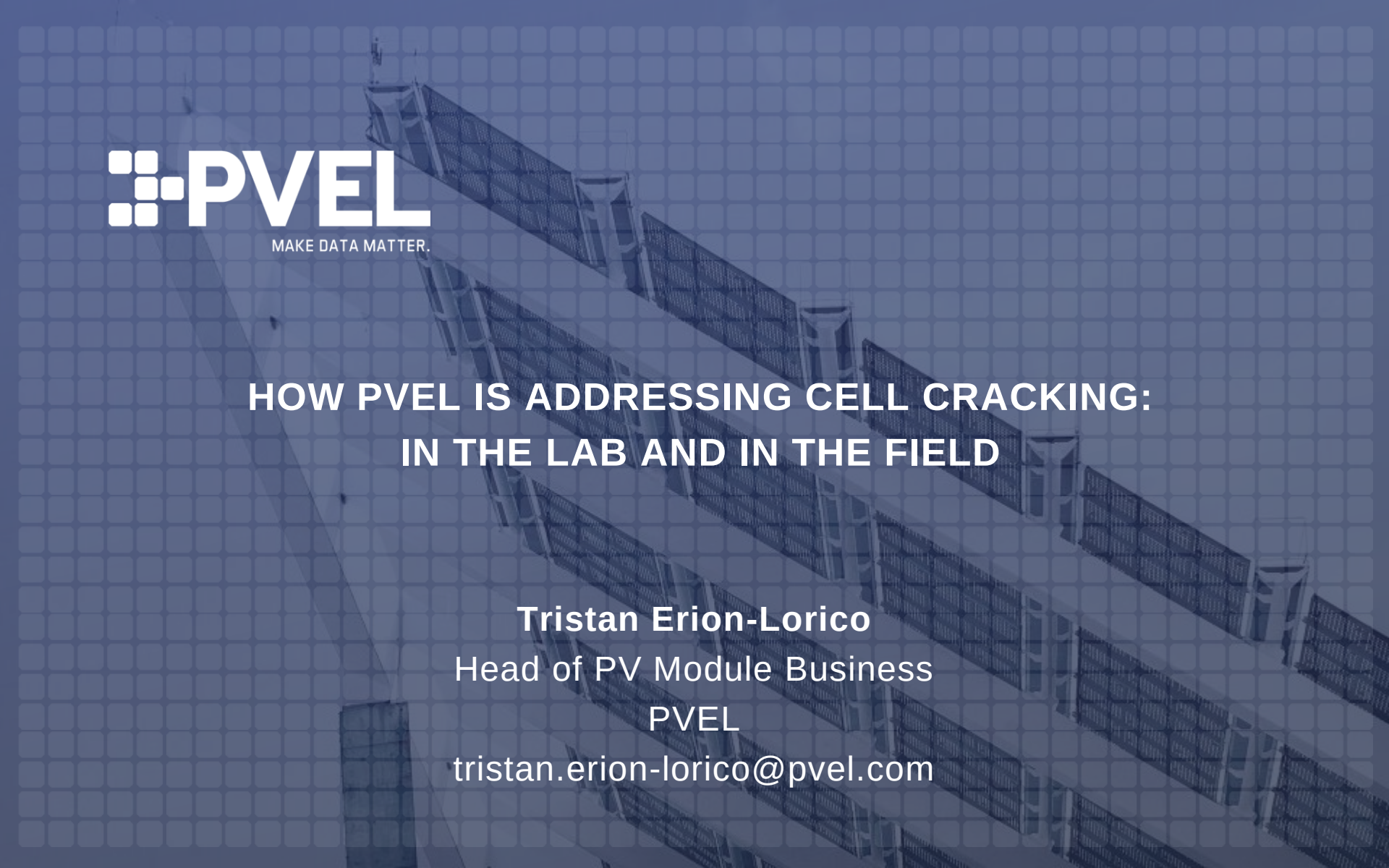

HOW PVEL IS ADDRESSING CELL CRACKING: IN THE LAB AND IN THE FIELD

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PVEL is the Independent Lab for the Downstream Solar Market

Global

300+ downstream partners worldwide with 30+GW of annual buying power

Comprehensive

Testing for every aspect of a PV project from procurement to O&M

Experienced

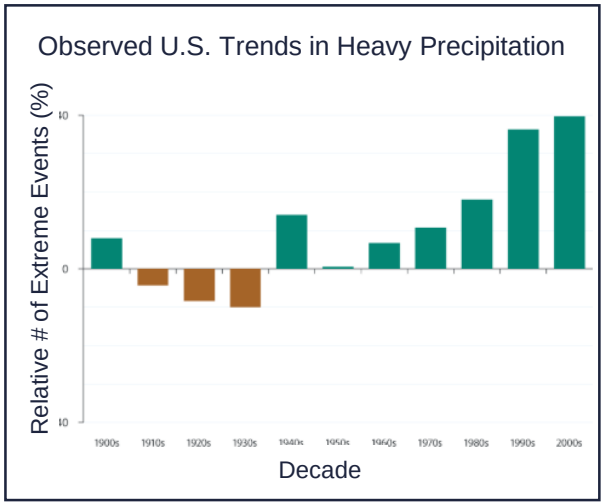
Pioneered bankability testing for PV products nearly a decade ago

Market-driven

Continuously refining test programs to meet partner needs

The solar industry needs an action plan for extreme weather

More Severe Weather



Source: National Climate Assessment 2014

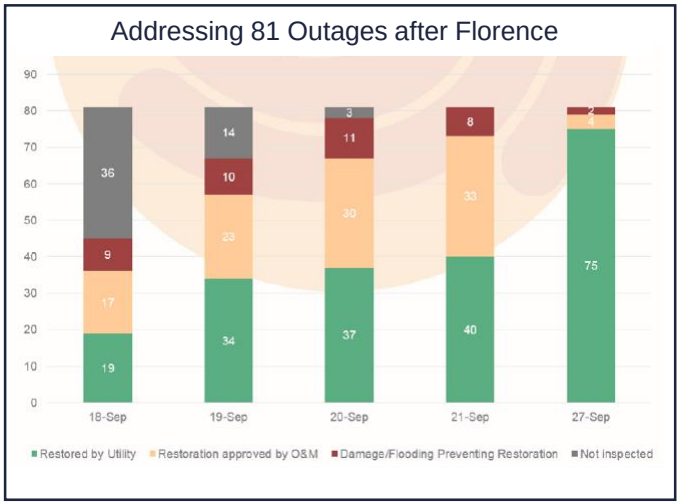
Insurance Landscape

GCube reports their weather-related claims in the renewables sector **doubled in 2018.**

GCube
Renewable Energy Insurance

Source: GCube, “Global Extreme Weather Losses Mount”

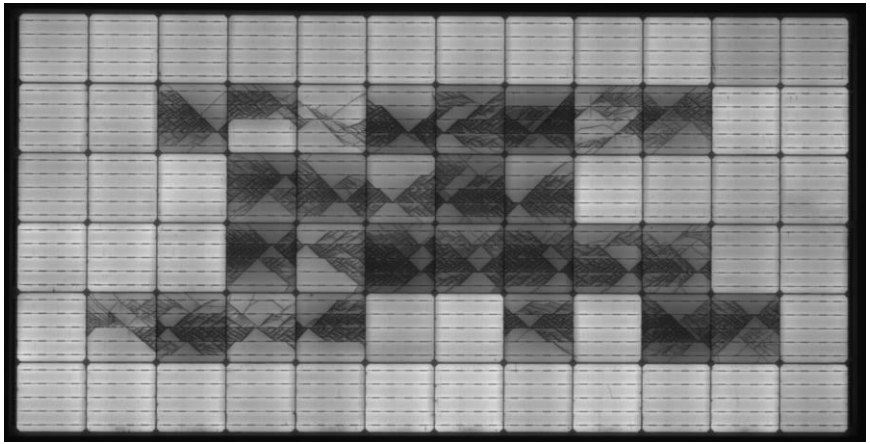
Returning to Operations



Source: Strata Solar, “Force Majeure & Energy Modeling: 1 Hurricane, 81 PV Plants Down”

Understanding cell cracking in PV modules

- Cells are *quite* thin (<0.2 mm)
- Glass thickness is 3.2 mm
- Causes of cell cracks:
  - Manufacturing defects
  - Transportation and shipping
  - improper installation
  - Force majeure/extreme weather events



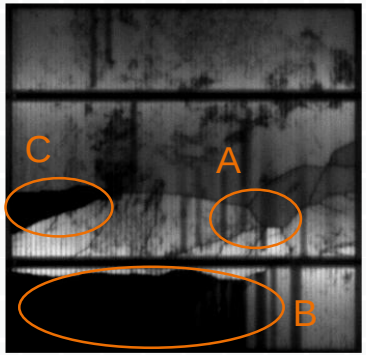
The Main Challenge:
Power loss is realized **over time** – not right away

Evaluating power loss and financial loss due to cell cracks

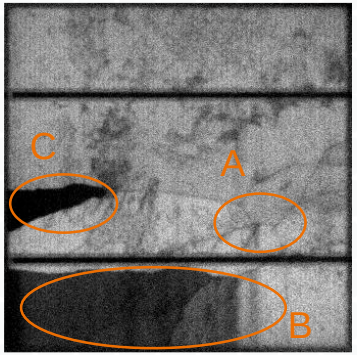
The bottom line: impact varies

- The potential for power loss varies by the type of crack
- Financial losses depend on model assumptions

EL Image at Isc



EL Image at 1/10 Isc



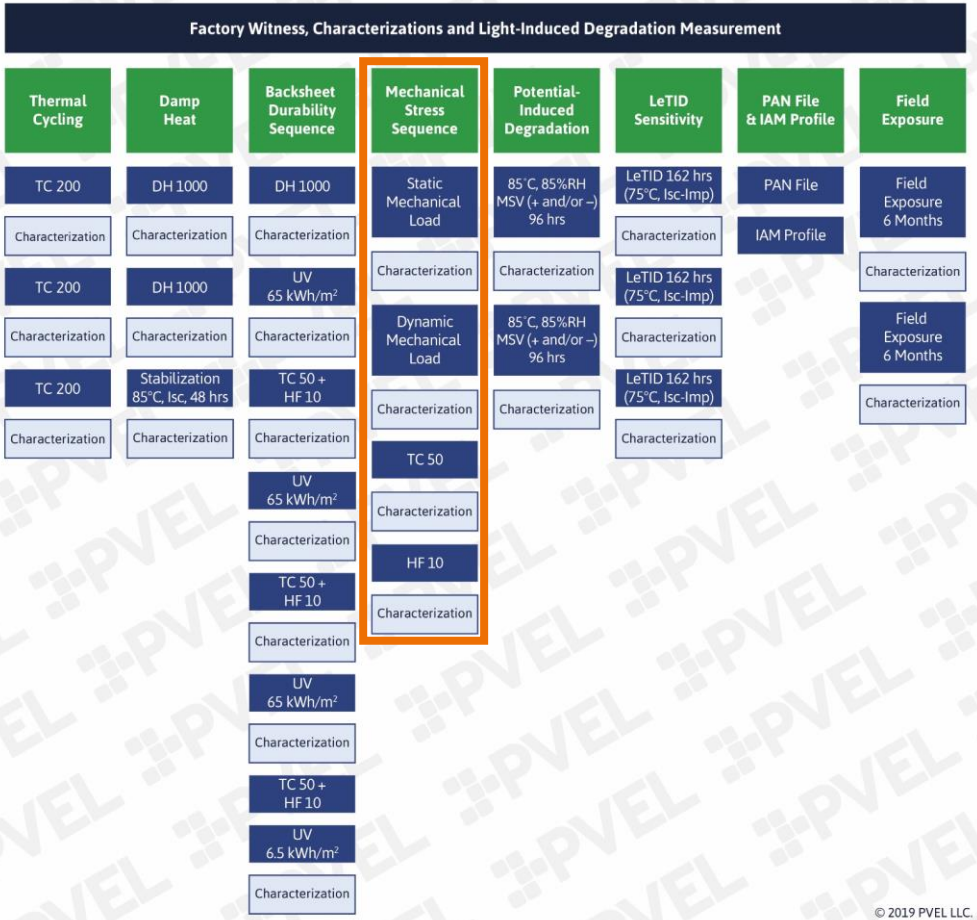
A: No resistance across crack
B: Degraded, still connected, but increased resistance
C: Isolated, inactive cell area

Source: Köntges et al., “Crack statistic of crystalline silicon photovoltaic modules,” Institute for Solar Energy Research Hamelin, (2010)

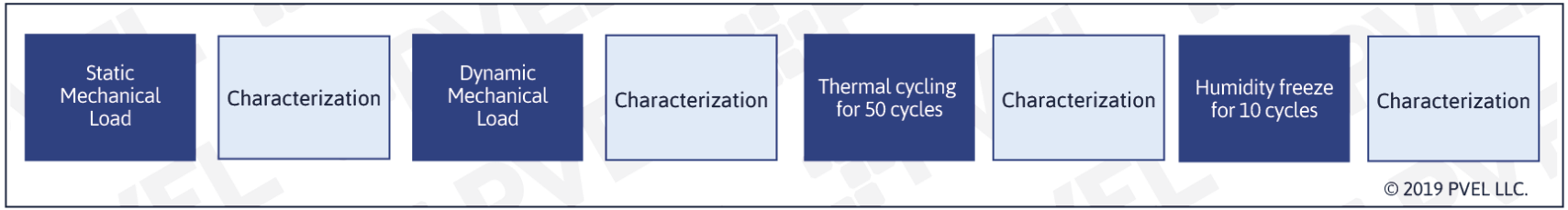
Certification testing for cell cracks

- IEC 61215
  - Static mechanical load testing at 2400 Pa with options for up to 5400 Pa
  - Includes minimum hail testing: 1” hail balls at 50 mph
- Challenges
  - No thermal cycling after stress
  - No dynamic mechanical loading
  - A pass means:
    - <5% power loss
    - No physical damage
    - **EL imaging not required**

PVEL's Module Product Qualification Program (PQP) Test Sequences



PVEL's mechanical stress sequence for cell cracking



Step 1:
Creates cell cracks in susceptible modules

Step 2:
Articulate cracks, opening them in susceptible modules

Step 3:
Reduces power output in susceptible modules

New Incident Response testing combines advanced field and aerial inspection to safeguard against financial losses

Incident Response:
A better way to manage force majeure events

Fires | Tornadoes | Hurricanes | Lightning | High Wind | Hail

Incident Response helps you:

1. Quantity the full extent of damage to a site
2. Prioritize repairs to quickly return sites to operation
3. Receive full insurance compensation

Hypothetical: A 100 MW site is hit by major wind and hail storm

- 270,000 370W modules on site are visually inspected
- 5% show visible damage and must be replaced – 13,500 modules
- Assumptions:
  - $0.35 USD/watt for PV modules
  - $50/module for labor

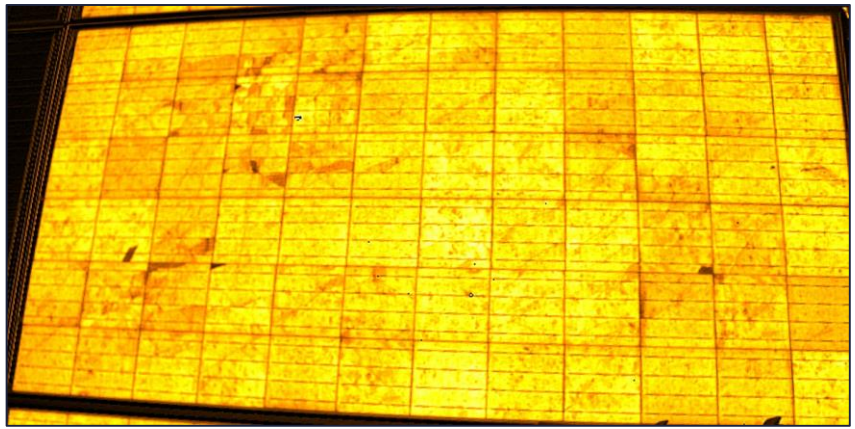
Value of insurance claim for visually inspected PV modules:
$2.42M

100 MW site damaged by major wind and hail storm
(Image Source: Heliolytics)

Insurance payout based on Incident Response

- EL imaging reveals that 15% of the modules on site have significant cell cracks
- An additional 40,500 modules must be replaced

Total payout for all damaged PV modules:
$9.69M – nearly 4x



EL image of cell cracked PV module in the field

QUESTIONS, AND THANKS!

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