

Reliability Consensus

- Textbook definition of ‘reliability’ as it might apply to our case: “a reliable PV module has a ‘high probability’ that it will perform its intended purpose adequately for 30 years, under the operating conditions encountered.”
- A PV module fails to provide service if its power output decreases by more than 30% before 30 years, e.g., require a loss less than 1%/yr, in its use environment.
- A ‘high probability’ could mean that 95% of the modules in the field will achieve this success.
- ‘Use environment,’ we mean any and all use environments that the PV module will experience during service. Site meteorology, handling, and installation are included in use-environment considerations.

FMs: Modules General

Field returns and anticipated failures

- ☐ Front Sheet/Encap failure
- ☐ Cell/Encap failure
- ☐ Back Sheet/Encap failure
- ☐ Stress breakage of glass/glass laminate
- ☐ Glass edge damage/breakage
- ☐ Corrosion of grid lines
- ☐ R_{series}
- ☐ Poor solder joint(string ribbons and J-boxes)
- ☐ By-pass diode failure
- ☐ Frame/mounting failure
- ☐ Failure of electrical safety

FMs: Modules Technology Specific

Field returns and anticipated failures

Wafer Si:

- ☐ Crack formation in thinner cells
- ☐ Solder joint degradation on cells
- ☐ Ribbon related open circuit or shunting

Thin Film:

- ☐ Flexible packaging interconnect failure
- ☐ Laser scribe interconnect failure
- ☐ De-adhesion of device layers, inc. CTOs and metal contacts
- ☐ Busbar adhesion and electrical contact
- ☐ Weak diode or shunt defects
- ☐ Decreasing ff (field collection or series resistance issues)
- ☐ Moisture ingress problems, esp. flexible with CIS
- ☐ Diffusion, esp. Cu in CdTe
- ☐ Staebler-Wronski, esp. single junction a-Si
- ☐ SnO₂ corrosion in superstrate cells

FMs: Modules Technology Specific

Field returns and anticipated

CPV (both low X and high X):

- **Degradation of optics (abrasion, corrosion of mirrors, yellowing, soiling, etc.) [either use this one or the next ones]**
- **Corrosion of mirrors**
- **High-flux damage to mirrors**
- **Abrasion of optics**
- **Voids or failures in solder bond between cell and heat sink**
- ☐ **Tracker mechanical breakdown**

High-X CPV:

- **Tracker pointing error**
- **Melting of or bubble formation in optical bond between cell and optic**
- **Cracking of optical bonding material**
- **Dopant or metal diffusion that affects electrical function**
- **Cracking of cells**

FMs: Inverters and BOS

Field returns and anticipated failure

Inverters

- **Failure due to improper torque on dc/ac terminal block**
- **Oxidation on improper/poor connections**
- **Breakage due to improper packaging (securing of heavy components e.g. transformers, capacitors, inductors)**
- **Failures due to tracking on PCB**
- **Failure of LCD display**
- **Mis-operation/failure of inverter integrated ac/dc disconnects**
- **Loss of communication**
- **Failure due to loss of active cooling component (s)**

FMs: Inverters and BOS

Field returns and anticipated failures

Inverters

- ☐ Loss of sensors
 - ☐ temperature
 - ☐ current
 - ☐ voltage
- ☐ Improper/loss of surge suppression devices
- ☐ Loss of control circuitry
- ☐ Failure of power supply (PCB)
- ☐ Failure of power electronic drive circuitry
- ☐ Failure of power electronic device/protection circuitry
- ☐ Failure of capacitors/inductors other filter components

FMs: Inverters and BOS

Field returns and anticipated failures

BOS

- ☐ Failure of string combiners (element intrusion)
- ☐ Fuse failures
- ☐ Conductor insulation breakdown
- ☐ Improper torque on connectors
- ☐ Improper connectors
- ☐ Failure of disconnects
- ☐ Failure of isolation transformers
- ☐ Loss of surge suppression devices
- ☐ Loss of GFI circuitry
- ☐ Loss of communications

AA Tests to Reveal Dominant Failure Modes

- **Commonly agreed dominant failure modes and required testing :**
 - Primary thin-film accelerated aging tests to reveal their dominant failure modes (device instability, corrosion, delamination, interconnects, and packaging integrity) are 1000h 85%rh/85°C, Thermal cycling with current bias, and 1000h light soak. Use I-V and IR imaging characterization.
 - Primary crystalline silicon accelerated aging tests to reveal their dominant failure modes (soldering, μ -cracks in thin-cells, and corrosion) are 1000h 85%rh/85°C, thermal cycling with current bias, and ????. Use I-V and IR imaging characterization.
- **Less well understood failure modes and required testing :**
 - Primary concentrating system accelerated aging tests to reveal their dominant failure modes (breakdown of electrical insulation, interconnect failures, corrosion, bypass diode failure, and misalignment of components) are Wet and dry insulation tests, thermal cycle tests of 500, 1000 or 2000 cycles at respective maximum temperatures of 110 C, 85 C or 65 C (depends on materials under test) with current bias, 85% humidity-freeze thermal cycling, bypass diode heat test, and off-axis beam damage test.(thanks Bob McConnell) .
 - Service life prediction AA testing requires detailed knowledge of all the failure modes for each of the module types produced in all use environments; if change in parts, design or materials supplier occurs, a new SLP must be conducted!!! We instead propose establishing a test protocol for the dominant failure modes for the established technologies first, followed by the developing technologies next. This protocol will have predictive capability and be a major undertaking.