Demonstrating Reliability of Ultra Barrier Solar Films for Flexible PV Applications

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3M Supplies Materials & Technology Based Solutions to all Segments of Solar

Crystalline Silicon (c-Si)

Thin Film

Concentrated Solar Power (CSP)

Flex CIGS

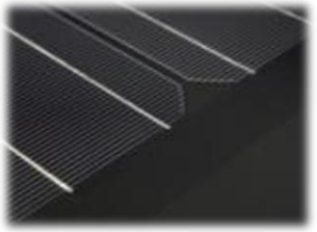
Product formats include films, tapes, coatings and adhesives

Product & Application Categories

Encapsulants

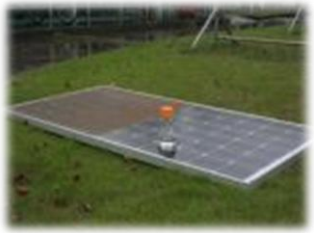
Backsheets

Ultra Barrier



EPE Films

Frameless Modules



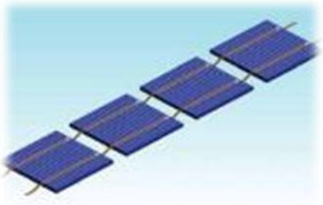
Anti-reflective & Anti-soil Coatings

Large Aperture Troughs (CSP)

Broadband Reflective Films

J-box Attachment

Frame Bonding



Solderless Stringing (c-Si)

Charge-Collection (Thin Film)

Cool Mirror (Low X)

3M Ultra Barrier Solar Films replace glass

- **Durable film with outstanding moisture barrier properties and high light transmission**
- **Enables high efficiency flexible PV modules to significantly reduce installation costs**

Ad
Adhesives

Fi
Films

Fl
Fluorinated Materials

Pm
Polymer Melt Processing

Vp
Vapor Processing

3M has a long history in Ultra Barrier Films

- 3M has been developing ultrabarrier technology for over a decade
- Proprietary vacuum roll-to-roll process
- Over 50 applications and 20 granted patents
- Applications in Flexible PV brings new challenges for durability and compatibility

Key Advantages of Flexible Solar Modules

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

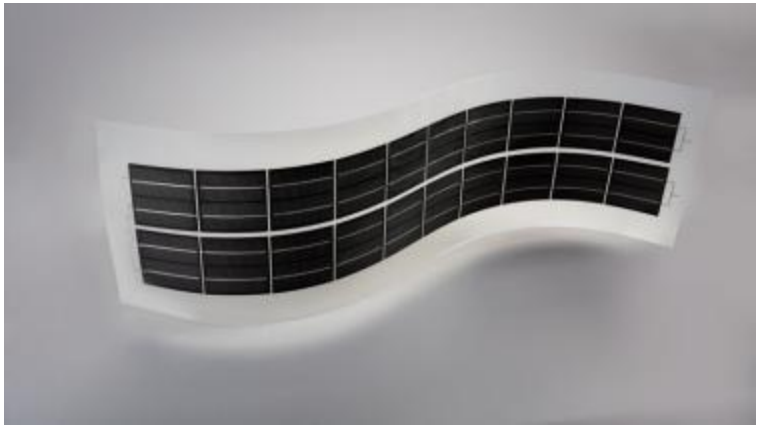
Lower Balance of System costs → less labor and no mechanical racking

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

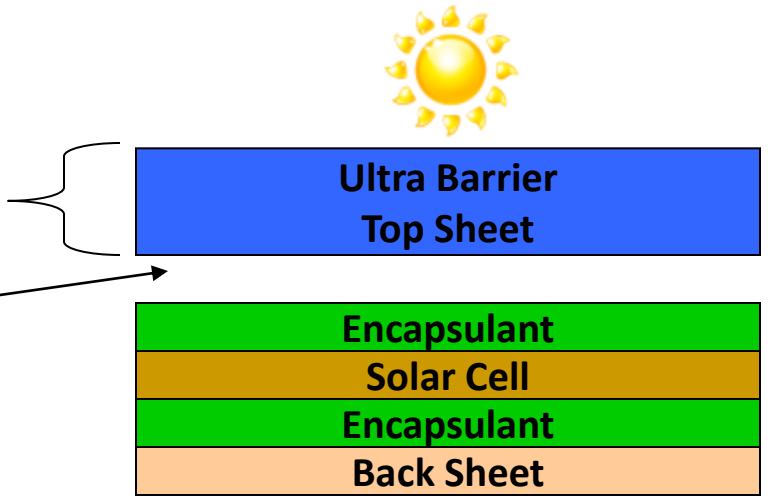
Lower manufacturing cost → Fully automated roll-to-roll processing



Ultra Barrier Solar Film Key Properties

3M Ultra Barrier Solar Film – UBF 9L

Optimized for adhesion to common solar encapsulants

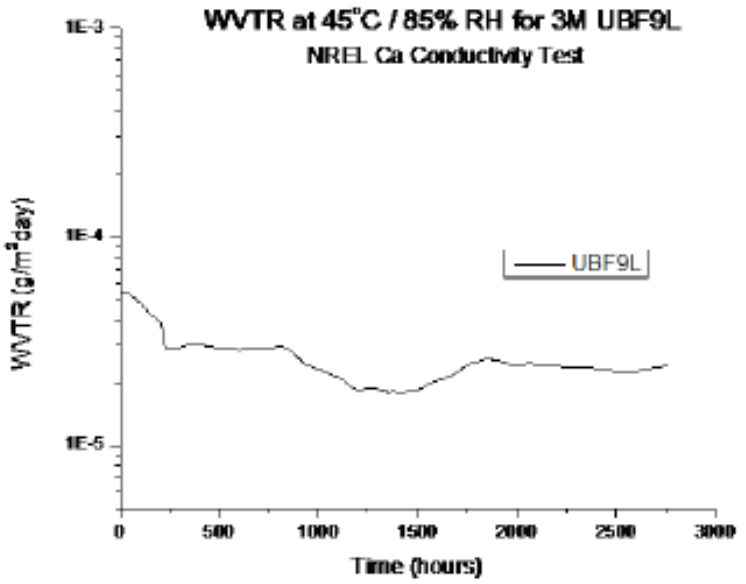


- WVTR = $5*10^{-4}$ g/m^2/day @ 23°C 85% RH
- Transmission > 89% (Avg 400nm–1400nm)
  - Effective transmission in a module is higher with only 3% reflection loss
- Low Shrinkage
- Low CTE
- Partial Discharge 1,000V
- UL Certified Component– E316895

Typical WVTR Data

Initial WVTR Performance of UBF9L by various Methods

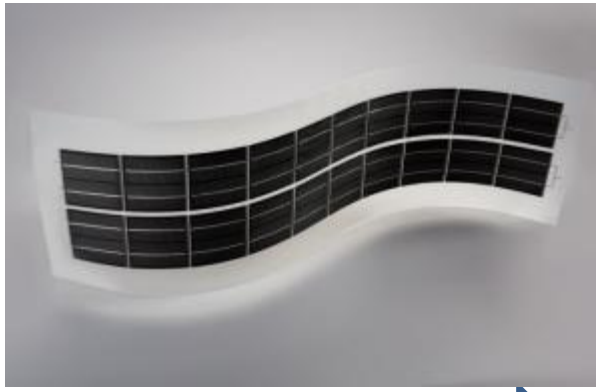
Method	Detection Limit (g/m^2day)	Temperature (oC)/RH(%)	UBF9L (g/m^2day)
MOCON Permatran	0.005	50/100	<0.005
MOCON Aquatran	0.0005	50/100	<0.0005
NREL Ca Test	10^{-6}	45/85	$5\pm3 \times 10^{-5}$



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

Project Overview

Photo courtesy of SoloPower



Enabling Lightweight, Flexible, Roof Top Solar Modules

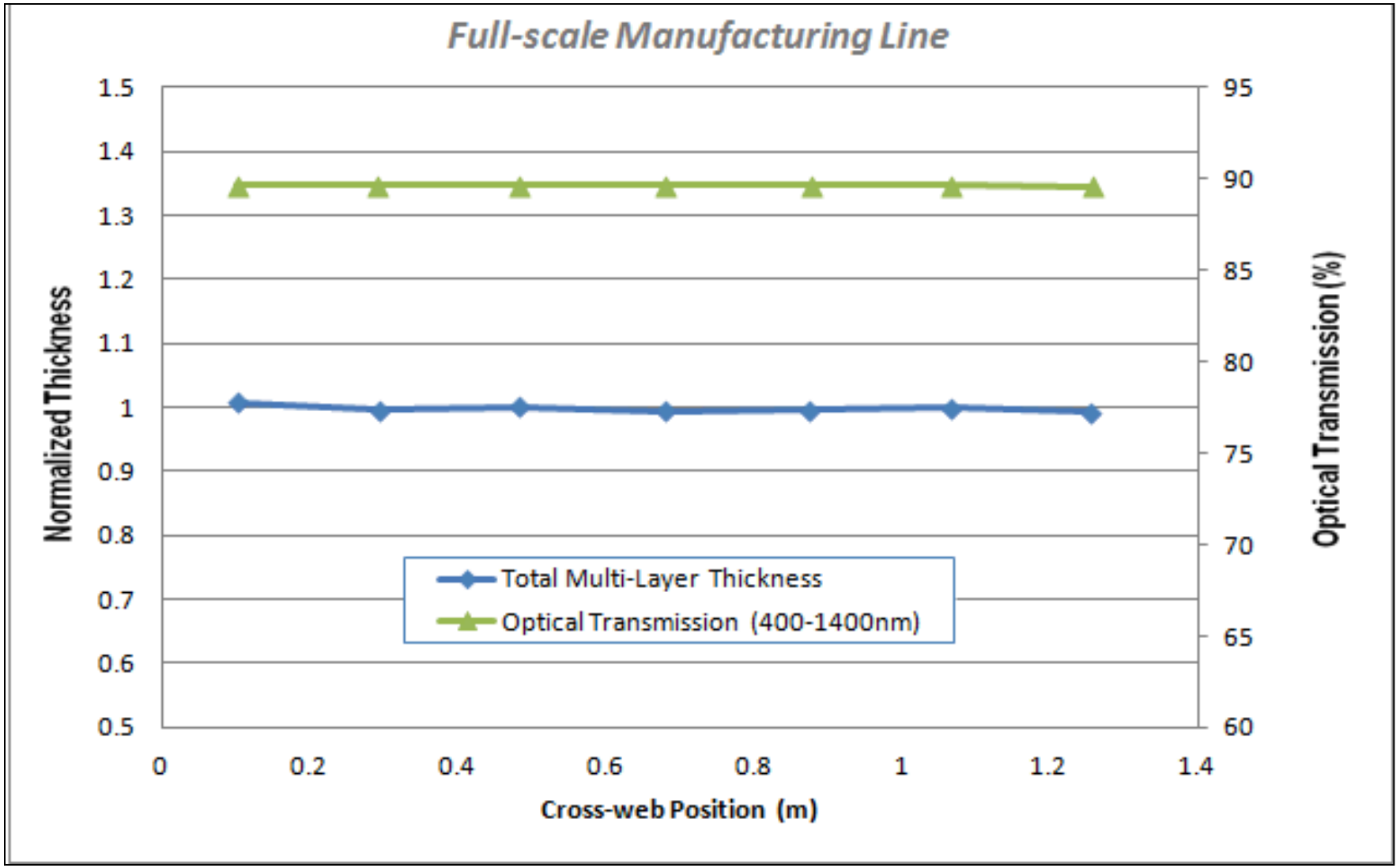
Property	Status	Goal	Current	Comment
WVTR (g/m^{2}day)		As low as 10^{-6}	5.0 x 10^{-5}	NREL independently verified w/eCa >6000hrs 45C/85RH
Transmission		Entitlement of 94%	90%	Film transmission as applied to module is >94%. Work underway to further increase
Production Scale		Up to 2m	1.2m	Accomplished June 2012
Product Certification		Certified Component and Module	UL, IEC certified from pilot line	UBF9L Certifications completed
Product Lifetime (yr)		>25	Validation in progress	Indoor and outdoor testing

Program Objectives

- Program Name: Ultra Barrier Topsheet (UBT) for flexible photovoltaics
- Objectives
  - Scale-up the Generation -1 UBT to 1+meter width full-scale manufacturing
  - Develop a Generation-2 UBT on the pilot line, targeting improved performance, longer lifetime and lower cost.
  - Transfer Generation-2 UBT from the pilot line to the full-scale manufacturing line in 2014.
  - Validate service life of Generation-1 UBT for the 25+ year lifetime
- Working Partners are NREL and Stanford University

Program is on track or ahead of schedule to meet all objectives

Cross Web Uniformity



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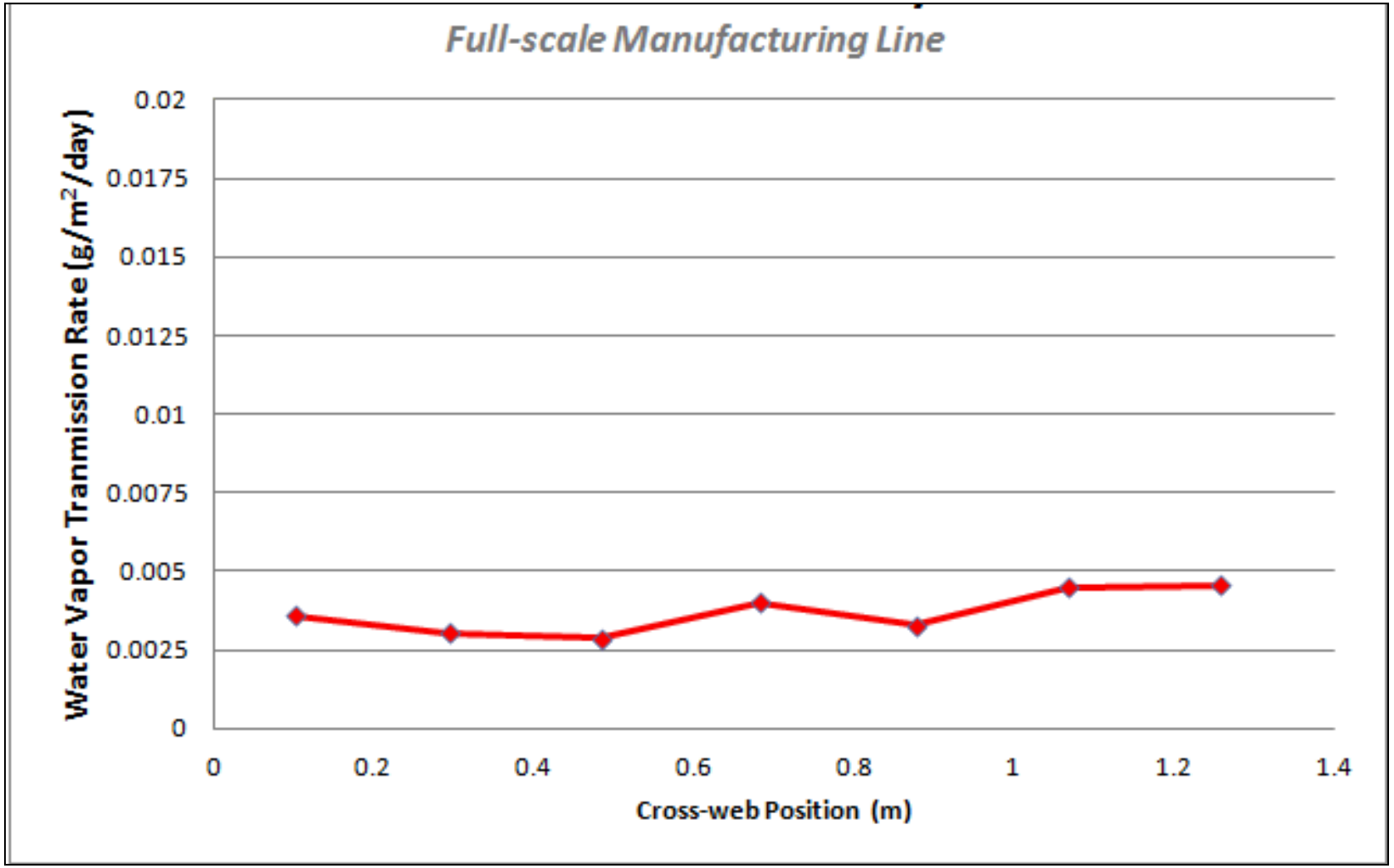


Measurements made at 50C / 100% RH. Mocon detection limit is 5 x 10^{-3}

Development of Generation 2 UBT

- Gen 2 samples available now
- Projected launch in Q3 2013

Generation 2	Property
	Adhesion to 3rd Party Materials
	Cost
	Transmission
	WVTR
	UL Cert

Weathering Testing is Critical 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

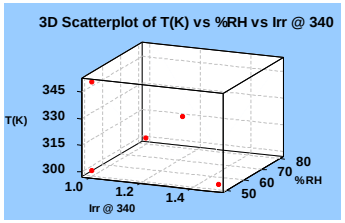
Mirrored Enclosure

G90-type

Large area G90-type

Indoor Exposure & Lifetime Modeling

Controlled
- Irradiance
- %RH
- Temperature



SWAT Exposure

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

Accelerated Outdoor

+ Damp Heat
+ Humidity Freeze
+ …

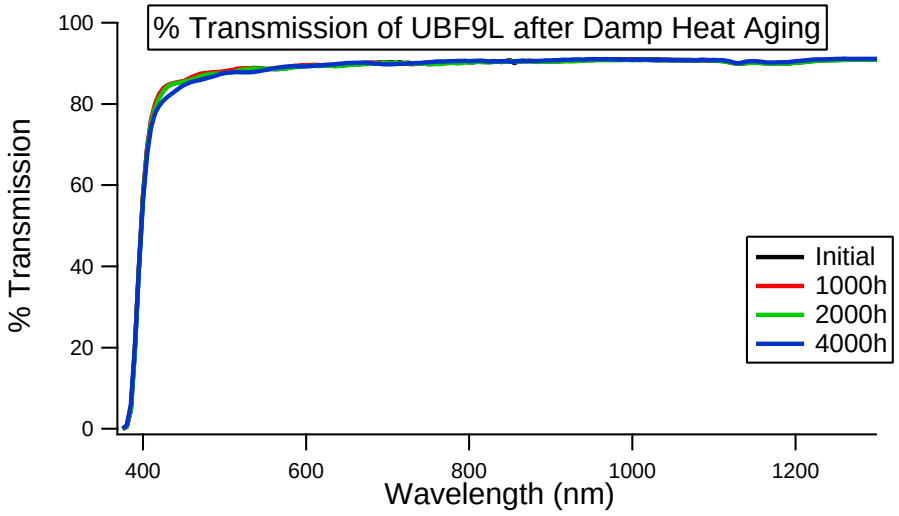
Update on WVTR and %T Data for UBF9L Constructions as a Function of Aging

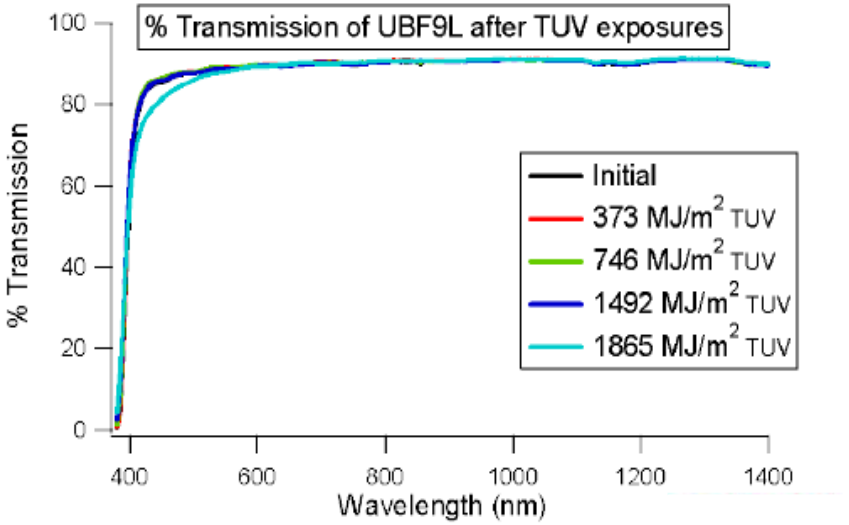
Cycle	Equivalent TUV (MJ/m2)*	Equivalent Years in AZ**	WVTR (gm/m2-day)
ASTM G155 (modified)	373	1.1	<.005
	746	2.2	<.005
	932	2.7	<.005
	1865	5.5	<.005
Cycle	Time (hours)	WVTR (gm/m2-day)	
85C/85RH DH	1000	<.005	
	2000	<.005	
	4000	<.005	

*Total UV Dose (TUV) is the time integrated energy over the range 295-385 nm

** Based on 10 year average annual total UV for a 5 degree pitch south facing exposure in Phoenix, AZ

***Reference: 1,000 MJ/m2 ~ 9,200 hrs ASTM G155 Cycle I Test (ie. UL 746C)



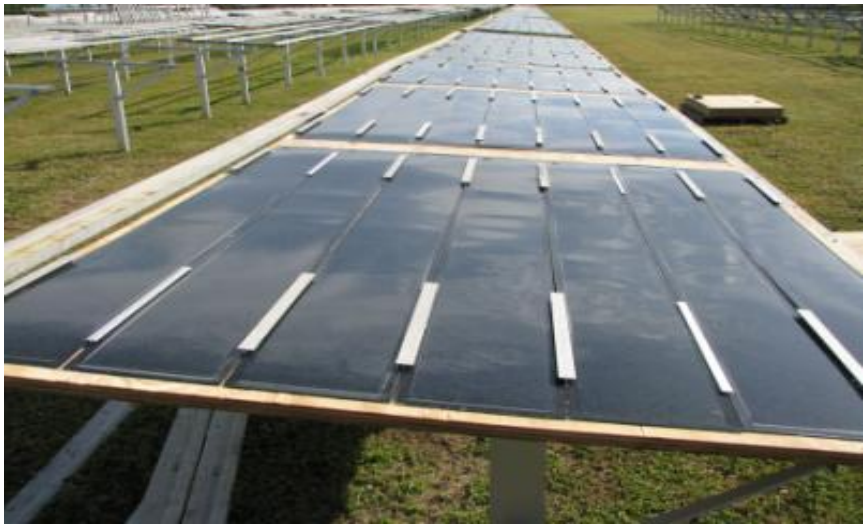


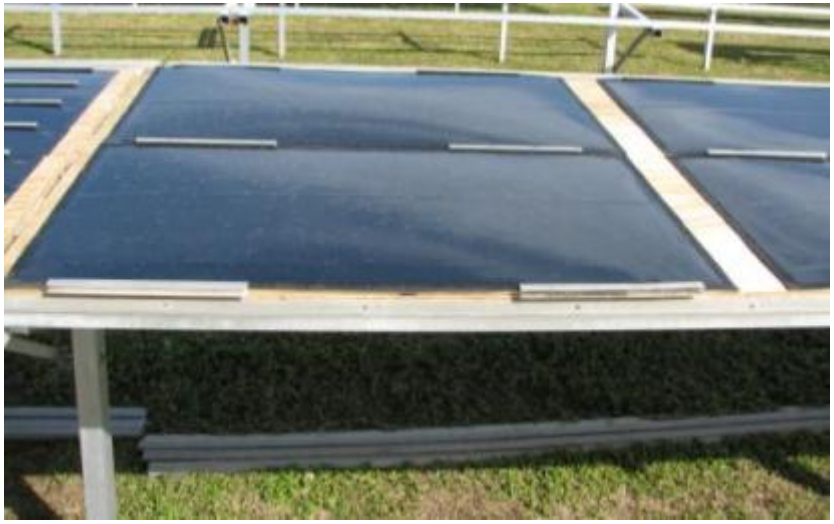
Reliability and Weathering: Important Insights

- Standard reliability test conditions (UL 1703, IEC61646) do not adequately anticipate conditions in field deployment
- New testing protocols have been developed to screen product modifications and evaluate lifetime performance including:
  - Higher temperatures
  - Higher RH and standing water
  - Higher irradiance

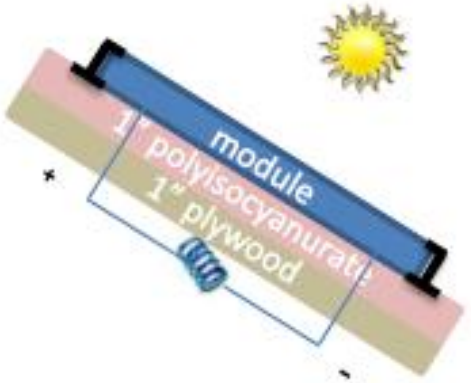
Reliability Testing

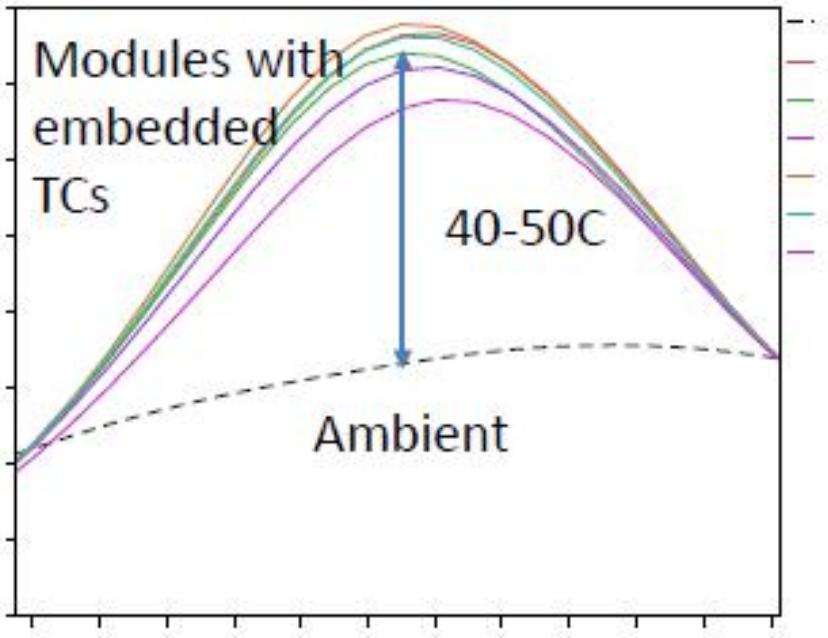
- Indoor and Outdoor Reliability testing in progress for:
  - Stand alone UBT film
  - Customer made modules
  - 3M made modules

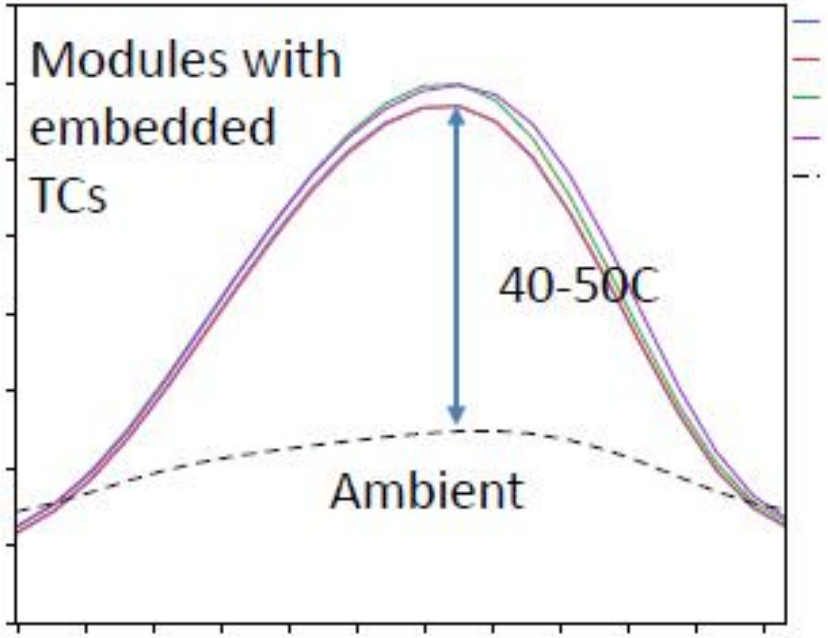




Simulated Rooftop Testing







Simulated Rooftop Testing – Standing Water

Summary

- 3M has scaled up UBT for production at 1.2 meter width
- 3M is conducting extensive lifetime studies including
  - Evaluation of customer processing and installation conditions
  - Indoor accelerated testing of UBT film and full CIGS modules
  - Outdoor testing of UBT film and CIGS modules
- Results have been used to improve ultra barrier film performance for flex module applications