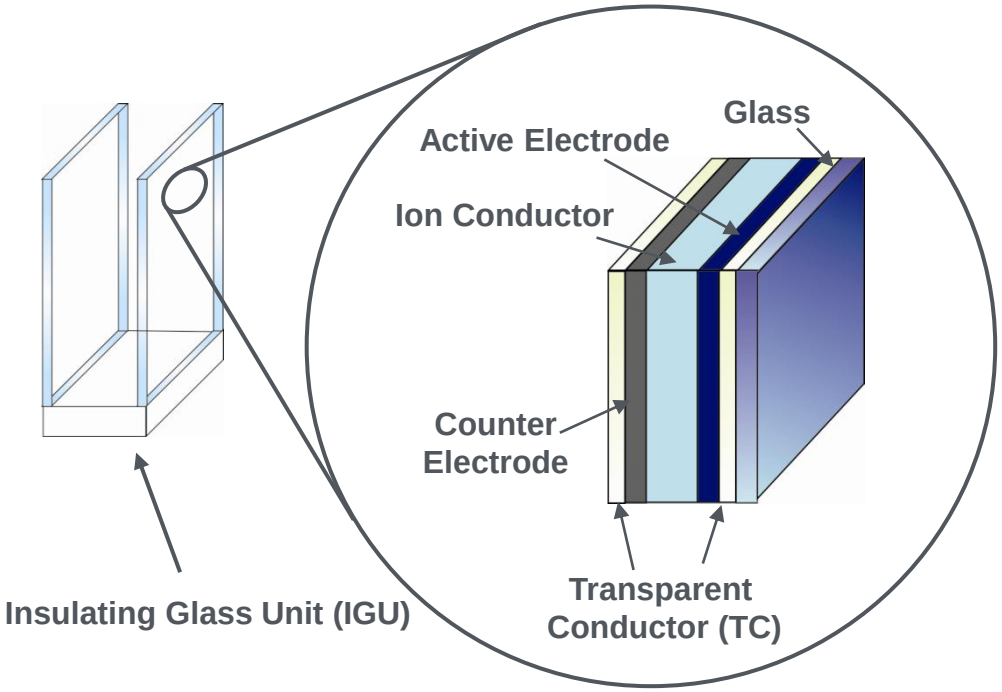
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Atmospheric Pressure Deposition for Electrochromic Windows

TDM – Karma Sawyer

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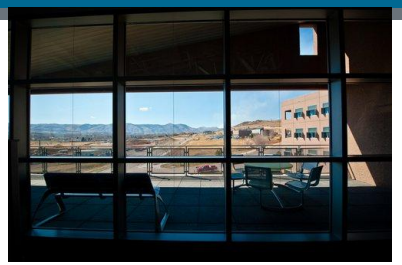
4/4/2013

Purpose and Objectives

Key Issues Limiting Electrochromic Windows

- Expense
  - Current market price of $50-$100/ft^2
  - Projections indicate under $20/ft^2 needed
  - A new production paradigm is required
- Aesthetics
  - Architects hesitant to adopt “smurf glass”
  - Switching speeds and uniformity
  - Improved materials must be developed
- Durability
  - New technologies must meet expected product lifetime of already existing systems
  - Valid and unbiased durability testing methods must be developed

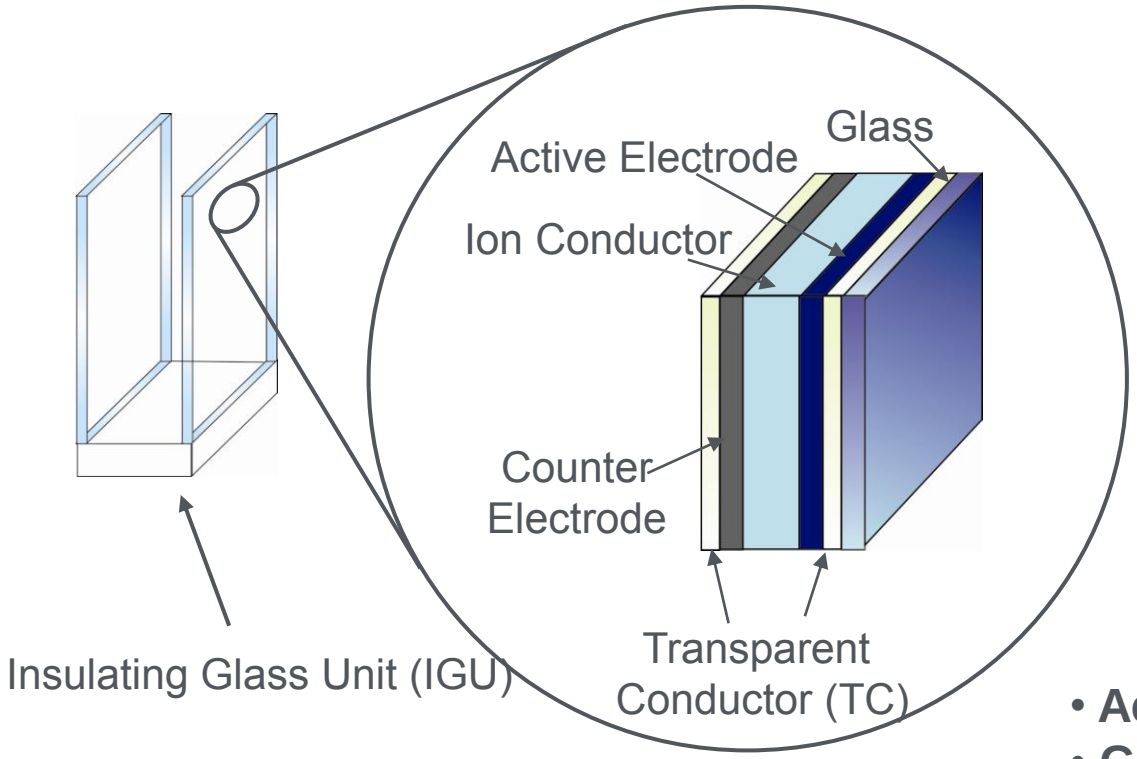


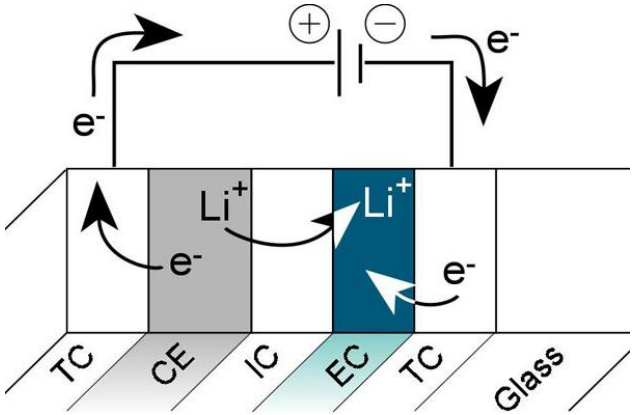
Purpose and Objectives (cont)

The NREL dynamic windows program seeks to address the key issues limiting large scale adoption of electrochromic windows in three ways:

- Low Cost Manufacturing Process Development
- Improved Performance for Existing EC Technologies
- Independent Third Party Validation of Electrochromic Window Performance

Background: Electrochromic Dynamic Windows Materials





- **Active Electrode Material: WO_3**
- **Counter Electrode Material: NiO**

Electrochromic windows act similarly to lithium ion batteries, but change color when charged and discharged.

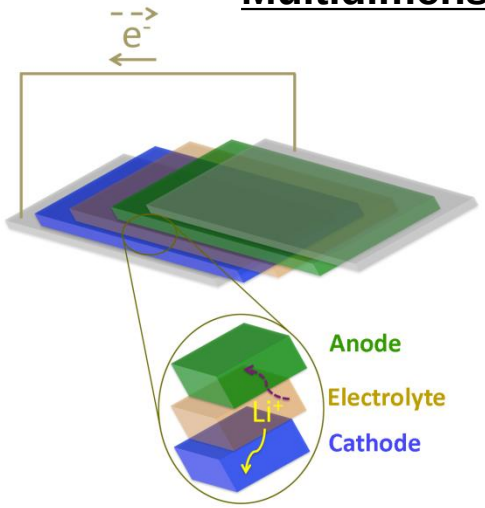
Approach: Improved Performance Electrochromic Materials (CRADA)

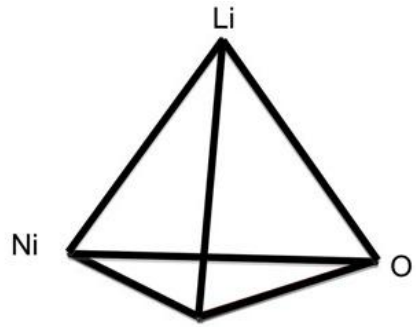
Our research strategy seeks to improve the relatively poor performance of the counter electrode

Goals:

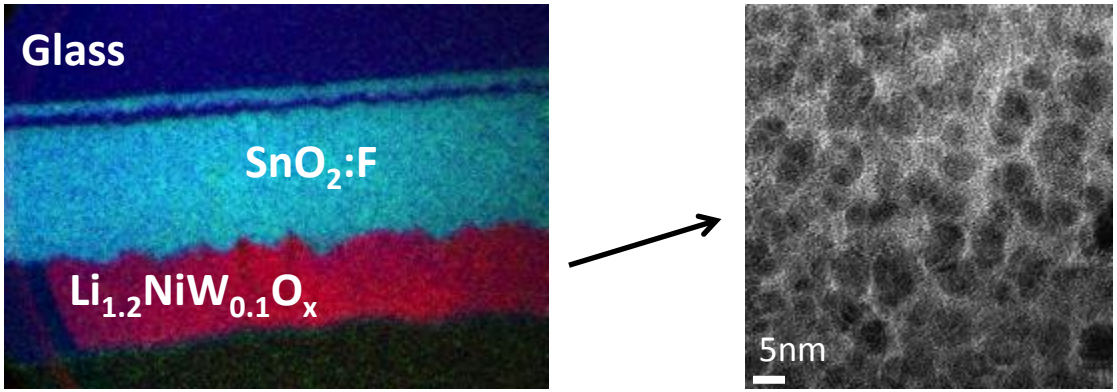
- Improve visual appearance
- Increase switching kinetics
- Increase device efficiency and durability to simultaneously improve energy and cost savings

Multidimensional Process Space





Nanocomposite Counter Electrodes



Gillaspie, D.; et al. *J. Electrochem. Soc.* **157**, *3*, H328-H331 (2010).

Accomplishments: Transfer of Improved Materials to Sage EC

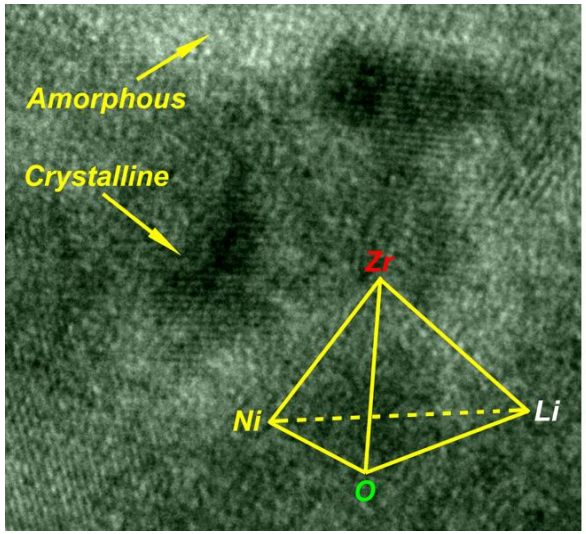
SAGE™

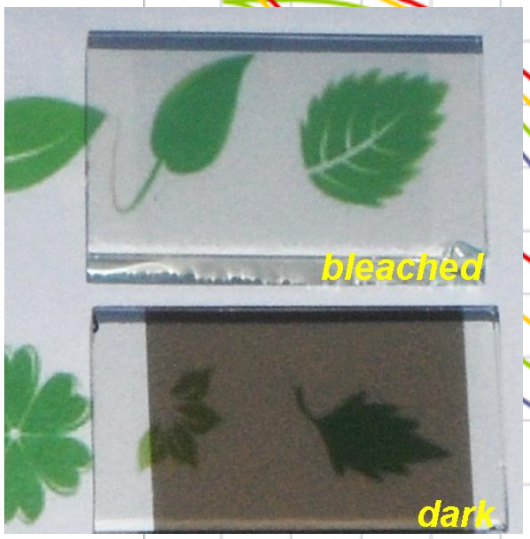
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Superior electrochromic performance (bleached state transparency, optical modulation, durability, switching speed) developed by NREL successfully verified by Sage Electrochromics

Patent applications submitted and licensing process initiated

$Li_{2.34}NiZr_{0.28}O_x$

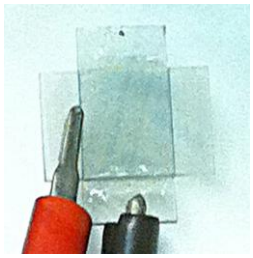


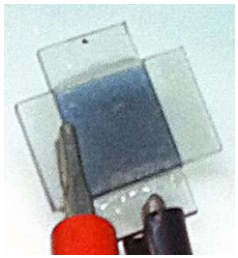


Improved NREL film deposited on Sage Glass (ITO)

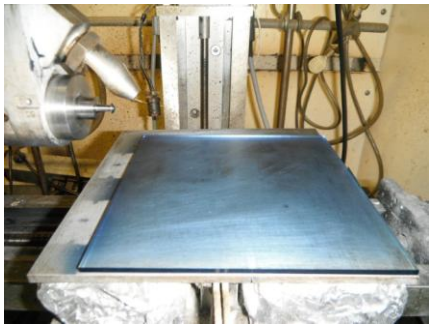
Approach: Low Cost EC Processing

Complete Device Fabrication





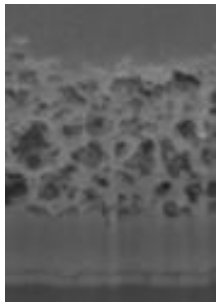
Ultrasonic Spray Deposition



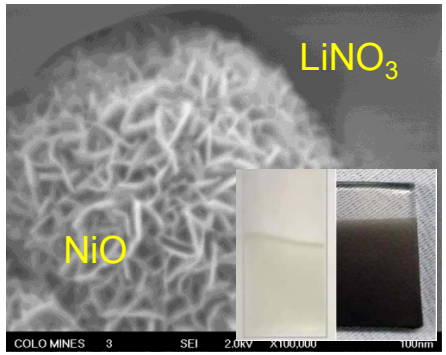
EC Lamination Process

- TCO-Coated Glass
- $NiO/LiNO_3$ Counter Electrode
- PVB Based Polymer Ion Conductor Layer
- Tungsten Oxide Active Electrode
- TCO-Coated Glass

Tungsten Oxide Active Electrode



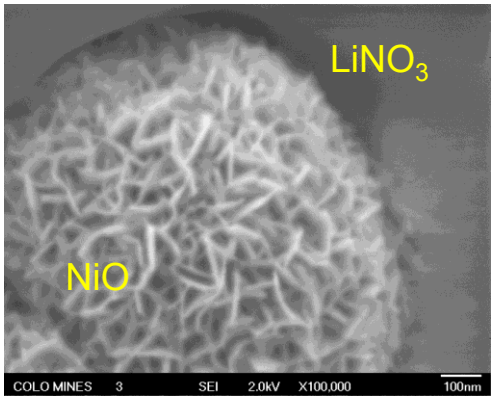
Nickel Oxide Counter Electrode



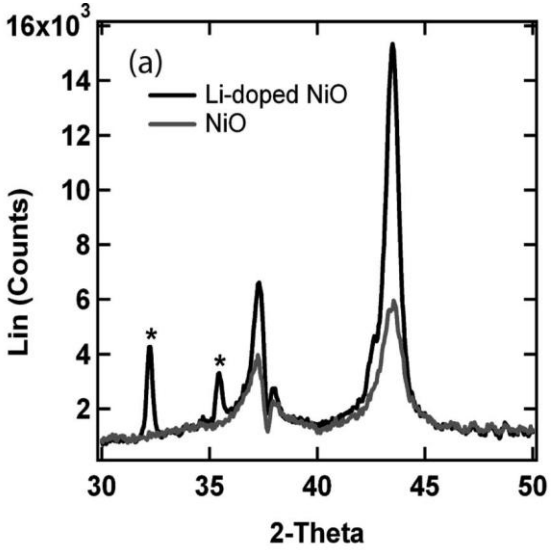
Accomplishment: Nickel Oxide Counter Electrode

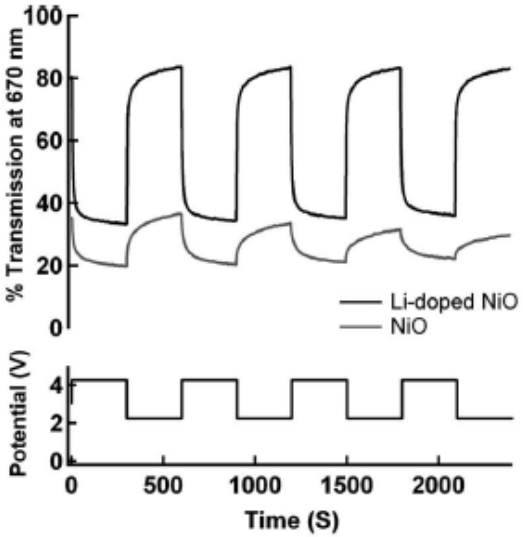
Key Innovation: Li Doping

- Aqueous Solutions of $Ni(NO_3)_2$: 0.1 – 1 M
- Substrate Temperature: 350 °C
- Add $LiNO_3$: 1 – 5 wt%



Electrochemical Performance: Dramatic Improvement

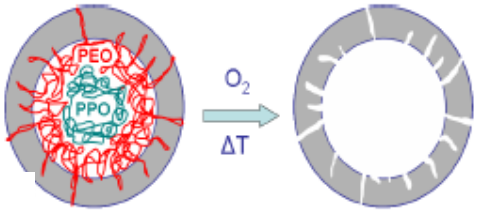




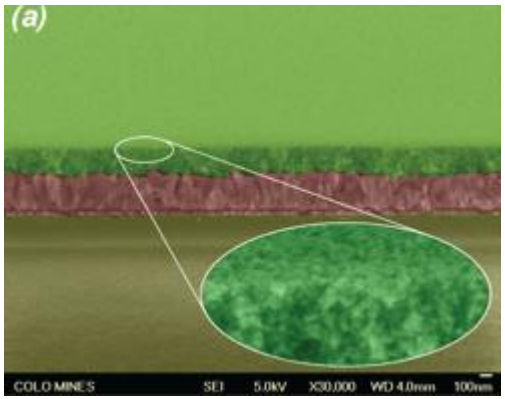
Tenent et al, *J. Electrochem. Soc.* **157**, H318 (2010)

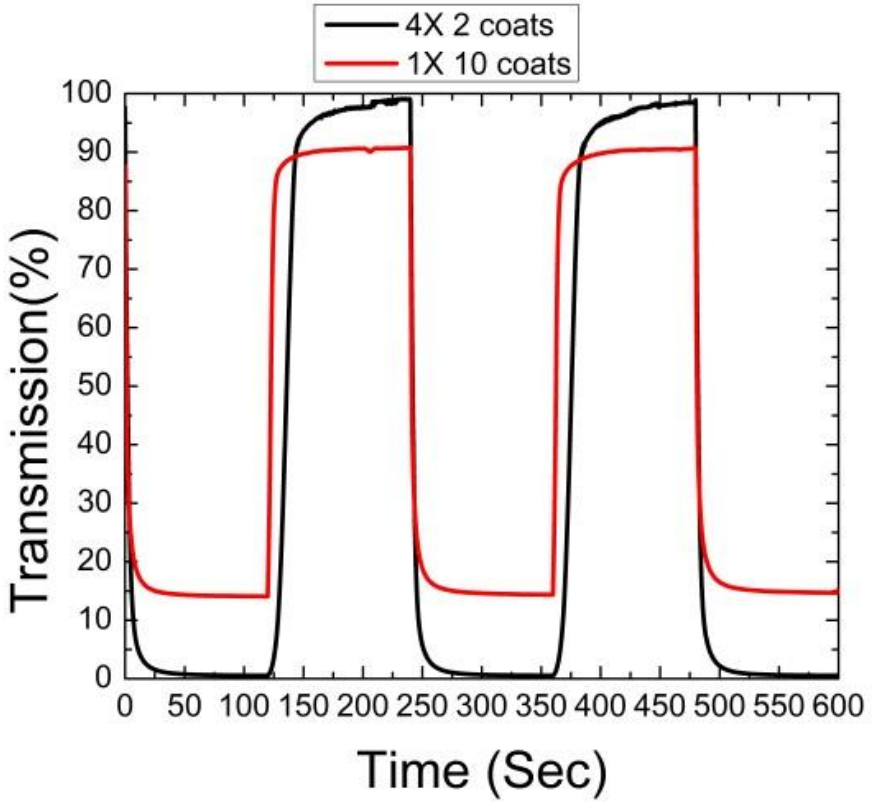
Accomplishment: Improved Performance for Tungsten Oxide

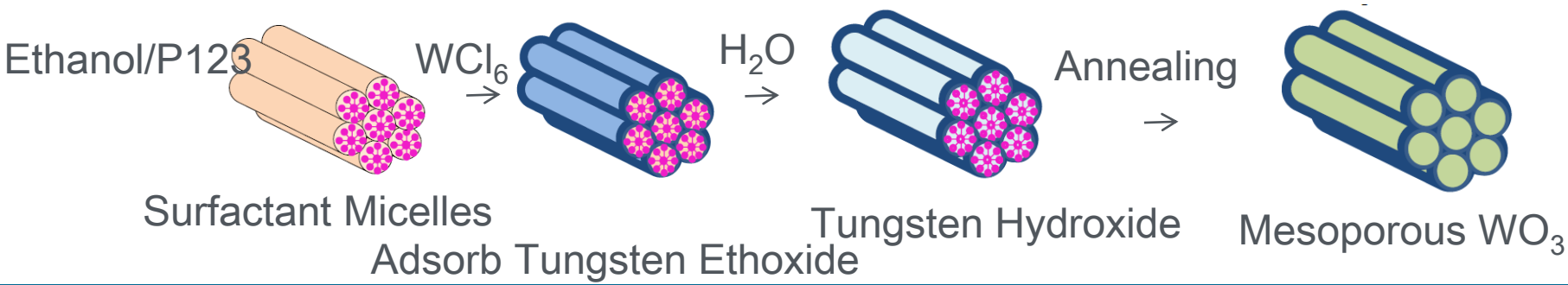
Triblock copolymer : P123



$HO(CH_2CH_2O)_{20}(CH_2CH(CH_3)O)_{70}(CH_2CH_2O)_{20}H$



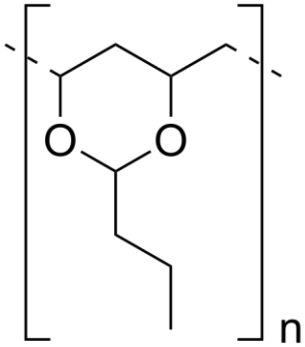




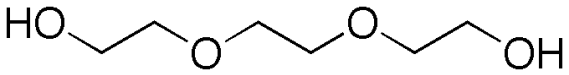
Progress on Goals: Lamination Process for EC Devices

Optically clear and mechanically stable films of PVB, plasticizer and lithium salt have been cast from ethanol

Polyvinyl Butyral



Triethylene Glycol



$LiClO_4$

Initial impedance testing follows expected trends for plasticizer loading, resin molecular weight and treatment temperature.

Lamination conditions studies are currently underway

Project Plan & Schedule

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Project Initiation Date(s):
Varying depending on project; Multiple on-going efforts in support of emerging electrochromic industry.

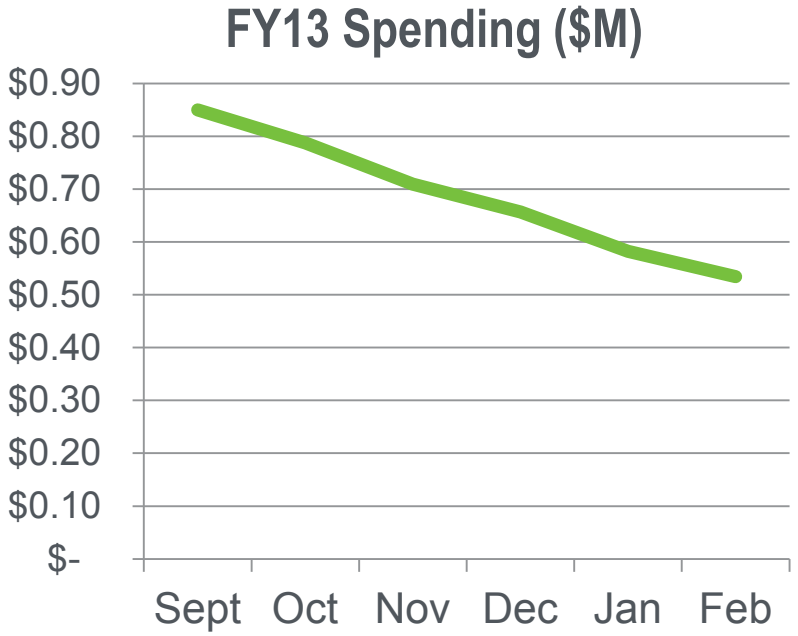
Planned Completion Dates: TBD
All current dynamic window AOP milestones are in progress and on schedule

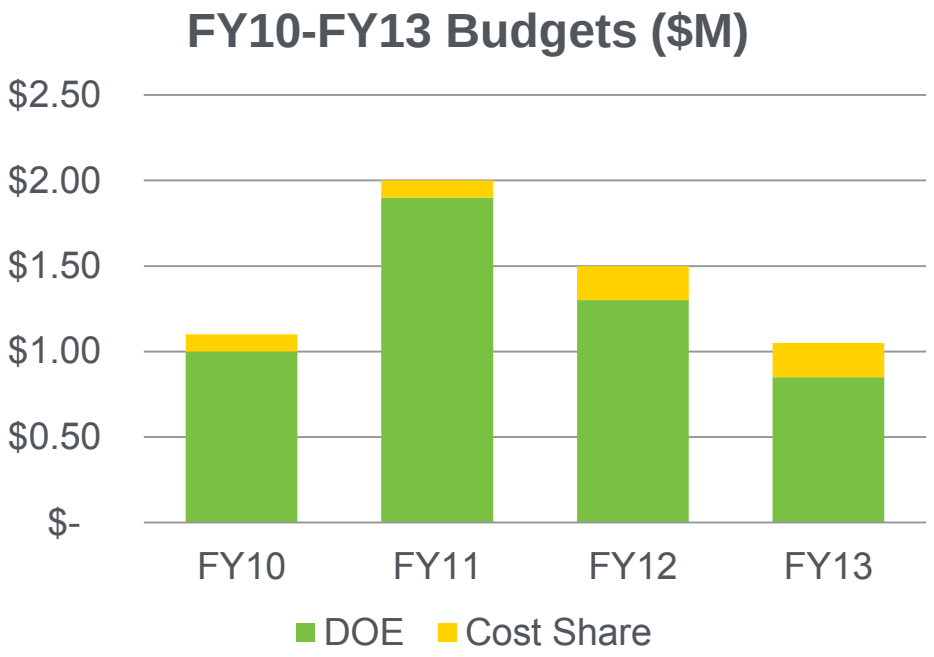
Summary	
WBS Number or Agreement Number	
Project Number	
Agreement Number	

Legend	
	Work completed
	Active Task
	Milestones & Deliverables (Original Plan)
	Milestones & Deliverables (Actual)

Task / Event	FY2012				FY2013				FY2014			
	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)	Q1 (Octt-Dec)	Q2 (Jan-Mar)	Q3 (Apr-Jun)	Q4 (Jul-Sep)
Project Name: Dynamic Glazing Technologies: Low-Cost Process Development												
FY12-Q4 Milestone: Complete Study of Doped NiO Counter Electrode Materials				◆								
FY12-Q2 Milestone: Synthesize VO2 Nanoparticles and Charcaterize Performance			◆									
FY12-Q4 Milestone: Demonstration Liquid Phase Spray for WO3 at 6" by 6"				◆								
Current work and future research												
Work with Sage Electrochromics to Transfer New NREL CE Technology												
Development of a Laminated EC Device for Preliminary Durability Testing							◆					

Project Budget





Additional Funding Sources:

SAGE™

US –e-Chromic

NREL Technology Transfer Office

Renewable Energy Materials Research Science and Engineering Center
REMRSEC

Project Integration, Collaboration & Market Impact

Partners, Subcontractors, and Collaborators:

- **Neil Sbar, Doug Weir, Jean-Christophe Giron**, Sage Electrochromics
- **Loren Burnett and Judith McFadden,** US e-Chromic
- **Chi-Ping Li, Feng Lin, Ryan Richards and Colin Wolden**, CSM
- **David Alie and Sean Shaheen**, University of Denver
- **Richard McCurdy,** McCurdy and Associates, Float Glass Processing Consultant
- **Alan Goodrich**, NREL Strategic Analysis Center, Cost Modeling
- **Rob Moore, Dennis Nordlund, Tsu-Chien Weng**, SLAC National Accelerator Laboratory

Technology Transfer, Deployment, Market Impact:

- Two patent applications filed; licensing agreement with Sage Electrochromics progressing
- Technical support provided to US e-Chromic (CRADA)

Communications:

- Six peer reviewed publications in high impact scientific journals
- Participation in scientific and trade organizations
  - ASTM, GANA, IGMA, Materials Research Society

Next Steps and Future Plans

Next Steps and Future Plans:

- Continue supporting efforts to transfer NREL developed LiNiZrO counter electrode into Sage manufacturing processes.
- Complete development of prototype laminated EC device structure.
- Develop external partnership agreement for low cost processing of EC materials.
- Continue to provide and expand testing services for next generation fenestration technologies (highly insulating architectures).

Acknowledgements

- Dr Karma Sawyer and Dr Patrick Phelan for funding from the U.S. Department of Energy (DOE) under subcontract number DE-AC36-08GO28308 through the DOE Office of Energy Efficiency and Renewable Energy, Office of Building Technologies Program

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