DuraMAT
Durable Module Materials Consortium

Combined-Accelerated Stress Testing (C-AST)

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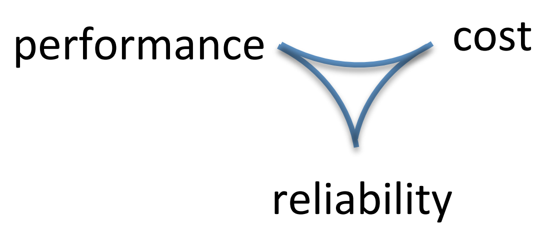
Overview

- Motivation
- Project Overview
- Stakeholders
- Timeline
- Testing
  - Philosophies
  - ASTM 7869 stress cycle – basis
  - Stress levels
    - Mechanical loading
    - Humidity
  - Project demonstration test matrix
- Modeling

Combined - Accelerated Stress Testing

- Now: mechanism-specific tests
  - Known failure mechanisms
  - Minimal examination of interdependencies
  - Numerous modules and multiple parallel tests
- Combined-accelerated stress testing
  - Combine the stress factors of the natural environment
  - Fewer modules, fewer parallel tests
  - Discover mechanisms not *a-priori* known in new module designs
  - Reduce residual risk, accelerate time to market and bankability
  - Reduce costly overdesign
  - Application of weathering models



Mechanisms missed by conventional tests

Findable by combined– accelerated stress testing

Backsheet cracking →

UV, cyclic oxidative/hydrolytic stress,
CTE stress, EVA acidity

PID

Grid finger corrosion – delamination

Light and elevated temperature induced degradation

Snail trails→ delamination

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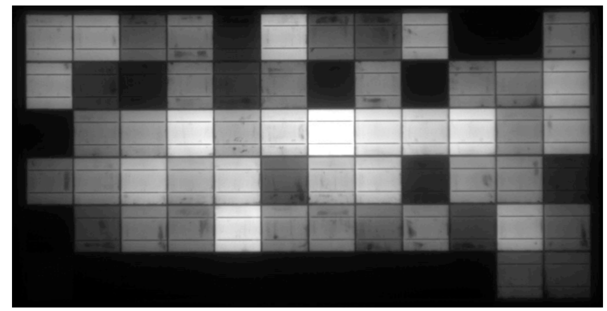
Backsheet cracking

PID →

System voltage, humidity, temperature, light, soiling



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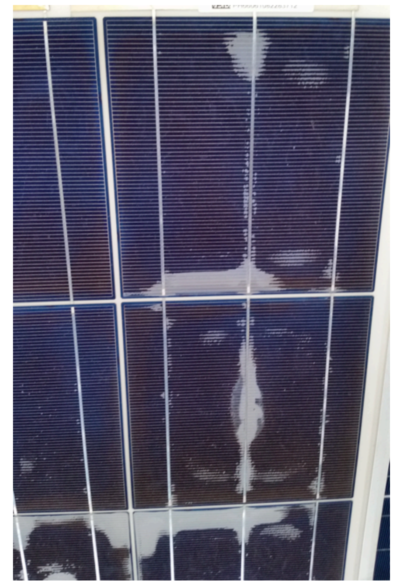

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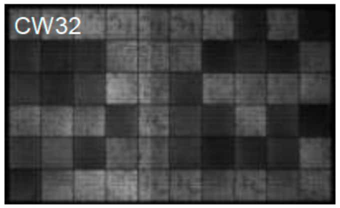
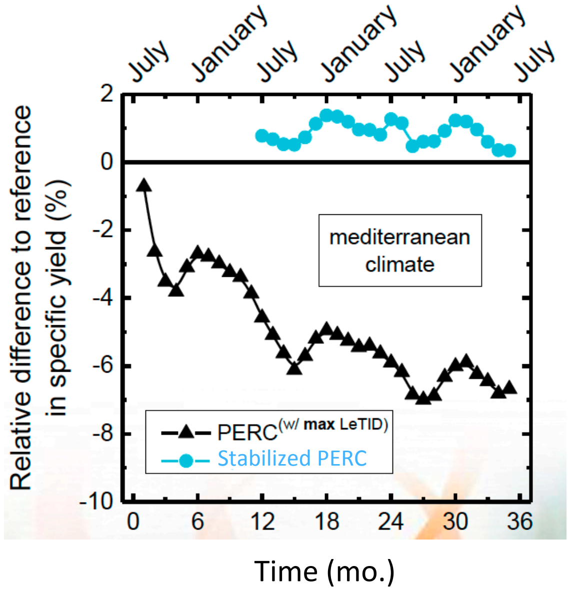


Grid finger corrosion – delamination



Light and elevated temperature induced degradation ↑

Light, elevated temperature, current

Snail trails→ delamination

Mechanisms missed by conventional tests

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Grid finger corrosion – delamination

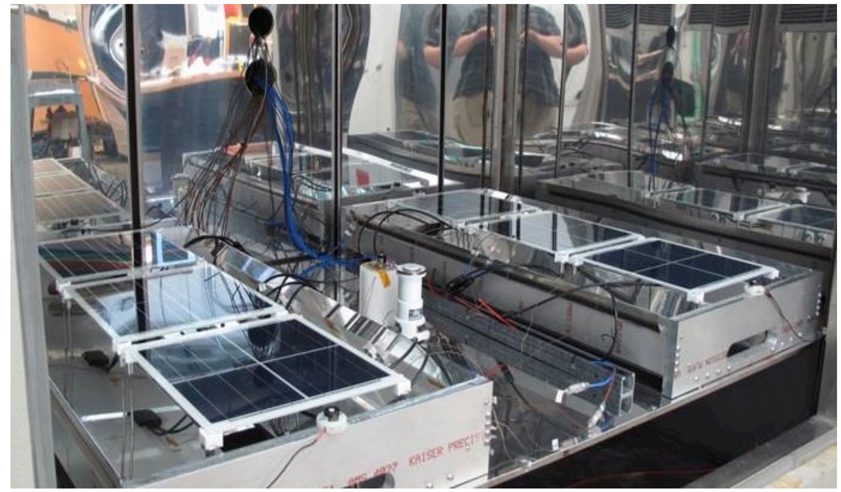
Light and elevated temperature induced degradation

Snail trails→ delamination→

Mech. load, UV, electric field, moisture, impurities

Combined - Accelerated Stress Testing – Overview

- **Stress factors of the natural environment applied using mini module platform:**
  - *light (with partial shading)*
  - *temperature*
  - *humidity (uncondensed)*
  - *rain*
  - *system voltage*
  - *mechanical stress*



- **Manifestation of degradation mechanisms**
- **Application of degradation models**
- **Comparison with field failures**
- **Applicability and limitations of the 4-cell mini module**
- **Indicators of degradation, characterization (i.e. adhesion, indentation hardness)**
- **In-situ mapping/monitoring**

Stakeholders

- Materials manufacturers
- Film makers
- Module makers (working with several)
- Customers
  - investors
  - Insurance
- Weathering tool makers
- Standards

Key timeline points

- Initial capability development completion, model development
  - *Spring to Fall 2017*
- Screening tests, trials, RFPs with tool
  - *Fall to Winter 2017*
- Backsheet evaluation demonstration (*milestone*)
  - *Winter to Spring 2018*
- Phase 2 of capability development (in-situ IV, imaging, testing…)
  - *2018…*

Test philosophies

Acceleration:

- You can accelerate to the point until you start causing non-field representative degradation mechanisms
  - Need to run multiple conditions for this to examine Arrhenius behavior
- Maintain levels occurring at the high end of that seen the natural environment so that the test is valid for any candidate product you put in it.
  - We will first work under this principle in C-AST

ASTM D7869 Test Cycle

Basis for stress cycle

Step Number	Step Minutes	Function	Irradiance Set Point[1] @340nm ($W/m^2/nm$)	Black Panel Temperature Set Point[1]	Chamber Air Temperature Set Point[1]	Relative Humidity Set Point[1]
1	240	dark + spray	-	-	40°C	95%
2	30	light	0.40	50°C	42°C	50%
3	270	light	0.80	70°C	50°C	50%
4	30	light	0.40	50°C	42°C	50%
5	150	dark + spray	-	-	40°C	95%
6	30	dark + spray	-	-	40°C	95%
7	20	light	0.40	50°C	42°C	50%
8	120	light	0.80	70°C	50°C	50%
9	10	dark	-	-	40°C	50%
10	Repeat steps 6-9 an additional 3 times (for a total of 24 hours = 1 cycle)					

Include a freeze here: -40°C

Move to higher temperature +90°C

Additional factors of mechanical stress and system voltage applied

- Longer dark/spray cycles to achieve moisture uptake levels (saturation)
- Multiple irradiance levels to simulate diurnal outdoor conditions; High level increases acceleration
- No light/spray together it doesn't typically rain in max sunshine conditions
- Interspersed light/dark sub-cycles to simulate thermal shock effects occurring in natural exposures

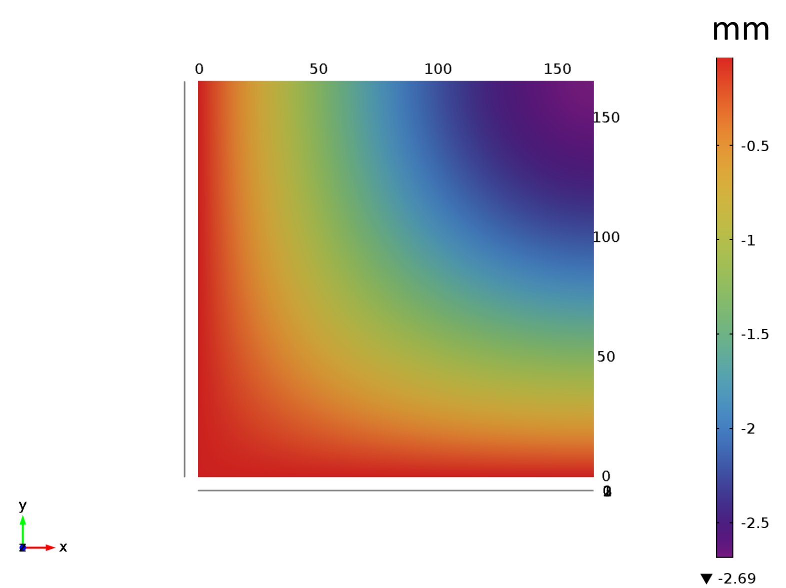
C-AST Test 1 - levels

Factor	Level	Notes
Temperature	-40°C + 90°C module T	Verify actual sample temperature is 90°C
Irradiance	0 to 2 Suns (120 W/m^2 to 400 nm)	Actually, 0.4 W/m^2/nm and 0.8 /m^2 /nm at 340 nm (1 sun = 0.5 W/m^2/nm ASTM G173–03)
HV bias	+ or - 1000 V on cells over load resistor	
Humidity	0-100 %	
Condensation	On/Off (with sprayers)	
Mechanical loading	15 kPa, or greater	

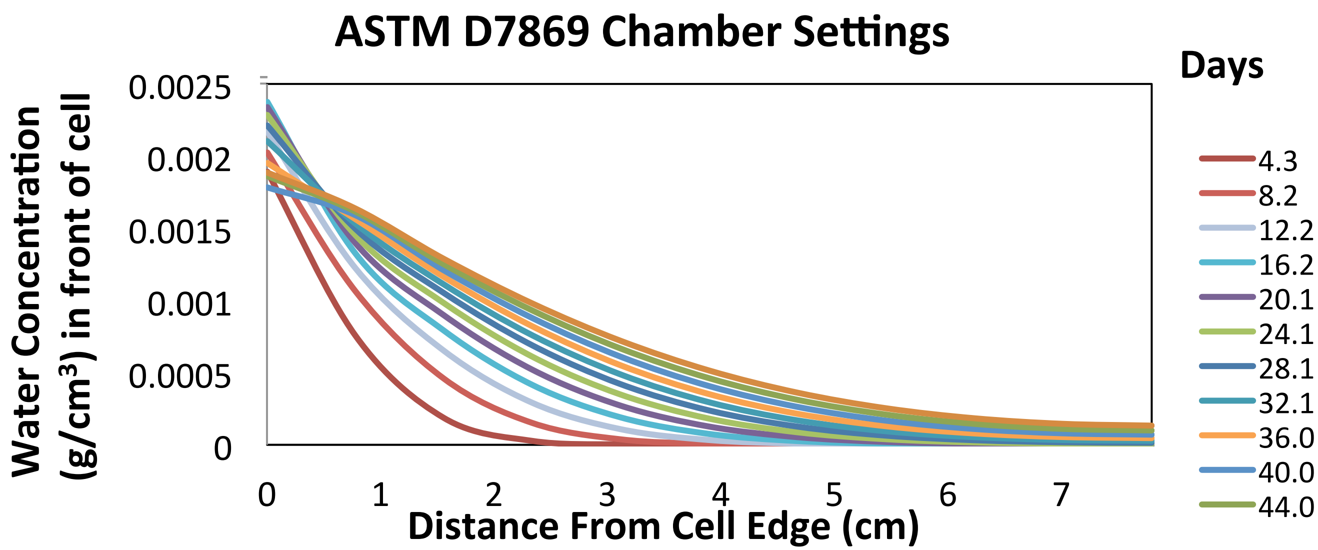
Consideration for reduction to mini - module:

FEA simulation: 1 kPa loading for full size module:15 kPa for 2 x 2 cell mini module.

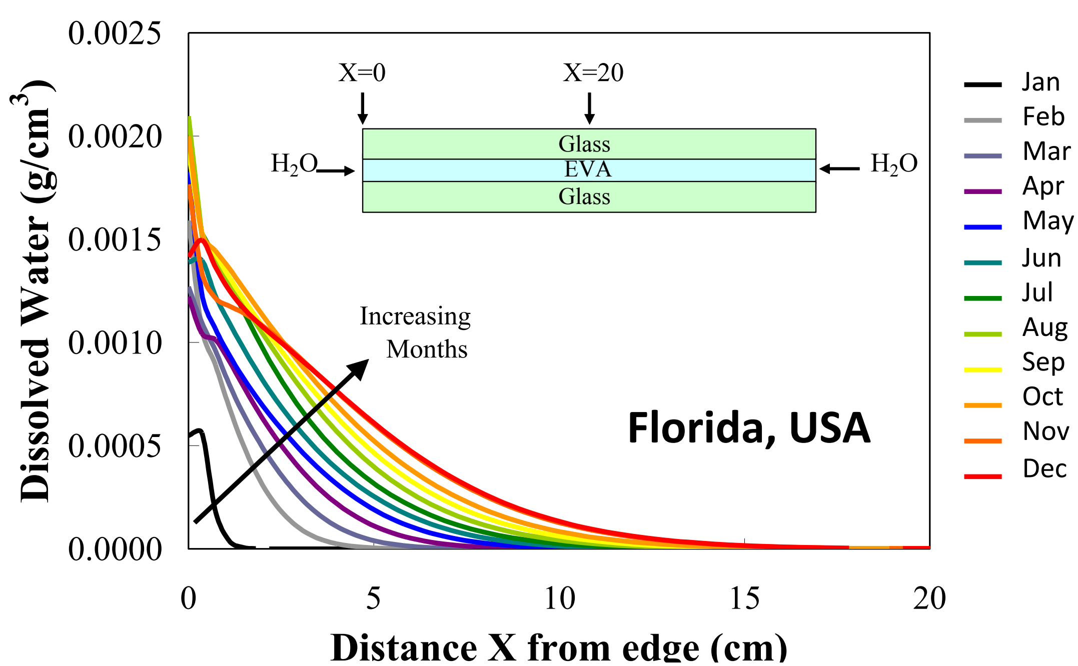
Out of plane displacement ~3 mm at the module center. Tests show similar radius of curvature to full size module at the maximum



Levels: Achieving field-representative humidity



- May apply humidity preconditioning before application of ASTM D7869-type cycle to more rapidly equilibrate moisture content for the testing



Test matrix 6 mini modules
(Demonstration for milestone deliverable)

Initial backsheet demonstration based on:

1) DuPont's experience
2) 130 types of backsheets out there, no clear method for differentiation
3) Focus on safety/integrity now vs. measurements of in-situ module power performance later

Backsheet type

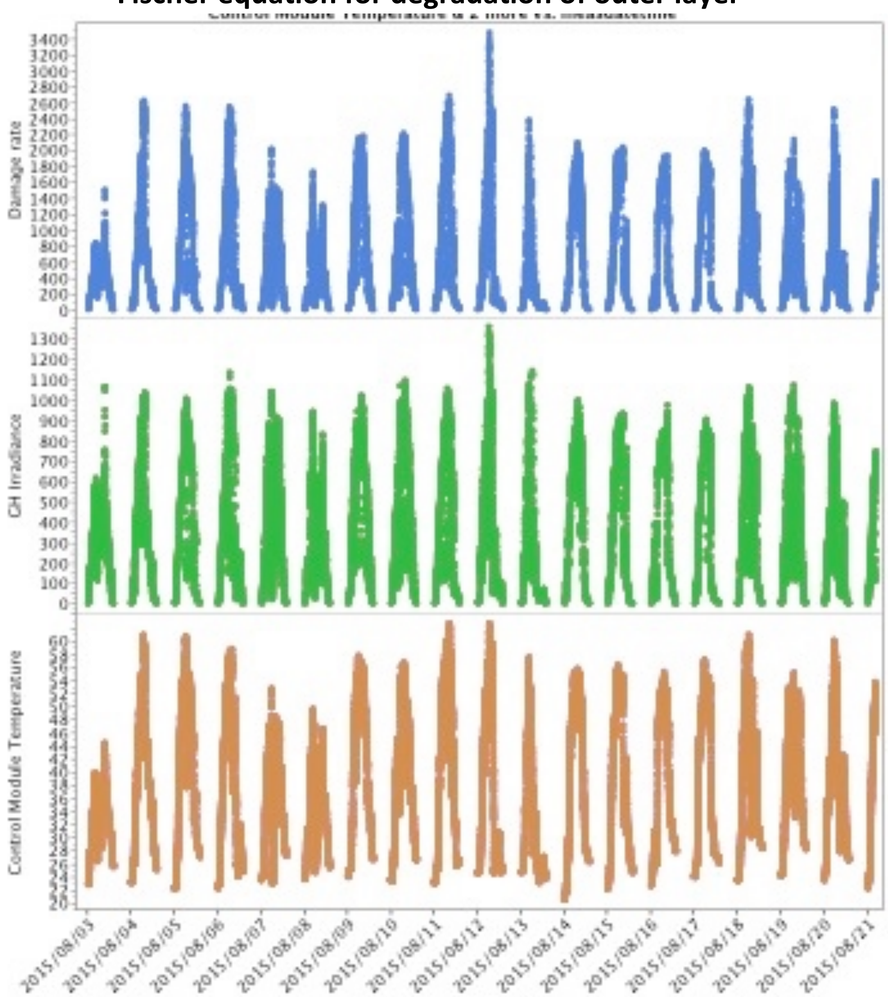
	Tedlar-Polyester-EVA	Polyamide	Stabilized PET
UV absorbing rear EVA	✓	✓	✓
Non UV absorbing EVA	✓	✓	✓

- Primary goal will be to differentiate these backsheets that show various extents of degradation in the field, but not in standardized stress tests

- Secondary goal will be to apply existing degradation rate equations

Degradation modeling - *f*(G,RH, T)

Fischer equation for degradation of outer layer



$$R_D \sim I^x \cdot (b + m \cdot TOW) \cdot T_f^{\frac{T-T_o}{10}}$$

*Fischer *et. al*

T_f=1.41±0.23 Acceleration per 10°C increase.

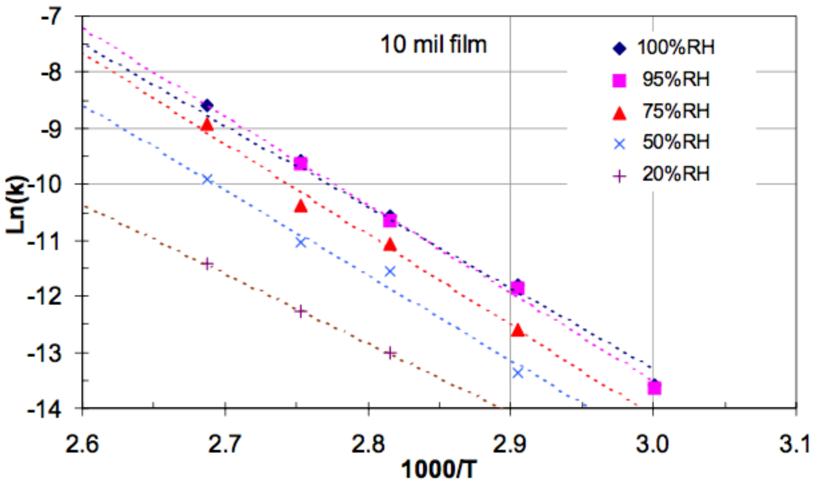
X=0.64±0.2 Irradiance acceleration exponent.

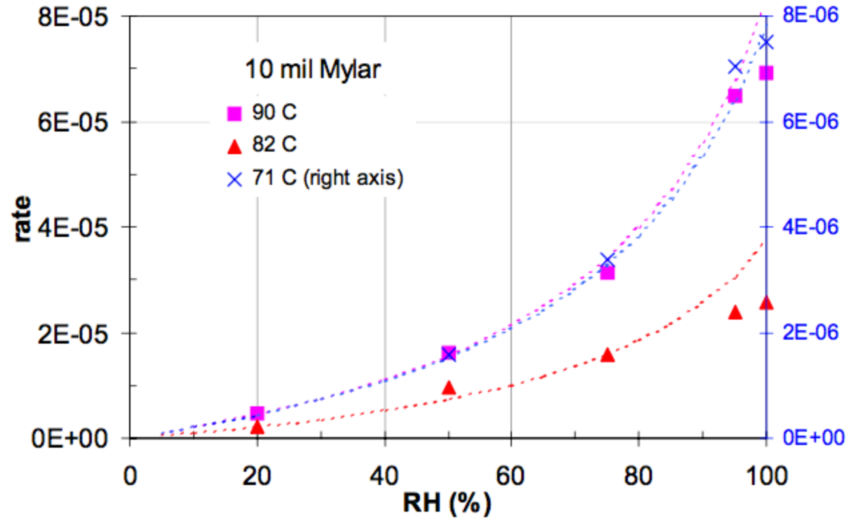
m=-0.0015±0.12 Time of Wetness (TOW) factor.

b=1.071±0.0026

PET Hydrolysis Kinetics

W. McMahon, *et al.*, *J. Chem. Eng. Data*, **4**, 57-79(1959)





$$\log[C/(C\text{-}x)] = kt = A\exp(-E_a/RT)\,[RH_{eff}]\,t$$

$A = 1.55 \times 10^{12}\ \text{hr}^{-1}$

E_a = 29,000 cal/mol (R = 1.987, T in kelvins)

$RH_{eff} = 0.3RH/(1.3\text{-}RH)$

t in hours

brittle when $\log[C/(C\text{-}x)]$ = ~0.0024 (0.6% conversion; $Mw/Mw_o \sim 0.7$)

Thanks for your attention !