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Module Prototyping and Accelerated Durability Testing

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1. Overview

Module prototyping and accelerated testing provides:

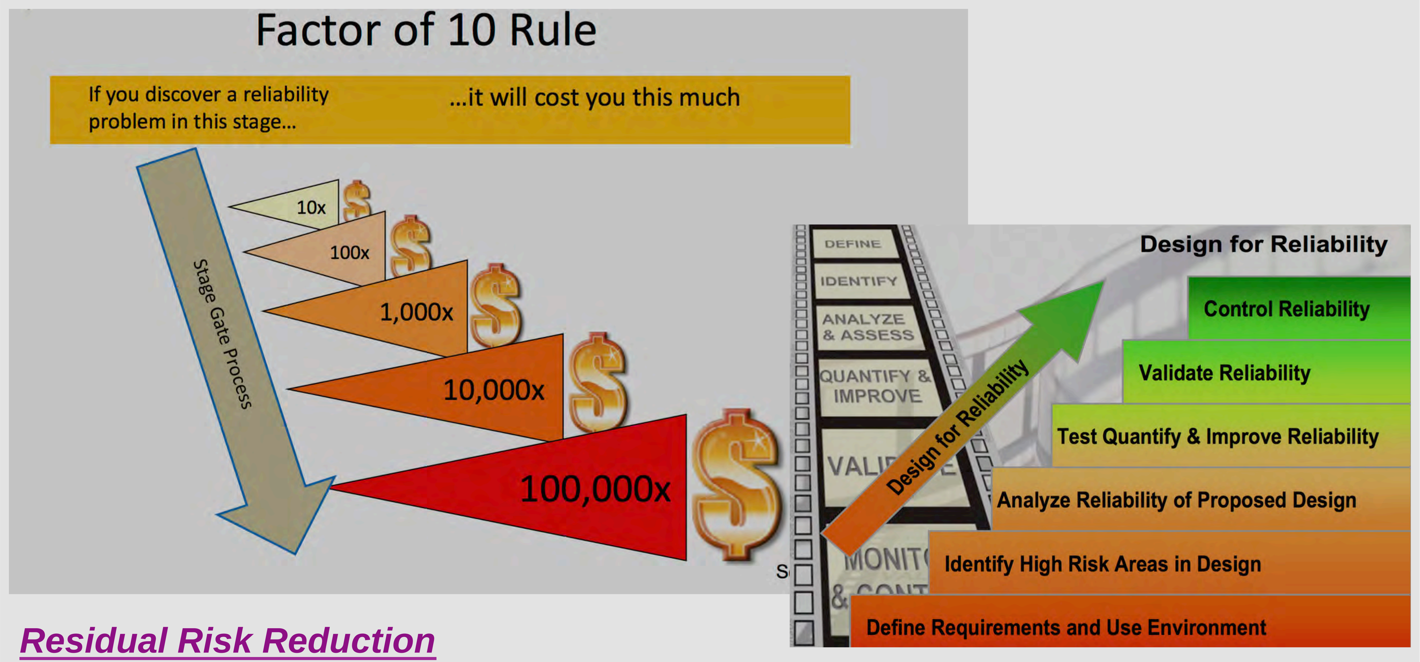
- ***Accelerated time to market***
- ***Bankability***
- ***Reduction of residual risk***

Capability platform offered:

- ***Assembling new module materials, components, prototypes (mini-module to full-size)****
- ***Evaluation of durability and performance using novel simultaneous and combinatorial accelerated stress testing (C-AST)***

**See also poster by Olga Lavrova (Sandia)*

2. Motivation



Residual Risk Reduction

• IEC 61215 Qualification Test
•• Qualification +
••• IEC TS 62941 Guideline for increased confidence in PV module design
•••• IECRE OD-401 System Certification
Significant unquantifiable remaining risk, RESIDUAL RISK, still driving up costs

→ Significant residual risk is reduced by Combinatorial-Accelerated Stress Testing

3. Motivation

Now: mechanism-specific tests

- *Known failure mechanisms*
- *Minimal examination of interdependencies*
- *Numerous modules and multiple parallel tests*

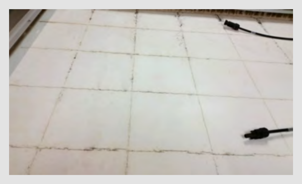
DuraMat: Combinatorial-accelerated stress testing (C-AST)

- *Weathering platform*
- *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*

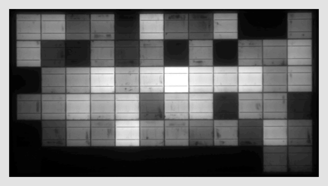
4. Missed by conventional tests

Findable by combinatorial-accelerated stress testing

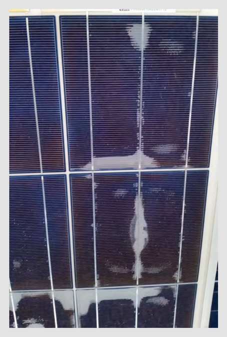
Backsheet cracking →
UV, cyclic oxidative/hydrolytic stress, CTE stress



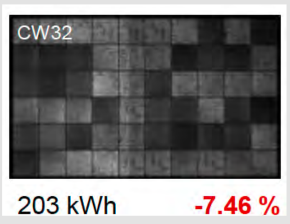
PID-s →
System voltage, humidity, temperature, light, soiling



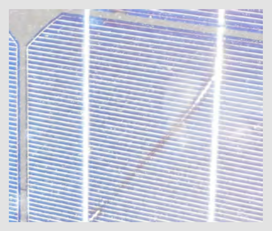
Grid finger corrosion – delamination →
System voltage, humidity, temperature, light, soiling



Light and elevated temperature induced → degradation (LeTID)
Light, elevated temperature, current



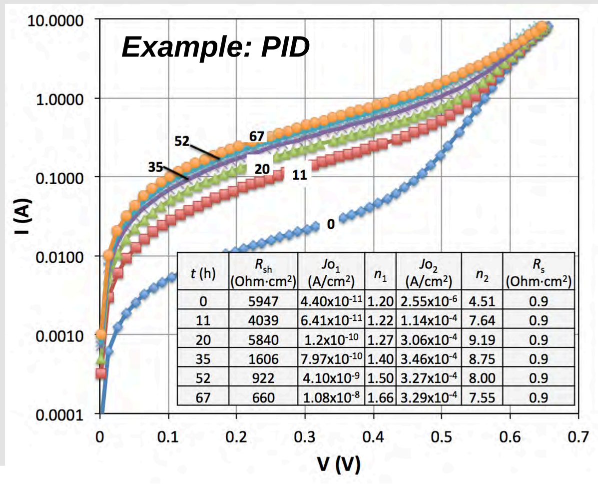
Snail trails→ delamination →
Mechanical load, UV, electric field, moisture



5. Combinatorial-accelerated stress testing (C-AST)

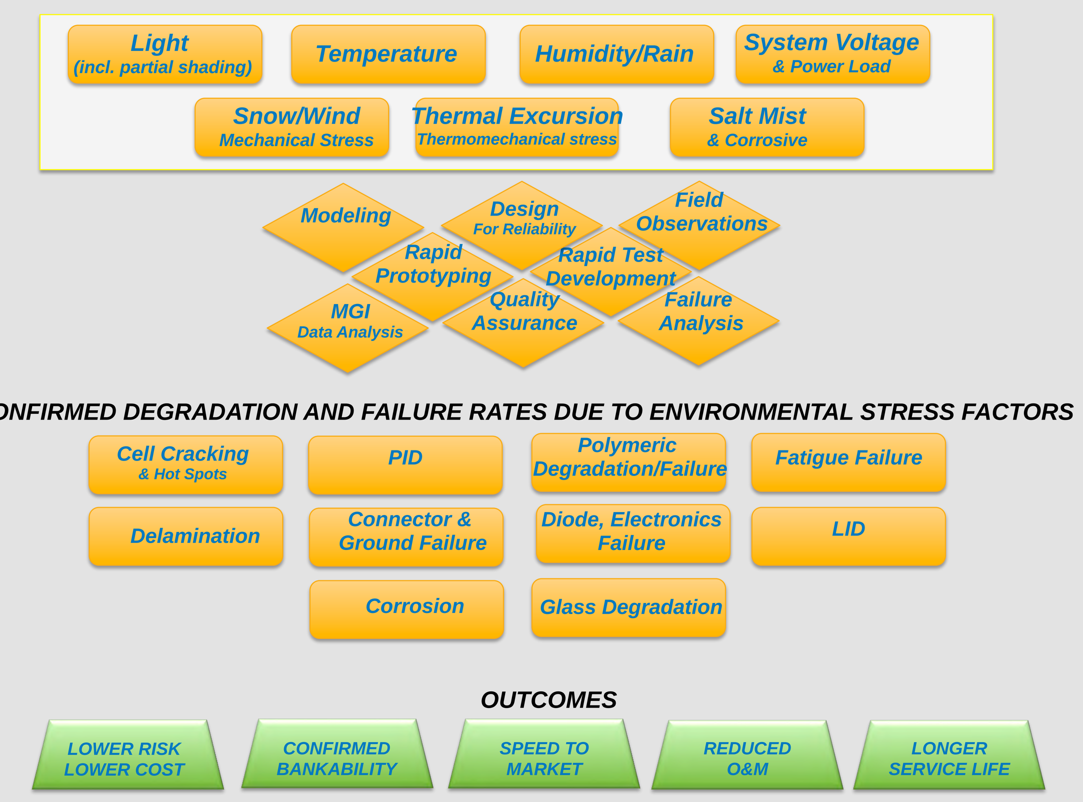
- ***Factors of the natural environment applied in combination on the mini-module platform-→***
  - *Light (with partial shading)*
  - *Temperature*
  - *Humidity (uncondensed)*
  - *Rain*
  - *System voltage*
  - *Mechanical stress*
- ***In-situ monitoring, mapping, DIV→ for in-situ failure analysis***
- ***Database connectivity***
- ***Comparison with field failures, avoidance of overdesign***

>Linked to: coupon testing, DOEs, kinetics, modeling i.e. backsheet weathering, encapsulant yellowing corrosion



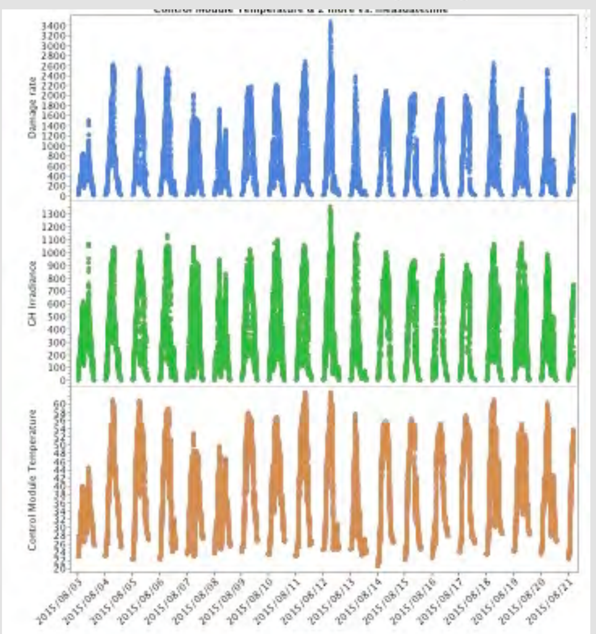
6. Stresses, mechanisms, outcomes

STRESS FACTORS OF THE NATURAL ENVIRONMENT APPLIED IN A SINGLE COMBINED TEST



7. Climate Factors and Levels

Application of the extremes seen in the daily cycles



Candidate damage rate calculation:

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

*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

Candidate C-AST cycle:

- ***Damp heat pre-exposure***
  - *Test weak interface bonds*
- ***ASTM G155-cycle (modified)***
  102 min radiation
  18 min radiation + water spray
  - *Cyclic hydrolytic oxidative stress*
- ***System bias voltage***
  Maximum-power loaded
  Degradation monitored
  - *Cyclic PID-shunting, delamination, corrosion*
- ***Cyclic mechanical loading***
  i.e. per IEC 62782 (modified)
  - *Cracking, hot-spots, metallization failure, moisture ingress, corrosion, delamination*
- ***Thermal cycling***
  Test effects of TCE mismatch

8. Links to other capabilities

Rapidly build and evaluate new module materials, components, and designs
Determine and validate methods for accelerated durability testing
Materials and components
Coupons → mini-modules → full-size modules
DOEs, Kinetics (with coupon testing and individual factors)
***Field deployment:* Validation of durability and failure mechanisms & acceleration factors**
***Predictive simulation:* How to accelerate the weather, model moisture ingress, reactions and phase changes**
***Discovery and Forensics:* Advance in-situ and ex-situ characterization of materials and modules to understand the physics of failure**
***Data analytics:* expanded in-situ/ex-situ stress test data, materials, and construction information recording to database**
***Tech-to-Market:* Develop cost models for materials, modules, and new durability testing useful to the whole value chain**

9. Example applications

- ***Testing new module materials***
- ***Testing of compatibility and interfaces between materials and components***
- ***Comparative testing between new and conventional materials and designs***
- ***Climate-specific testing for performance in hot/humid, hot/dry, temperate, etc.***
- ***Field validation to show how C-AST can replicate field failures with given problematic BOMS***

Interconnects, adhesives, backsheet, encapsulant, frame, glass, grounding parts, and junction box

module level power electronics, contacts/switches, interconnects, and mountings

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