Demonstrating Reliability of Ultra Barrier Solar Films for Flexible PV Applications

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Outline

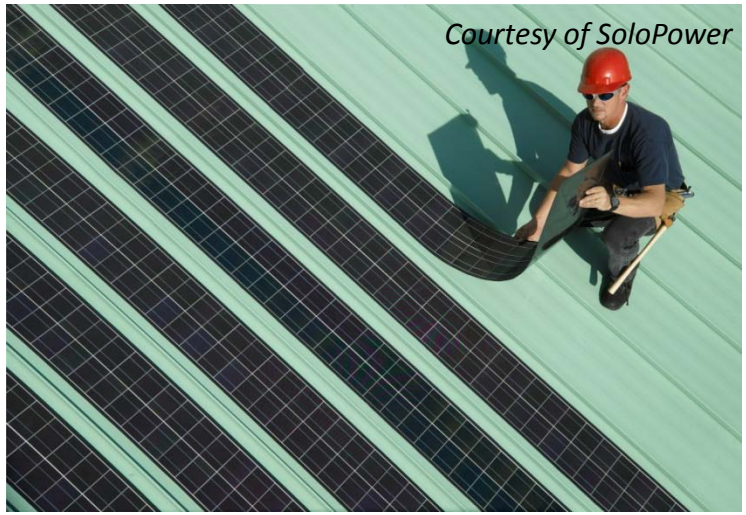
1. 3M Ultra Barrier Solar Film Product Overview
2. Challenges Measuring WVTR at Ultra Barrier Levels
3. Demonstrating Reliability
4. Summary

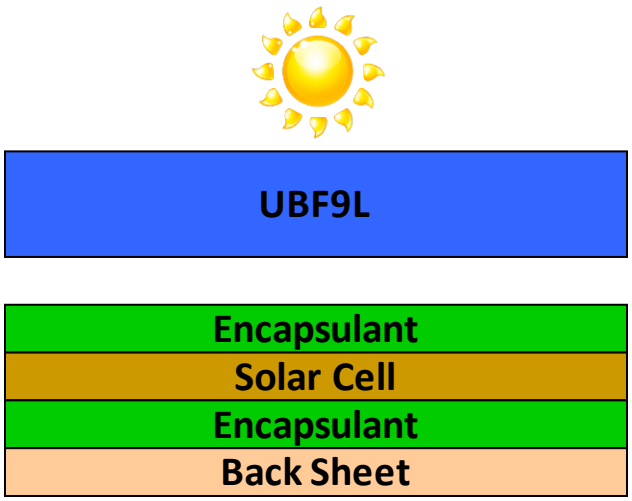
3M Ultra Barrier Solar Film Overview

Advantages of Flexible PV Modules

- Durable film with outstanding moisture barrier properties and high light transmission

- Enables high efficiency flexible PV modules to significantly reduce installation costs





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

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

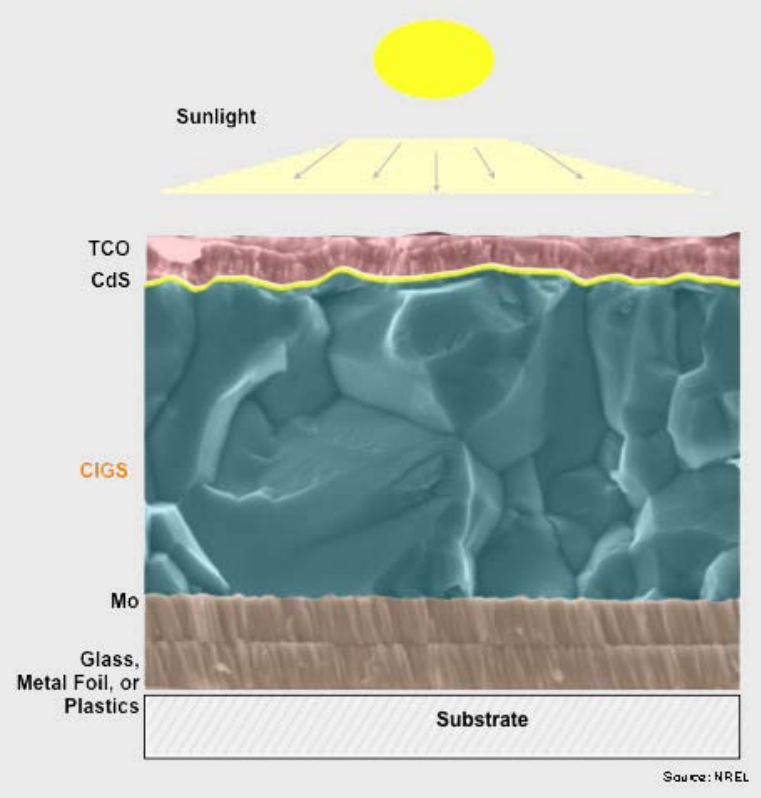
Higher packing density → Significantly more kW per shipping container

Higher energy output → Better transmission and off-angle performance

Large area modules → Lower relative “fixed” module costs

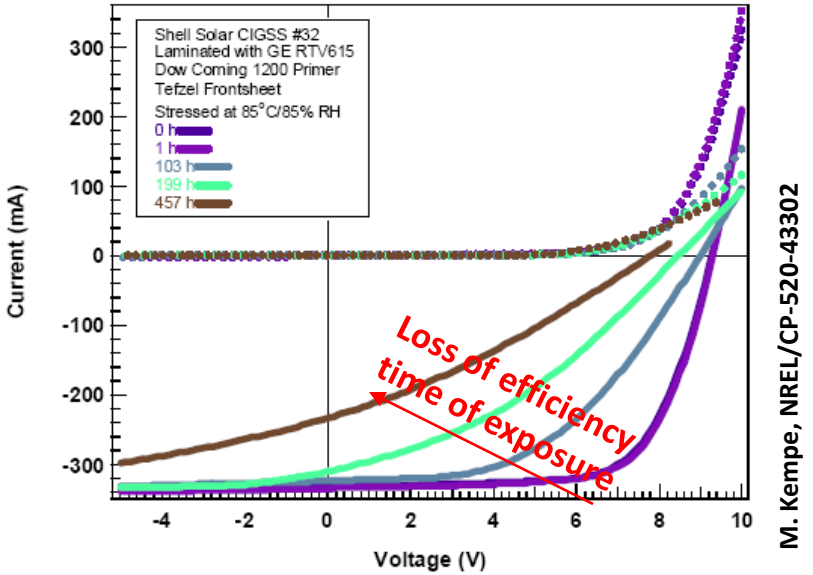
Lower manufacturing cost → Fully automated roll to roll processing

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



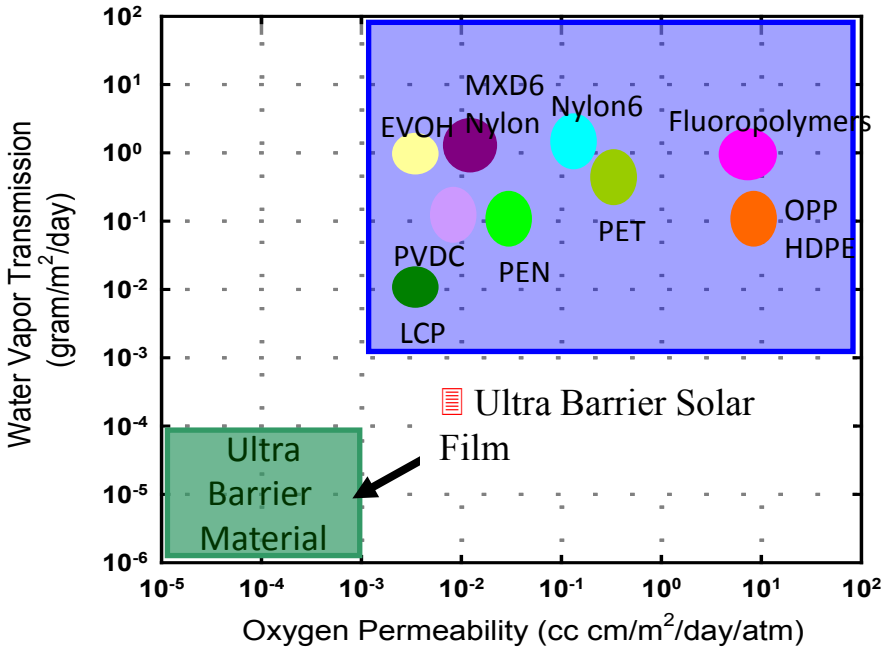
Water vapor migrates to electrode and degrades electrical contacts

Degradation in Efficiency in CIGS Exposure to Water (85%RH & 85°C)



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

- 3M has been developing ultra barrier technology for over a decade
- Over 50 applications and 20 granted patents
- Currently validating 1.2m wide film from manufacturing line



Description

Designed to address the needs of the flexible thin film solar manufacturers, 3M™ Ultra Barrier Solar Film acts as a replacement for glass with its high light transmission, superb moisture barrier performance and excellent weatherability. 3M combined its knowledge of polymer films, adhesives and advanced materials to deliver a high performing, multi-layered front sheet barrier film to the solar industry.

Features

- Good optical transmission from 400-1400 nm
- Very low moisture vapor transmission rate
- Excellent UV stability
- Flexible

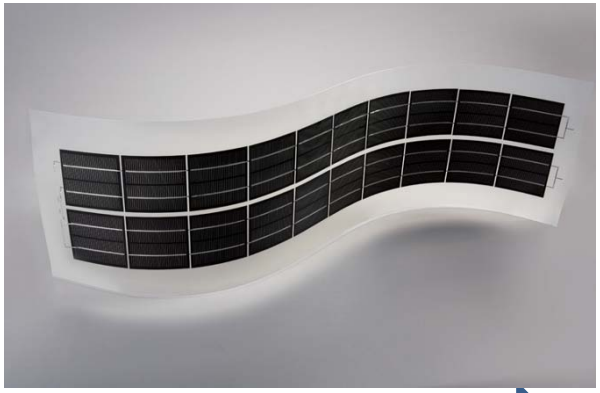
Key Highlights

- UL Certified Component (E316895)
- WVTR = 5×10^{-4} g/m²/day @ 23°C 85% RH
- Transmission >89% (Avg 400 nm-1400 nm)
- Low Shrinkage
- Partial Discharge 1,000V
- Low CTE

Typical Properties (Data not for specification purposes)

Property	Test Method	Value*	Comment
Mechanical			
Thickness	ASTM D 6988	.229 mm (.009")	
Width		1.2 meters (47.24")	
Tensile Strength	ASTM D 882	106 MPa	
Elongation	ASTM D 5026	157%	
Optical			
Optical Transmission	3M	>89%	Average (400–1400 nm)
Thermal			
Processing Temperature		150°C for <15 min	
Operating Temperature		-40 to 100°C	
Storage Temperature		0 to 40°C	
Electrical			
Dielectric	ASTM D 149	>10KV	
Partial Discharge	IEC 61730-2 MST 15	≥1000V	
Other			
Moisture Vapor Transmission Rate	See Application Guide	<5×10^{-4} g/m²/day	@ 23°C 85% RH
Outdoor Exposure	UL746C	f2	Water immersion and UV exposure
Certifications	UL Recognized Component		E316895
	TUV		

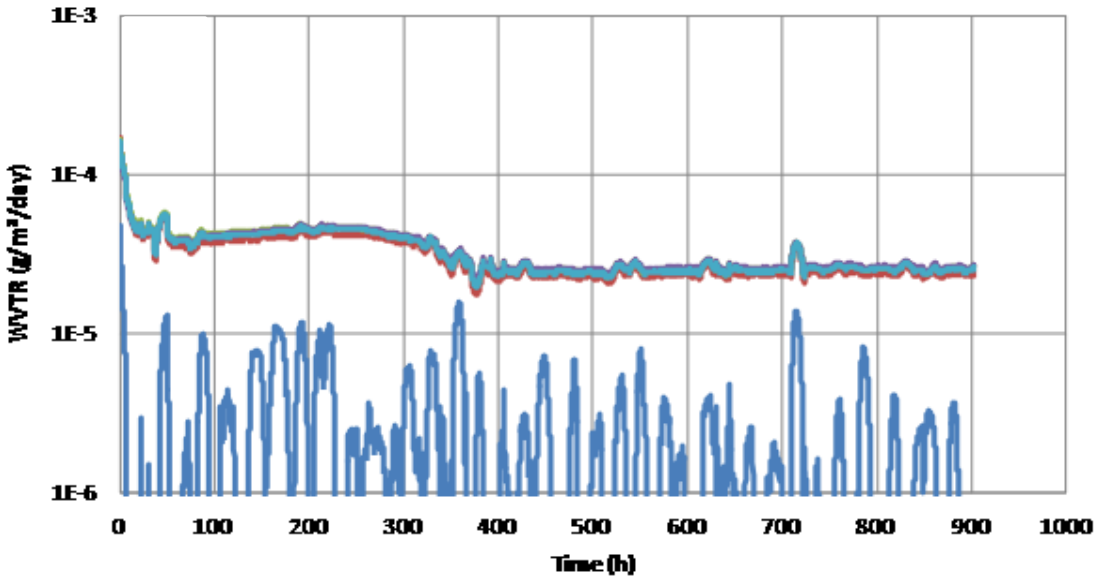
* Values listed are preliminary and for reference only.



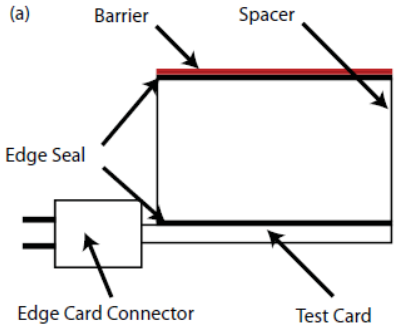
Enabling Lightweight, Flexible, Roof Top Solar Modules

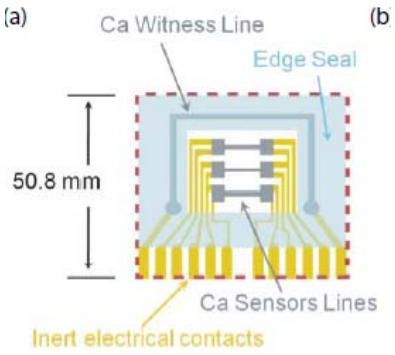
Property	Status	Goal	Current	Comment
WVTR (g/m^{2}day)		As low as 10^{-6}	5.0 x 10^{-5}	NREL independently verified w/eCa >6000hrs 45C/85RH
Transmission		Entitlement of 94%	90%	2% gain through processing changes
Production Scale		Up to 2m	1.2m	1.2m wide films being made for qualification and certification
Product Certification		Certified Component and Module	UL, IEC certified from pilot line	Certifications with 1.2m film in progress
Product Lifetime (yr)		>25	Validation in progress	Service Life Prediction work and outdoor correlations in testing

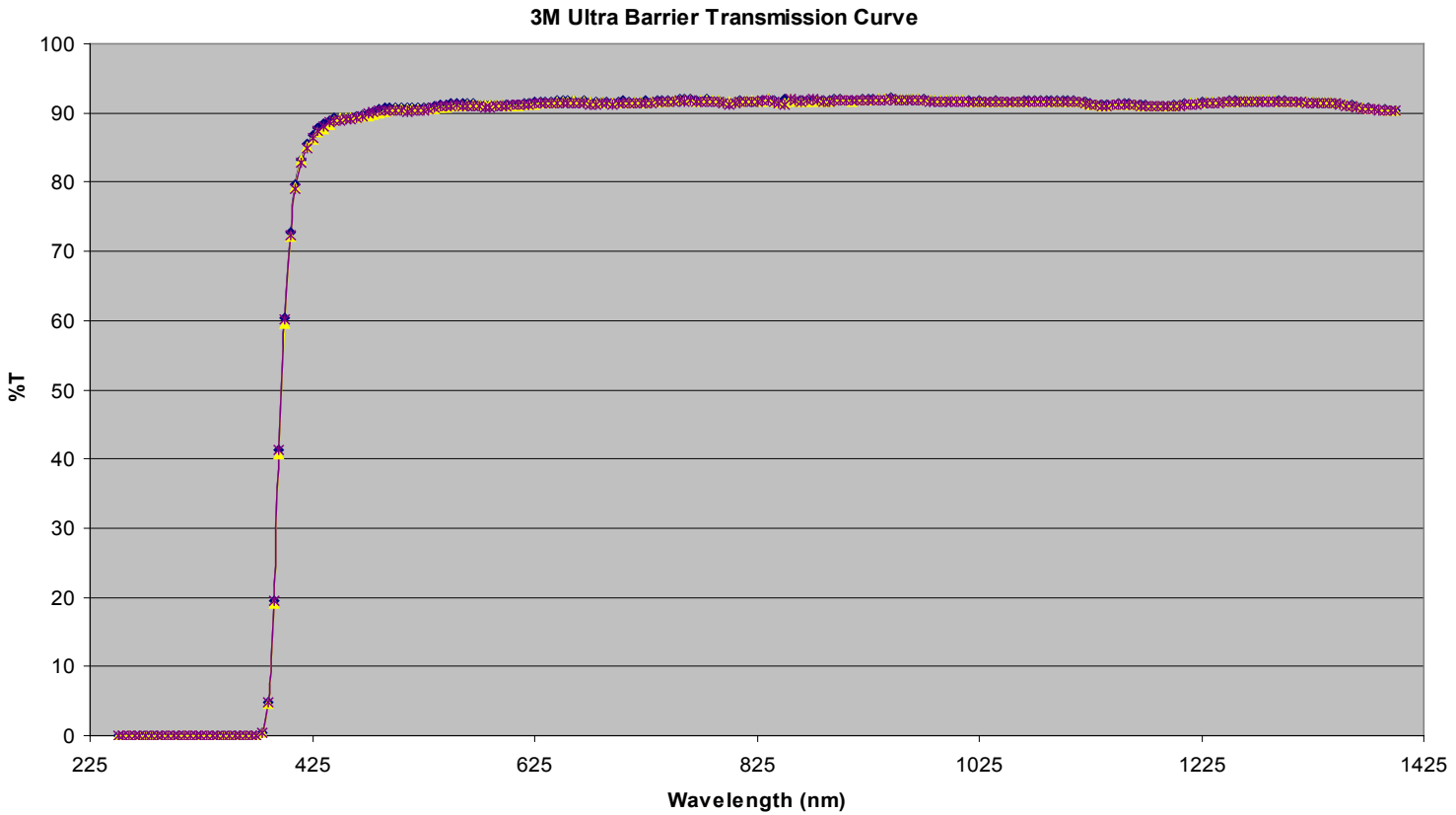
NREL e-Ca Test 45C, 85%RH



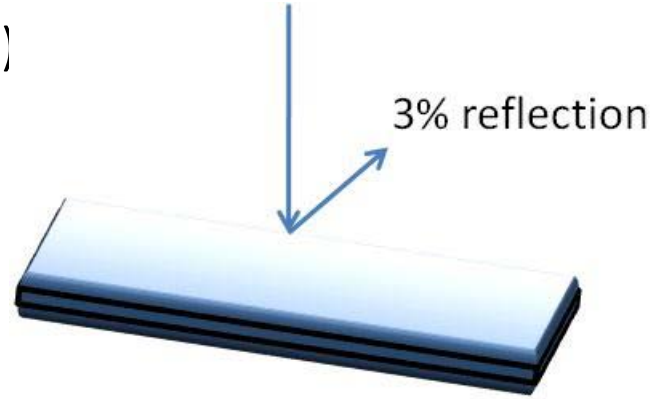
For information on e-Ca test method: Quantitative calcium resistivity based method for accurate and scalable water vapor transmission rate measurement, *Reese, M.O. , Dameron, A.A., Kempe, M.D. ,National Renewable Energy Laboratory, 1617 Cole Blvd., Golden, CO 80401, United States*
Review of Scientific Instruments, Volume 82, Issue 8, August 2011, Article number 085101







Average = 89-91% (400nm to 1400nm)



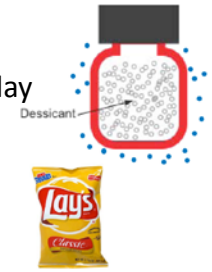
Challenges in Measuring WVTR

Scavenger Methods
(Indirect)

Detection Level
g/m²day

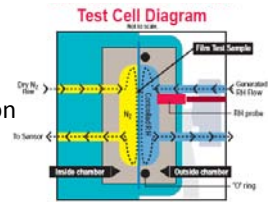
Permeation Cell
(Direct)

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



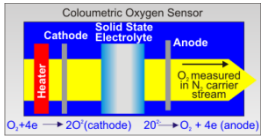
1

Mocon™



Permatran: IR detection

Aquatran: Coloumbic detection



Ultra-Barrier Below this line

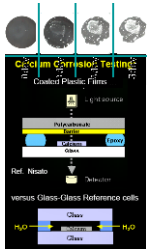
0.001

Calcium Test

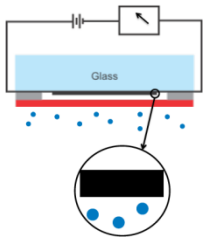
$Ca + H_2O \rightarrow CaO + H_2$

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

Optical Density

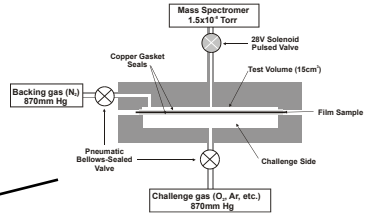


Flex Solar



NREL Electrical Conductivity

Mass Spec



HTO: Radioactivity

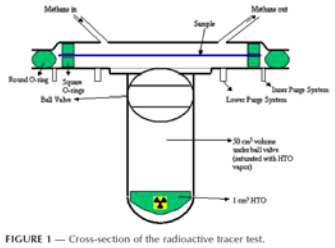


FIGURE 1 — Cross-section of the radioactive tracer test.

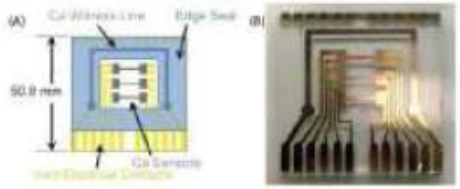
0.000001

Arrelaine Dameron, NREL PVMRWS 2010

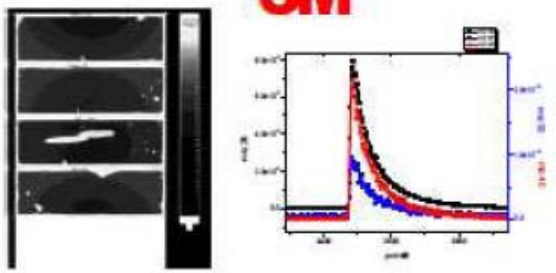
Comparative Measurement Capability

mocon

NREL



3M



GENERAL ATOMICS

Measurement Methods

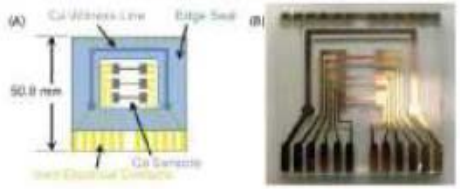
Measurement	Source	Lower Detection Limit ($g/m^2/day$)	Minimum Test Time Required (hours)
Infrared Sensor	Mocon™	$5x10^{-3}$	50 hours
Coulometric Sensor	Mocon™	$5x10^{-4}$	200 hours
Calcium (Resistance)	NREL	$1x10^{-6}$	200-1000
Calcium (Optical)	3M	$1x10^{-6}$	200-1000
Pulsed Valve Mass Spectrometry	3M	$1x10^{-5}$ demonstrated; Lower correlation possible	8
Tritiated Water	General Atomics	$1x10^{-8}$	100

3M

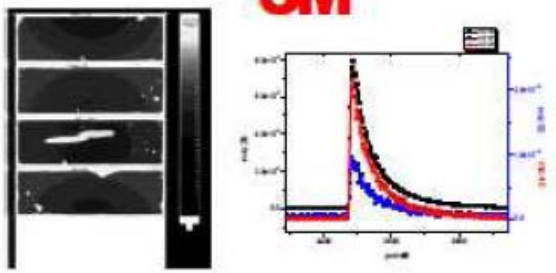
Comparative Measurement Capability

mocon

NREL



3M



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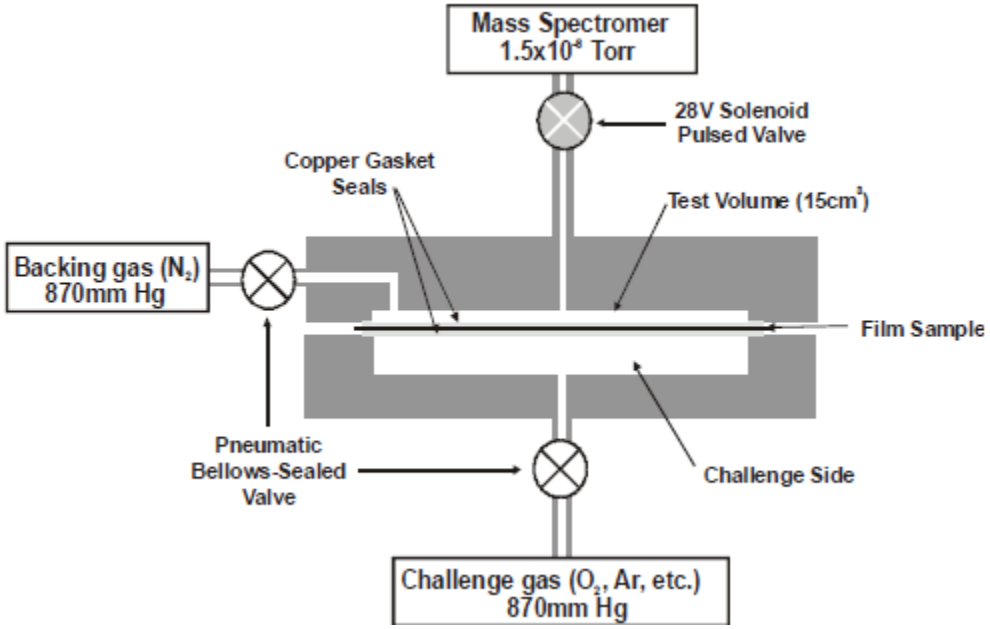
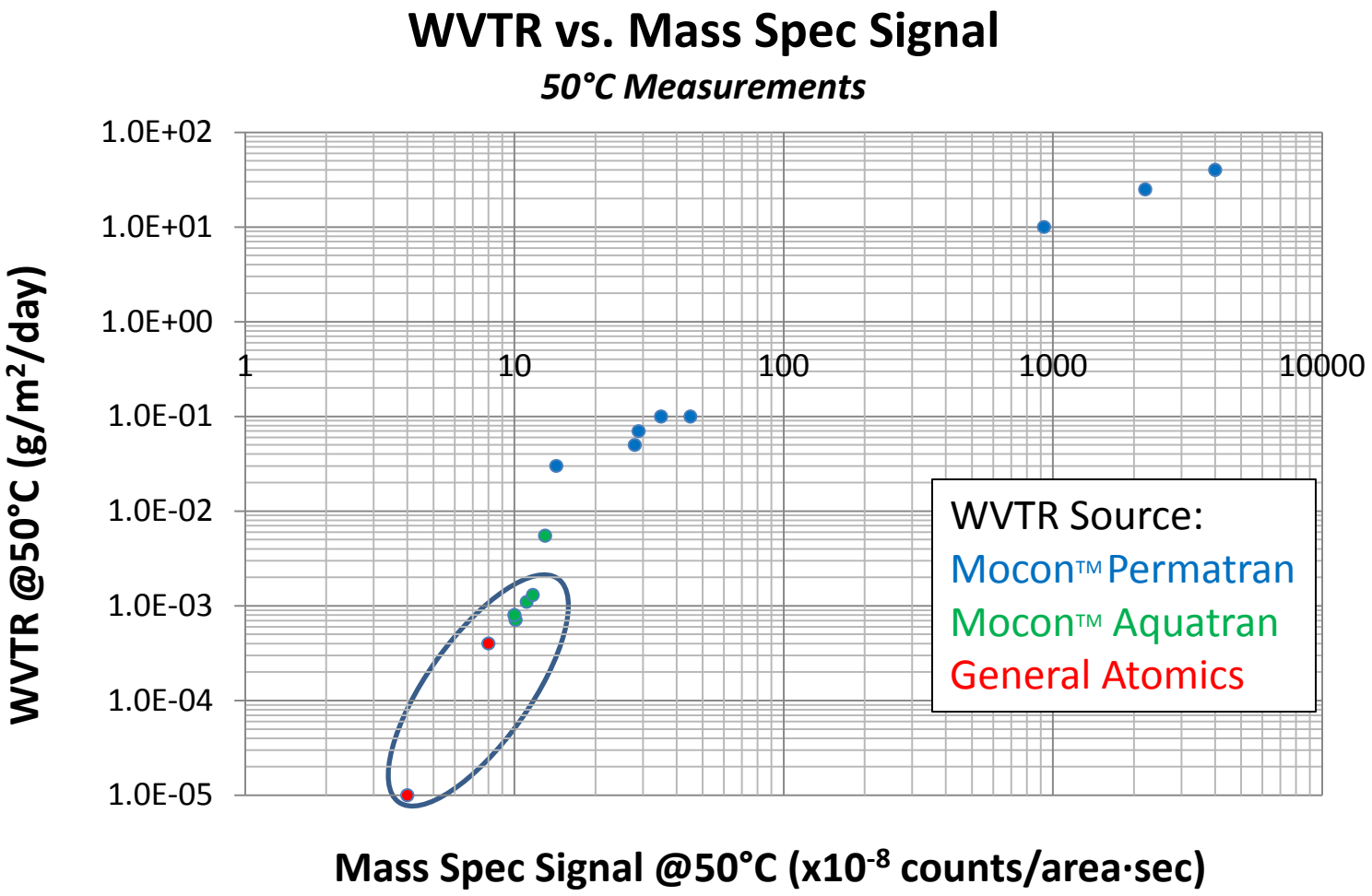
3M

3M Developed Mass Spec Tool

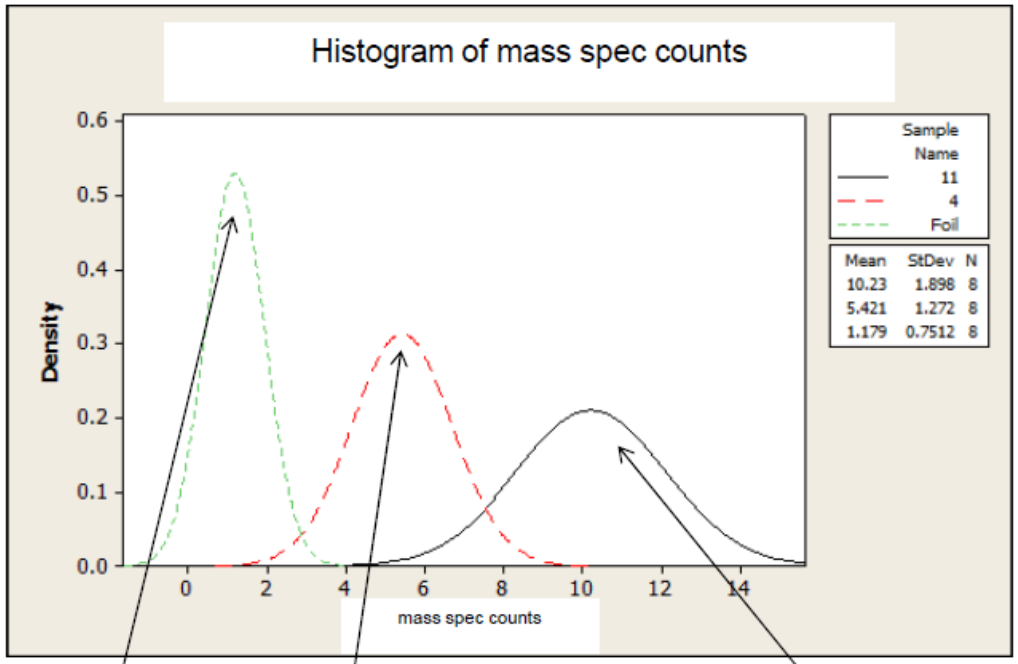


5x higher throughput than Mocon™ Permatran
100x improved barrier quality detection

Mass Spectrometry Measurements Correlate to WVTR



Recent MSA



Metal Foil

Standard Barrier

Barrier "Just Below" Mocon

Demonstrating Reliability

Demonstrating Reliability

Flex modules and “mock” modules

Outdoor Field Test Data

Indoor Testing

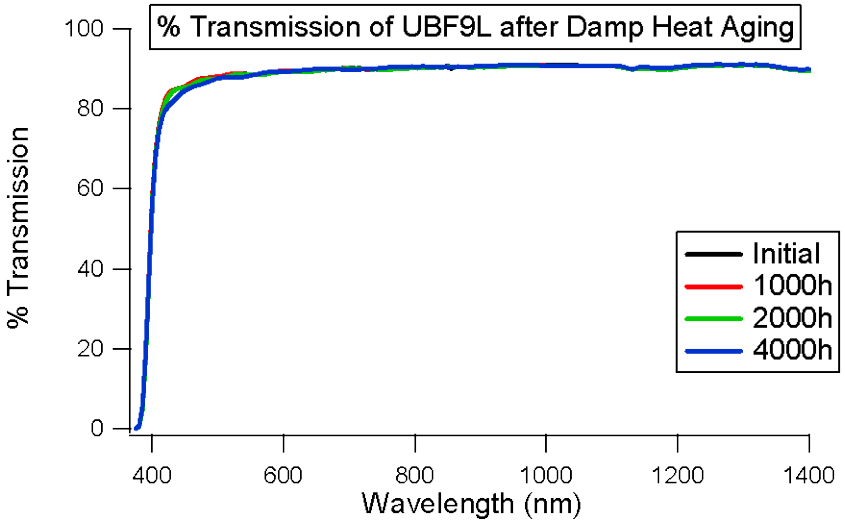
- Qualification
- Test to Failure
- Service Life Prediction

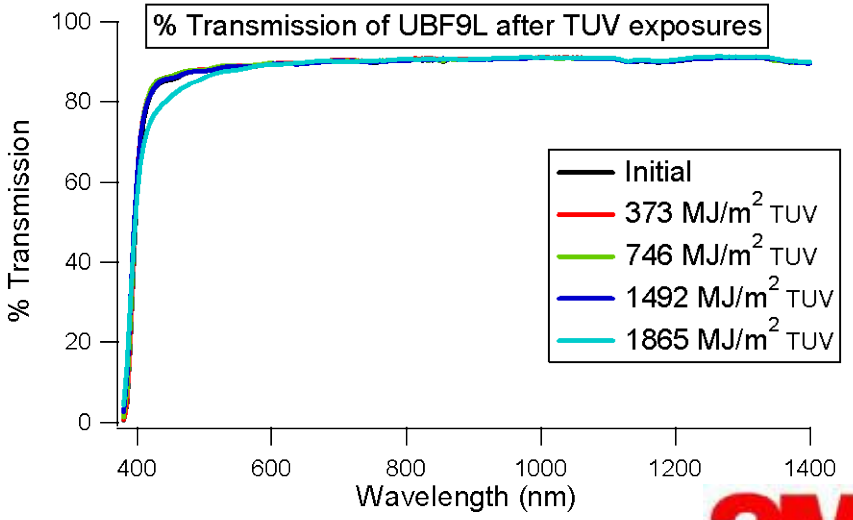
Product Lifetime

Cycle	Equivalent TUV (MJ/m2)*	WVTR (gm/m2-day)
ASTM G155 (modified)	373	<.005
	746	<.005
	932	<.005
	1865	<.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

Note that 1,000MJ/m^2 is roughly equivalent to 9,300 hours in ASTM G155 Cycle 1





Natural Outdoor Exposure

Multiple Locations and Environments

Static Racks (5° or latitude w/ backing)

Accelerated Outdoor Exposure

2x to 5x UV range acceleration

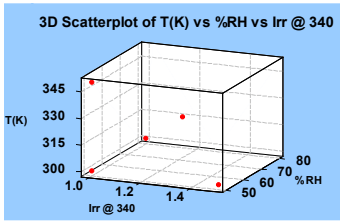
Mirrored Enclosure

G90-type

Large area G90-type

Accelerated Indoor Exposure & Lifetime Modeling

Controlled
- Irradiance
- %RH
- Temperature

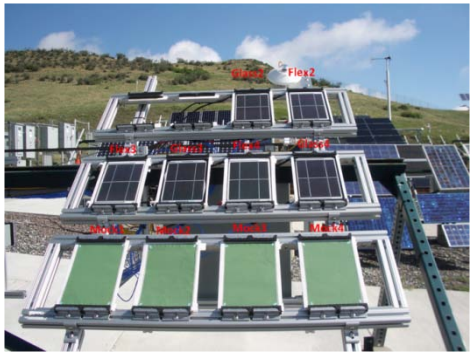


SWAT Exposure

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

Accelerated Outdoor

+ Damp Heat
+ Humidity Freeze
+ repeat



		2011												2012											
Location	**Exposure Type**	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Arizona	Natural Outdoor Static Rack																								
	Accelerated Outdoor 2.1x																								
	Accelerated Outdoor 5x																								
	SWAT																								
	Outdoor Tracking Bed																								
Florida	Natural Outdoor Static Rack																								
Colorado	Natural Outdoor Static Rack																								
Minnesota	Natural Outdoor Static Rack																								
	SWAT																								
	Indoor																								

outdoor with no acceleration

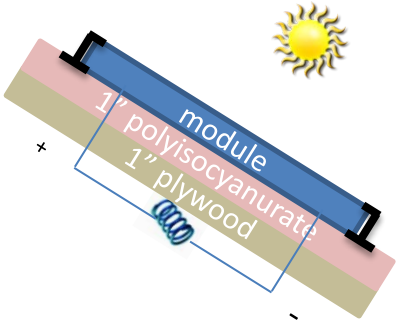
accelerated w/ night spray

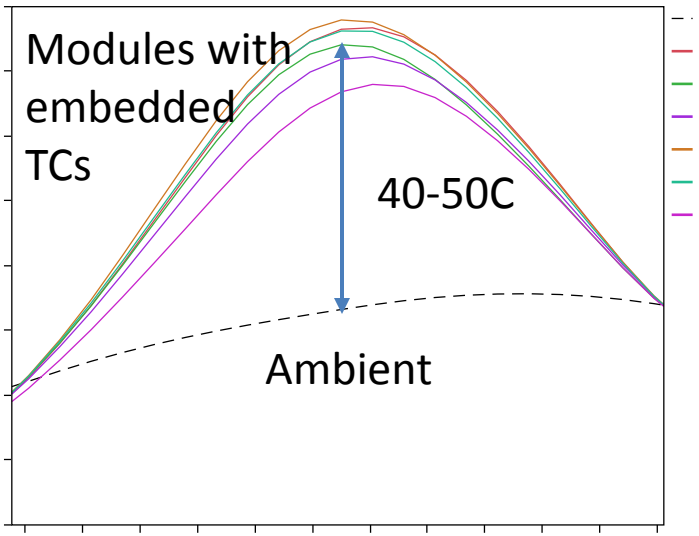
indoor humidity-freeze

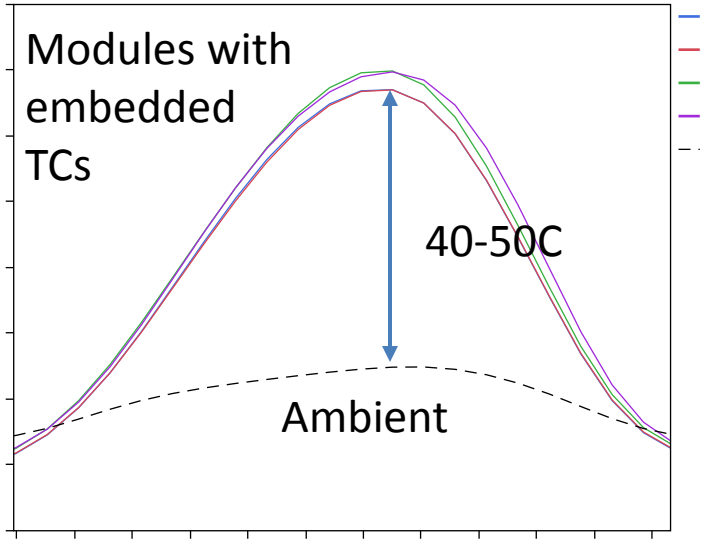
indoor damp-heat

indoor controlled T, RH & irrad.

Data for Simulated Rooftop Mounted Flex Modules Outside

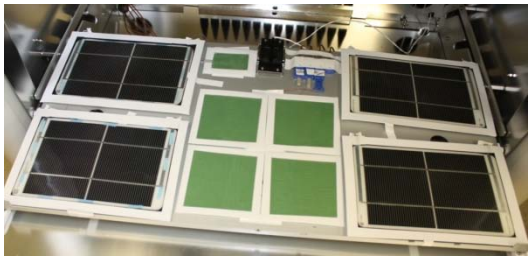






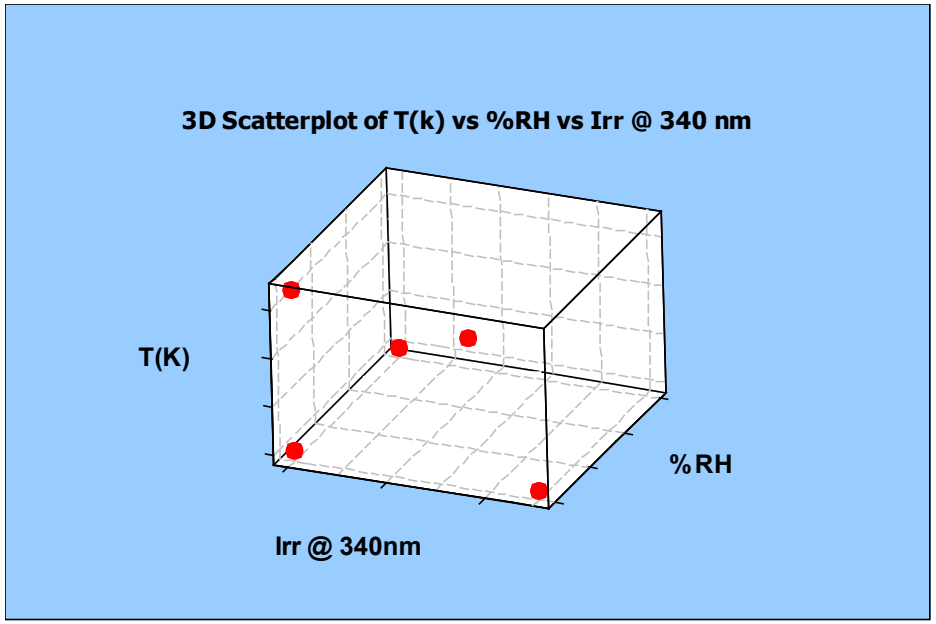
Accelerated Indoor Exposure & Lifetime Modeling

Controlled
- Irradiance
- %RH
- Temperature



Temperature	Relative Humidity	Irradiance at 340nm
BPT1	RH1	Irr1
BPT2	RH1	Irr1
BPT1	RH3	Irr1
BPT1	RH1	Irr3
BPT2	RH2	Irr2

- **Five unique accelerated stress conditions**
- **Multiple specimens per condition**
- **Performance parameters measured monthly**
- **Time to failure (80% initial Pmax) estimated by regression, per specimen**



Summary

- WVTR as low as 10^{-5} g/m^2 day
- Developing fast, sensitive test for WVTR based on mass spec
- Reliability Test Plan Initiated and Collecting Data on Flex Modules, Glass Module controls and Film-Only Performance (%T, color, T&E, WVTR)
- Scale-up: Manufacturing Line in Columbia, Missouri
- 1.2m wide film with capability to go to 2m
- Launch of product expected Q2 2012

Acknowledgment: "This material is based upon work supported by the Department of Energy under Award DE-EE0004739."