Durability of Ultra Barrier Solar Films for Flexible PV Applications

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3M

Outline

- Flexible Solar Modules & Barrier Needs
- Flexible WVTR Requirements
  - Performance & Measurements
- Reliability Testing Ultra Barrier Films
  - Framework for 25 years
  - Test results to date
- Summary

Advantages of Flexible Solar Modules

Light weight →1/8th compared with glass-on-glass

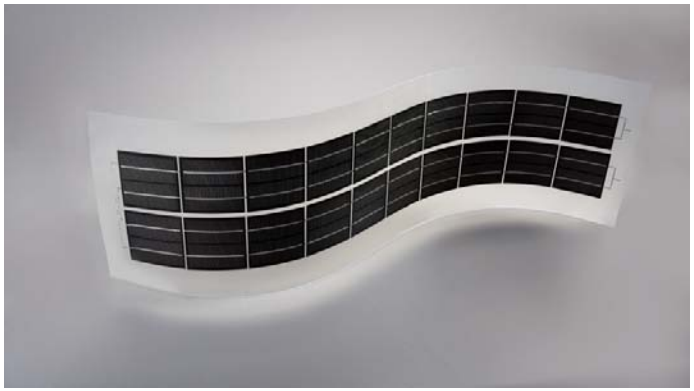
Lower Balance of System costs → less labor and no mechanical racking

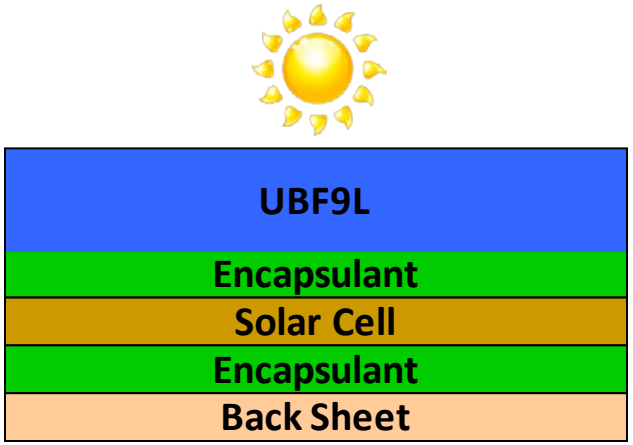
Higher packing density → Significantly more kW per shipping container

Higher energy output → Better transmission and off-angle performance

Large area modules → Lower relative “fixed” module costs

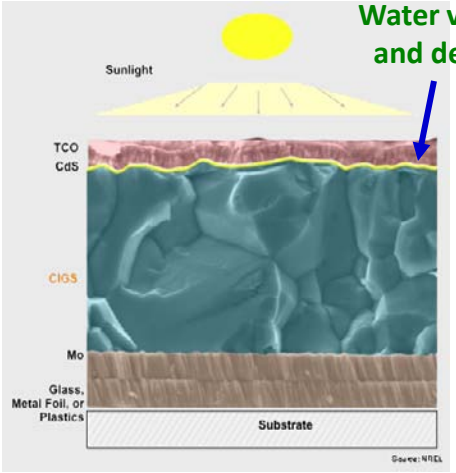
Lower manufacturing cost → Fully automated roll to roll processing





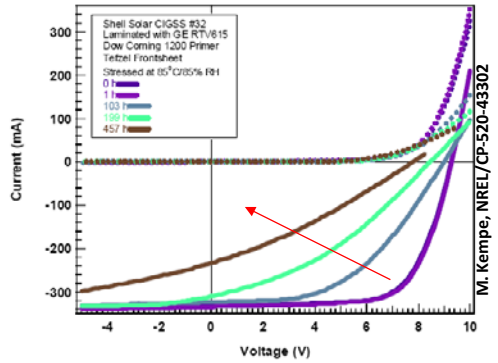
Thin Film Solar Barrier Needs

Failure Mode & CIGS Degradation Modeling



Degradation in Efficiency in CIGS

Exposure to Water (85%RH & 85°C)



CIGS Lifetime Model for Free Standing and Roof Mounted Modules , Time to 20% loss in Pmax

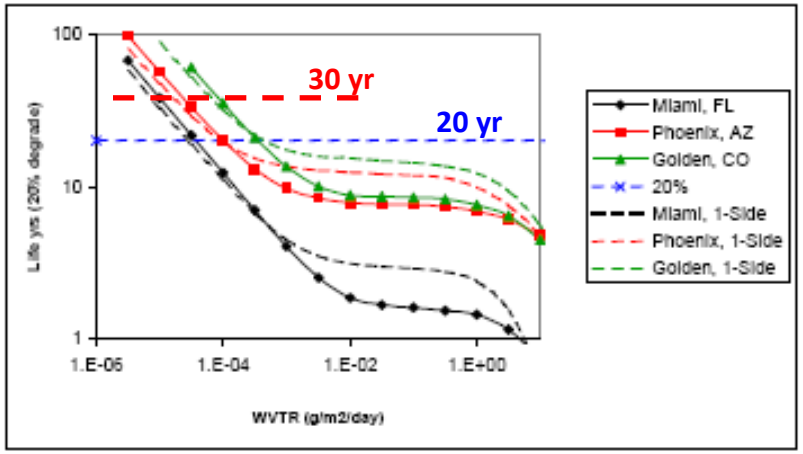


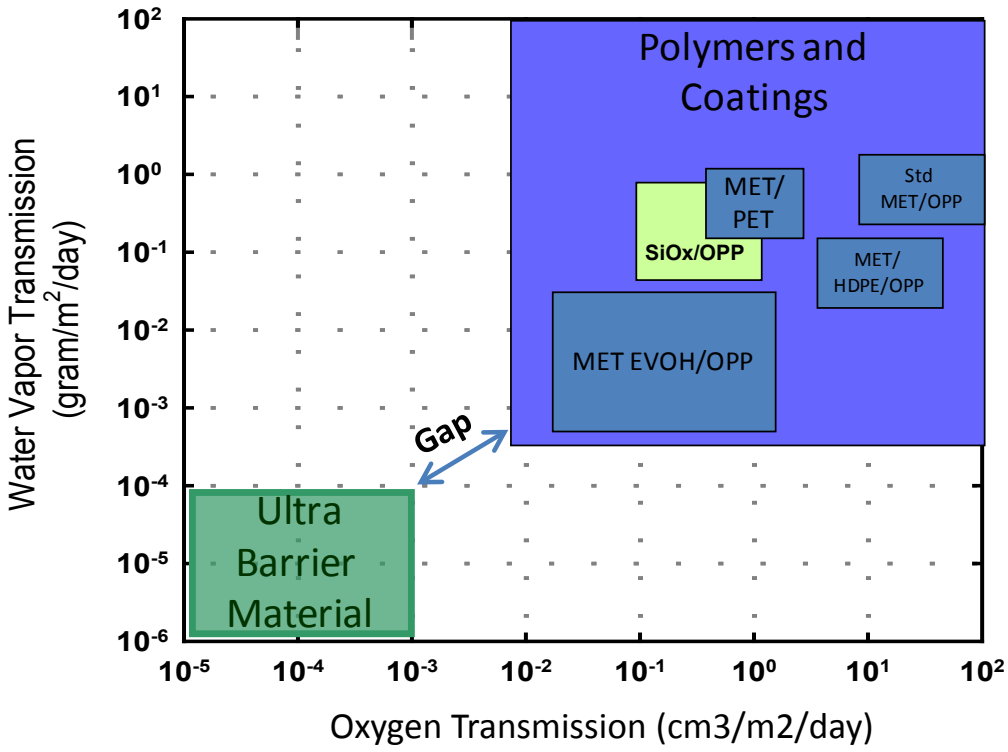
Figure 8. Module life for 2-side cooled (with symbols) and 1-side insulated (dashed) modules.

D.J. Coyle, etal , 2009 34th IEEE, pg. 001943 (2009)

***Ultra*-Barrier Requirements: 10^{-6} to 10^{-4} g/m^{2}day for 25 year**

Ultra Barrier Films

- Ultrabarrier technology in development for over a decade
- Proprietary vacuum roll-to-roll process
  - Over 50 applications and 20 granted patents
- Challenge to actually measure < 10^{-3}g/m^{2}day



Ultra Barrier Film WVTR Measurement

Methods Overview

Scavenger Methods (Indirect)

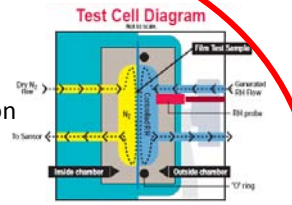
Detection Level g/m²day

Permeation Cell (Direct)

Gravametric:
(ASTM E96) 1 to 1000g/m²day

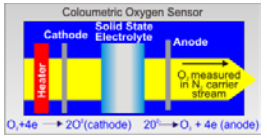
1

Mocon



Permatran: IR detection

Aquatran: Coloumbic detection



Ultra-Barrier Below this line

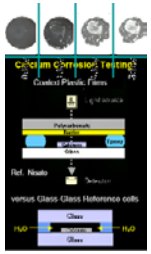
0.001

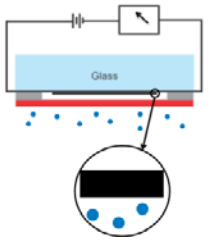
Calcium Test

$Ca + H_2O \rightarrow CaO + H_2$

$Ca + 2H_2O \rightarrow Ca(OH)_2 + H_2$

Optical Density

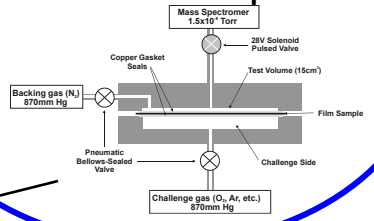




NREL Electrical Conductivity

Flex Solar

Mass Spec Under Development



HTO: Radioactivity

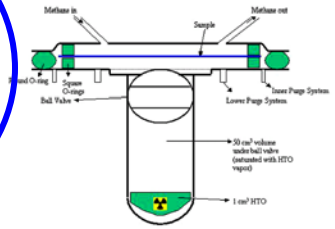


FIGURE 1 — Cross-section of the radioactive tracer test.

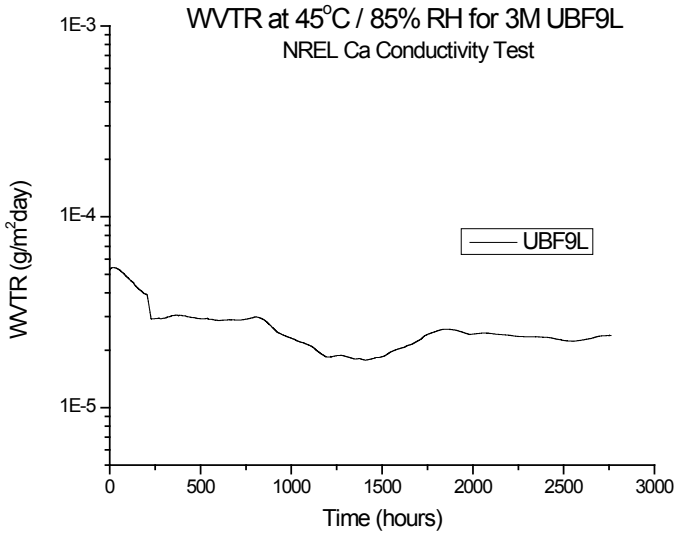
0.000001

WVTR Measurements

Initial WVTR Performance of UBF9L by various Methods

Method	Detection Limit (g/m^2day)	Temperature (^oC)/RH(%)	UBF9L (g/m^2day)
MOCON Permatran	0.005	50/100	<0.005
MOCON Aquatran	0.0005	50/100	<0.0005
NREL Ca Test	10^{-6}	45/85	$5\pm3 \times 10^{-5}$

NREL Electrical Ca WVTR Test*



*Michael Kempe, Arrelaine Dameron, and Matthew Reese, "NREL Electrical Ca WVTR Test", *manuscript in preparation, 2011*.

- UBF9L still holding after 2750hr
- Variable temperature
- Size: 5cm2 to 50cm2
- Multiplexing for through-put
- Supported by NREL/3M CRADA CRD-08-293

Reliability Testing of Ultrabarriers

Key performance and safety properties need to be retained for 25+ years

- WVTR—one of a few key properties for flex solar
- Other key performance properties
  - Percent transmission—high output
  - Mechanical strength—robust module
- Key safety factors
  - Component & Module partial discharge
- Reliability and lifetime testing program needs to include all of these

Reliability Testing of Ultrabarriers

3 Weathering Resource Center

Historical products

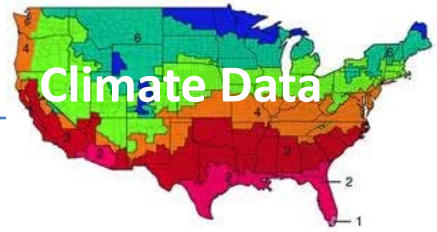
Less direct sun exposure, shorter lifetimes

Products for Solar

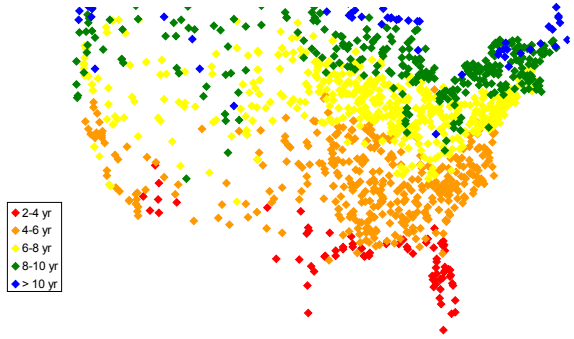
More direct sunlight, longer lifetimes, under electrical load

Technabob.com

Mathematical models



Product Lifetimes



Successfully Used in Numerous Products

Reliability Testing of Ultrabarriers

3M Weathering Testing Plan for 25 year Lifetime

Natural Outdoor Exposure

Multiple Locations and Environments

Static Racks (5° or latitude w/ backing)

Accelerated Outdoor Exposure

2x to 5x UV range acceleration

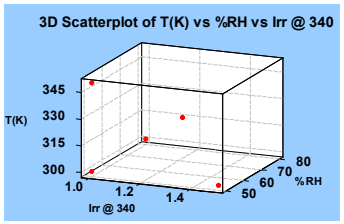
Mirrored Enclosure

G90-type

Large area G90-type

Accelerated Indoor Exposure & Lifetime Modeling

Controlled
- Irradiance
- %RH
- Temperature



SWAT Exposure

Sequential **W**eathering **A**ccelerated **T**est

Accelerated Outdoor

+ Damp Heat
+ Humidity Freeze
+ …

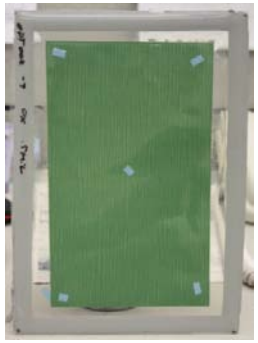
Reliability Testing of Ultrabarriers

UBF9L Film and Module Testing Plan

Multiple Testing Modes
for 25 Year

Film Performance

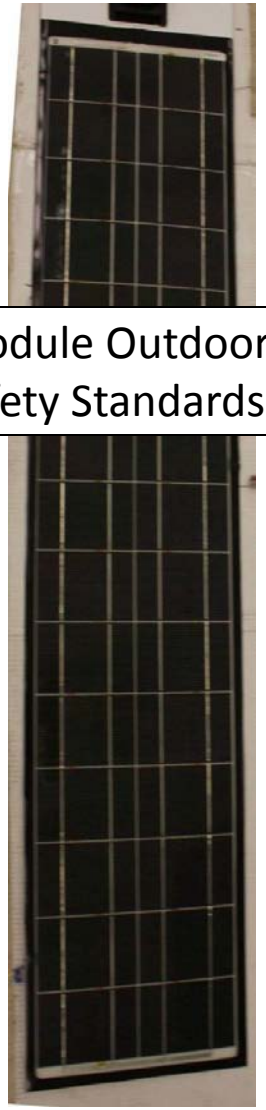
WVTR <10^{-4}g/m^{2}day
T>90%
Mechanical



Mini Module Performance

Solar module output
Controlled environments

Full Module Outdoor UL Safety Standards



Reporting on UBF9L initial results

Reliability Testing of Ultrabarriers

Preliminary Accelerated Indoor Testing Baseline

Weathering Cycle Information		
Cycle	Light Source	Cycle
Damp Heat (DH)	n/a	n/a
Full Spectrum Dry	Xe-arc	ASTM G155 (mod)
Full Spectrum Wet	Xe-arc	ASTM G155 (mod)
UV Spectrum Wet	UV fluorescent	ASTM G154 (mod)

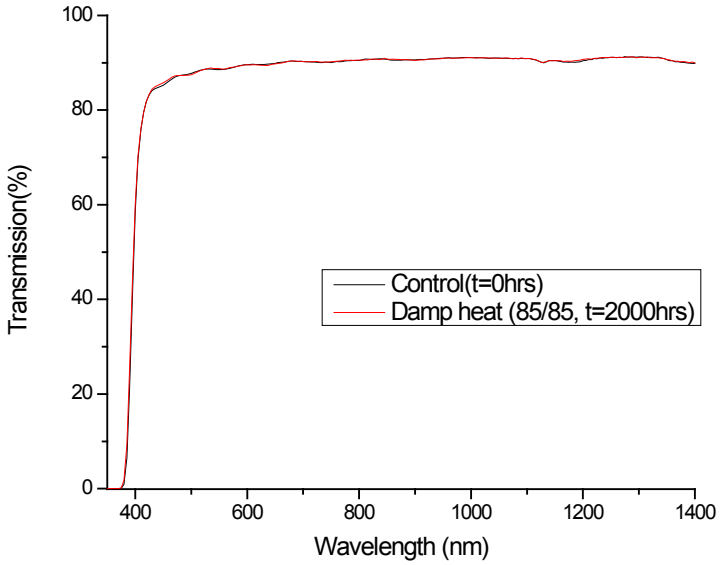
- Test results so far
  - WVTR and Optical Transmission

Damp Heat (85ºC/85%RH)

WVTR and Optical Transmission Results

Permatran measurements

Time in Damp Heat (hrs)	WVTR (50C/100%RH) (g/m2day)
0	<0.005
1000	<0.005
2000	<0.005



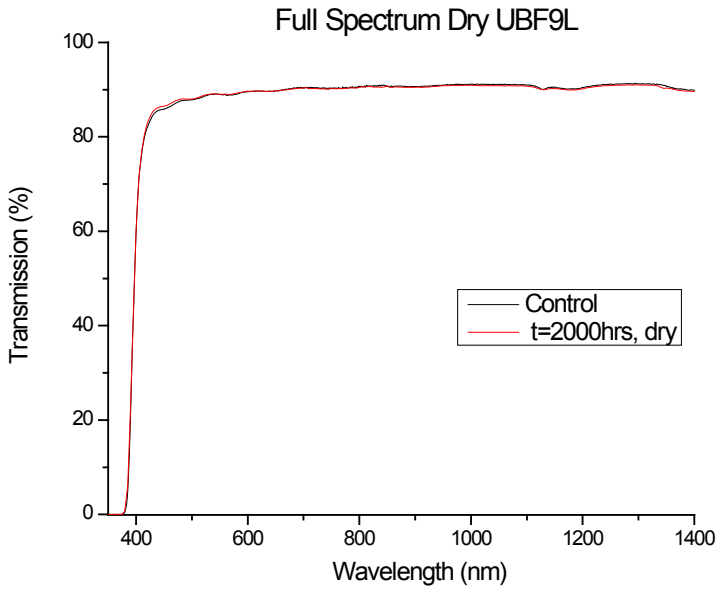
Full Spectrum Dry

Xe-Arc Lamp, Modified ASTM G155

WVTR and Optical Transmission Results

Permatran measurements

Time in Damp Heat (hrs)	WVTR (50C/100%RH) (g/m2day)
0	<0.005
1000	<0.005
1500	<0.005

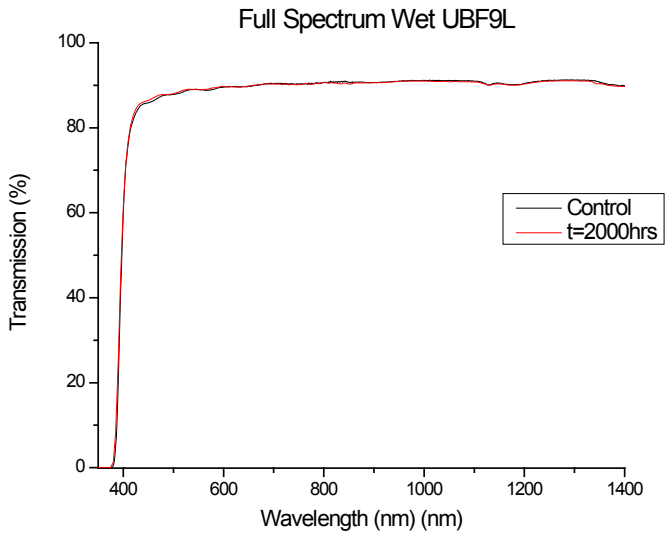


Full Spectrum Wet

Xe-Arc, Modified ASTM G155

WVTR and Optical Transmission Results

Time in Damp Heat (hrs)	WVTR (50C/100%RH) (g/m2day)
0	<0.005
1000	<0.005
1500	<0.005



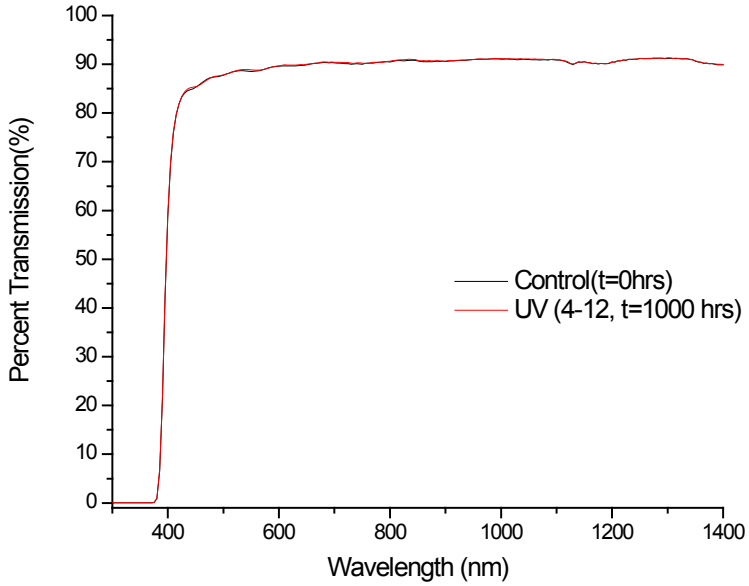
UV Spectrum Wet

UV Fluorescent, Modified ASTM G154

WVTR and Optical Transmission Results

Permatran measurements

Time in Damp Heat (hrs)	WVTR (50C/100%RH) (g/m2day)
0	<0.005
1000	<0.005
1500	<0.005



Next Step for WVTR: NREL Ca test values for aged samples

Reliability Testing of Ultrabarriers

Safety of UBF9L

- UL certified front sheet component
- UL and TUV front sheet partial discharge rating of 1,000V
- Solar Modules with our film have passed UL 1703 and IEC 61646/61730 certifications.

Reliability Testing of Ultrabarriers

The goal of this project is to develop and commercialize a flexible, highly transparent Ultra Barrier Topsheet that will enable successful commercialization of flexible photovoltaic modules.

3 **Renewable Energy Division & Corporate Research Lab**

Barrier Film Development & Scale-up, Accelerated Weathering, Lifetime Modeling

Module Reliability
Ca Conductivity WVTR Testing

Summary

- Ultra Barrier Solar Film for flexible modules
  - WVTR $5\pm3x10^{-5}$ g/m^{2}day after 2750 hrs at 45^{o}C/85%RH (NREL Ca Cond. Test)
- Preliminary accelerated aging results, *need many more hours*
  - No WVTR (MOCON) degradation after 1500hrs exposure full spectrum (wet/dry), 1000hrs UV wet
  - No degradation of optical transmission after 1500hrs of full spectrum (wet/dry)
  - No WVTR (MOCON) degradation after 2000 hrs of damp heat (85/85)
- 25 year lifetime plan
  - Leveraging internal 3M weathering resources/expertise
  - Indoor accelerated + outdoor acceleration → validation with outdoor
  - Looking at possible combination of in/out-door accl. Testing→SWAT
  - DOE SunShot Award: Reliability and scale up of ultra barrier films for flex solar