



# Fielded PV Module Condition

*27<sup>th</sup> EU PVSEC and IEA PVPS Task 13 Subtask 3.2 Meeting*

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NREL/PR-5200-56781





# Cataloging Module Condition by Visual Inspection

## The Need-

Understanding PV module aging in different climate zones is crucial for predicting lifetime, but **no accepted tool for the collection of large-scale, consistent data on module degradation exists**



NREL/PIX 11060, NREL/PIX 14729

## The Charge-

IEA PVPS Task 13: Performance and Reliability of PV Systems, Subtask 3.2: Collecting Failures and Adapting Testing Methods to Failure Mechanism for PV Modules (Lead: Marc Koentges)

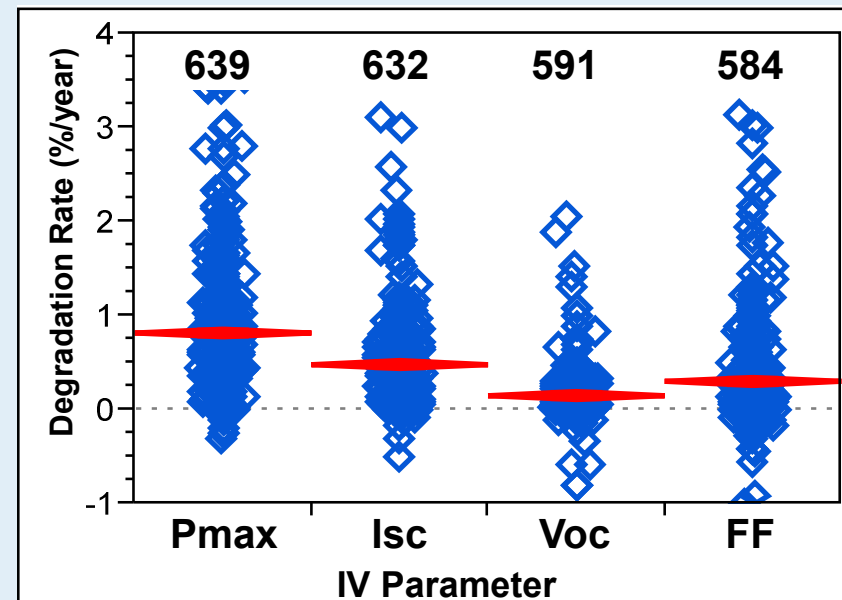
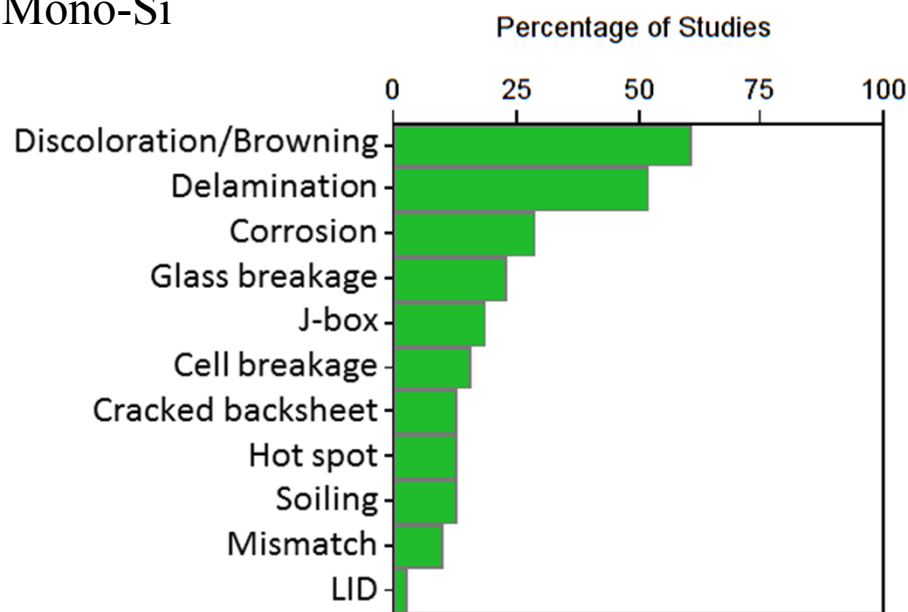
**NREL's Role- Create an inspection tool for documentation of visually observable defects in PV modules**



# Connecting visually observed defects to power loss

- Important for prediction of lifetime and setting of warranty

Mono-Si



Dirk Jordan, Thursday 15:15, 4DO.5.1

PVPS

Visual  
Observations



Electrical  
Measurements

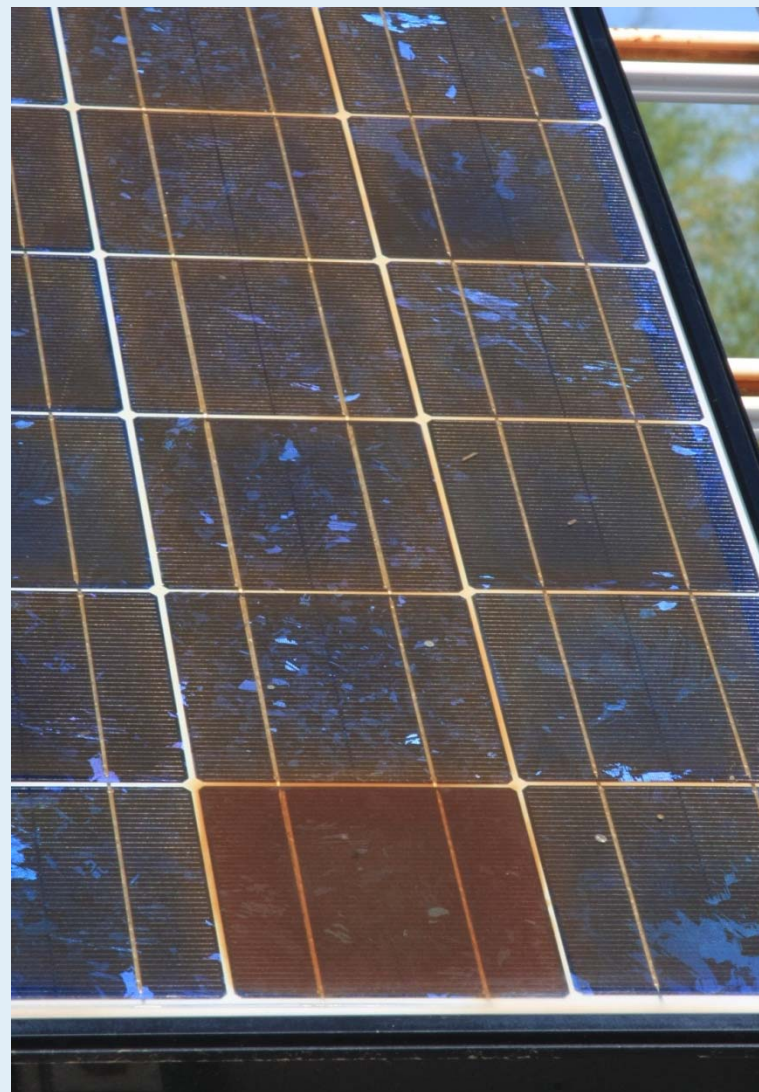
Establish Causality



# Quantification and standardization are necessary

## Describe the problems with this module

- *Brown with one spot worse than others*
- *One cell is orange*
- *Minor and major discoloration*
- *Overheating over the junction box*
- *Severe encapsulant yellowing*
- *...etc.*





# Overview of Visual Inspection Data Collection Tool

- Uses IEC/UL standard terminology
- Attempts to balance collection of sufficient detail for failure mode evaluation against minimizing recording time per module
- Consists of 14 sections- based on module component
  - Long form & short form evaluations

Additional detail can be found in the  
full NREL report TP-5200-56154

***Development of a Visual Inspection Data Collection Tool  
for Evaluation of Fielded PV Module Condition***

*C.E. Packard, J.H. Wohlgemuth, S.R. Kurtz*



**Development of a Visual  
Inspection Data Collection Tool  
for Evaluation of Fielded PV  
Module Condition**

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy  
Efficiency & Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Technical Report  
NREL/TP-5200-56154  
August 2012

Contract No. DE-AC36-08GO21308





# Development of the Inspection Tools

- Developed by members of NREL's PV Reliability Group (led by Sarah Kurtz) with input from IEA Collaborators
  - Ulrike Jahn (TÜV Rheinland Immissionsschutz und Energiesysteme GmbH, Germany), Karl Berger (Austrian Institute of Technology), Thomas Friesen (Scuola Universitaria Professionale della Svizzera Italiana), Marc Koentges (Institut fuer Solarenergieforschung GmbH Hameln/Emmerthal)
- Evaluated with a total of >60 modules from 3 different sites.
  - Broad range of technologies, vintages, and field exposure times
- Based on ***SYMPTOMS, not DIAGNOSES***
  - Unexpected degradation can't be captured if you don't know what you're looking for



# 1. System Data

## Documentation of module condition

Date \_\_\_\_\_ Name of data recorder \_\_\_\_\_

Location \_\_\_\_\_

Latitude \_\_\_\_\_ Longitude \_\_\_\_\_ Altitude \_\_\_\_\_

## 1. System Data

**System design:** ☐ single module ☐ multiple modules ☐ unknown

**Multiple module system:** ☐ not applicable

Module location/number in a series string (from negative) \_\_\_\_\_

# of modules in series (string) \_\_\_\_\_ # of strings in parallel (array) \_\_\_\_\_

# of bypass diodes \_\_\_\_\_ # of modules per bypass diode \_\_\_\_\_

**System Bias:** ☐ open circuit ☐ resistive load ☐ max. power tracked ☐ short circuit  
☐ unknown

**System Grounding:** ☐ negative ☐ positive ☐ center tap on one ☐ unknown

**BEGIN INSPECTION AT BACK SIDE OF MODULE**



# 2. Module Data

Technology: ☐ mono Si   ☐ multi Si   ☐ a--Si   ☐ CdTe   ☐ CIGS/CIS  
☐ other: \_\_\_\_\_

Certified: ☒ unknown   ☐ UL 1703   ☐ IEC 61215   ☐ IEC 61646   ☐ IEC 61730  
☐ other: \_\_\_\_\_

As indicated on nameplate

Estimated deployment date \_\_\_\_\_

Photo taken of nameplate: ☒ yes   ☐ no

Manufacturer \_\_\_\_\_

Model # \_\_\_\_\_

Serial # \_\_\_\_\_

Installation Site/Facility Serial # \_\_\_\_\_

Width \_\_\_\_\_ cm   Length \_\_\_\_\_ cm

Nameplate: ☐ nameplate missing

$P_{max}$  \_\_\_\_\_    $V_{oc}$  \_\_\_\_\_    $J_{sc}$  \_\_\_\_\_

Sys Volt \_\_\_\_\_    $V_{max}$  \_\_\_\_\_    $I_{max}$  \_\_\_\_\_

Bypass diode,  $I_f$  \_\_\_\_\_

Series fuse \_\_\_\_\_







# 3. Rear-side Glass

## 3. Rear-side Glass: ☐ not applicable ☐ applicable

**Damage:** ☐ no damage ☐ small, localized ☐ extensive

Damage Type (mark all that apply):

☐ crazing or other non--crack damage

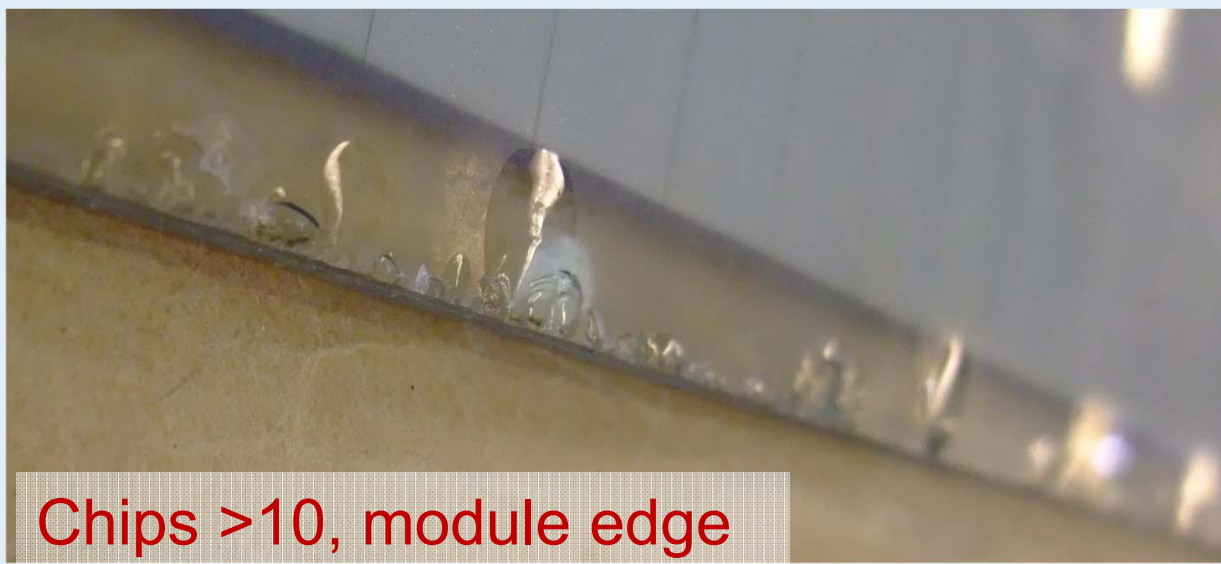
☐ shattered (tempered ) ☐ shattered (non-tempered ) ☐ Cracked (a.) ☐ Chipped (b.)

(a.) Cracks (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

Crack(s) start from: ☐ module corner ☐ module edge ☐ cell ☐ junction box

(b.) Chips (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

Chipping location: ☐ module corner ☐ module edge

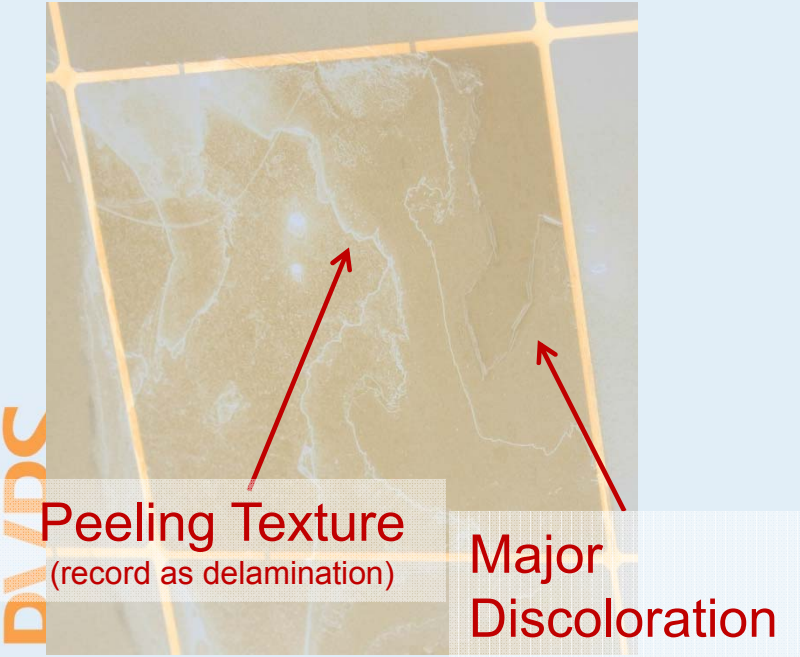


Chips >10, module edge

# 4. Backsheet

4. Backsheet: ☐ not applicable ☐ applicable

- Appearance: ☐ like new ☐ minor discoloration ☐ major discoloration
- Texture: ☐ like new ☐ wavy (not delaminated) ☐ wavy (delaminated) ☐ dented
- Material quality --chalking: ☐ none ☐ slight ☐ substantial
- Damage: ☐ no damage ☐ small, localized ☐ extensive
- Damage Type (mark all that apply):
- ☐ burn marks (a.) ☐ bubbles (b.) ☐ delamination (c.) ☐ cracks/scratches (d.)







## 4. Backsheet- Detail on Damage Type

Damage Type (mark all that apply):

☒ burn marks (a.) ☐ bubbles (b.) ☐ delamination (c.) ☐ cracks/scratches (d.)

(a.) Burn marks (#): ☐ 1 ☒ 2 ☐ 3 ☐ 4--10 ☐ >10

Fraction of area burned:

☒ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

(b.) Bubbles(#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

Average bubble dimension: ☐ <5mm ☐ 5--30mm ☐ >30mm

Fraction of area with bubbles > 5 mm:

☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

(c.) Fraction of area delaminated:

☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

Fraction of delamination that exposes circuit or cell(s)

☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

(d.) Cracks/scratches (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

Cracks/scratches location: ☐ random/no pattern ☐ over cells ☐ between cells

Fraction of area affected by cracks/scratches (approx.):

☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

Fraction of cracks/scratches that expose circuit (approx.):

☐ 0% ☐ 25% ☐ 50% ☐ 75% ☐ 100%



Burn Marks



# 5. Wires/ Connectors

## 5. Wires/Connectors:

**Wires:** ☐ not applicable ☐ like new ☐ pliable, but degraded ☐ embrittled

(mark all that apply): ☐ cracked/disintegrated insulation ☐ burnt

☐ corroded ☐ animal bites/marks

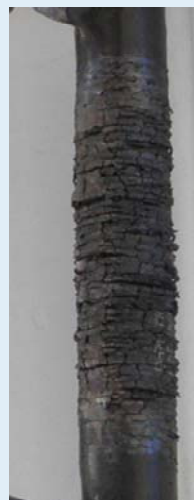
**Connectors:** ☐ not applicable ☐ like new ☐ pliable, but degraded ☐ embrittled

**Type:** ☐ unsure ☐ MC3 or MC4 ☐ Tyco Solarlok ☐ other

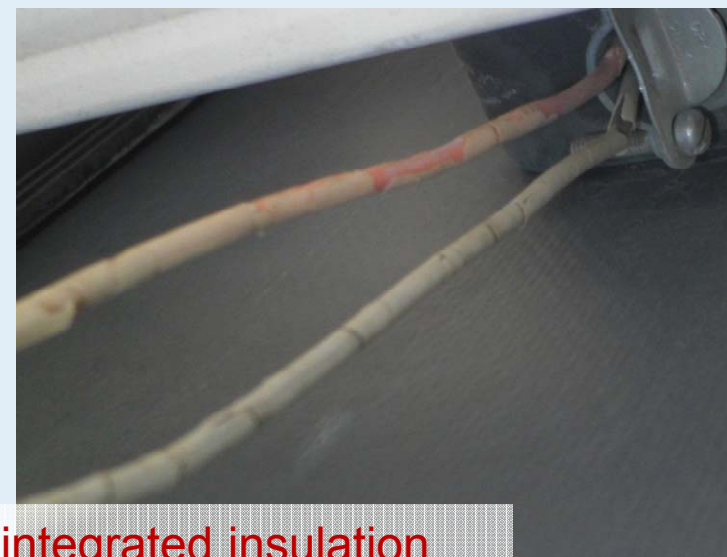
(mark all that apply): ☐ cracked/disintegrated insulation ☐ burnt ☐ corroded



<http://www.gutachten.streib.de/bilder/index.html>



Cracked/disintegrated insulation







# 5. Wires/ Connectors

**Connectors:** ☐ not applicable ☐ like new ☐ pliable, but degraded ☐ embrittled

**Type:** ☐ unsure ☐ MC3 or MC4 ☐ Tyco Solarlok ☐ other

(mark all that apply): ☐ cracked/disintegrated insulation ☐ burnt ☐ corroded

MC3

MC4



Tyco Solarlok

Multi-Contact Staubli Group



Tyco Electronics





# 6. Junction Box

## 6. Junction Box:

**Junction box itself:** ☐ not applicable/observable ☐ applicable

Physical state: ☐ intact ☐ unsound structure

(mark all that apply): ☐ weathered ☐ cracked ☐ burnt ☐ warped

Lid: ☐ intact/potted ☐ loose ☐ fell off ☐ cracked

**Junction box adhesive:** ☐ not applicable/observable ☐ applicable

Attachment: ☐ well attached ☒ loose/brittle ☐ fell off

Pliability: ☐ like new ☐ pliable, but degraded ☐ embrittled

**Junction box wire attachments:** ☐ not applicable/observable ☐ applicable

Attachment: ☐ well attached ☐ loose ☐ fell off

Seal: ☐ good seal ☐ seal will leak

other: ☐ arced/started a fire





# 7. Frame Grounding

## 7. Frame Grounding:

Original state: ☐ Wired ground    ☐ Resistive ground    ☐ No ground    ☐ unknown

Appearance: ☐ N/A    ☐ Like new    ☐ Some corrosion    ☐ Major corrosion

Function: ☐ Well grounded    ☐ No connection

Photos taken of ☐ back, label, and junction box

***CONTINUE INSPECTION ON FRONT SIDE OF MODULE***



## 8. Frame

**8. Frame:** ☐ not applicable ☐ applicable

**Appearance:** ☐ like new ☐ bent ☐ discolored ☐ missing

(mark all that apply): ☐ minor corrosion ☐ major corrosion ☐ frame joint separation  
☐ frame cracking

**Frame Adhesive:** ☐ like new/not visible ☐ degraded

(mark all that apply): ☐ adhesive oozed out ☐ adhesive missing in areas





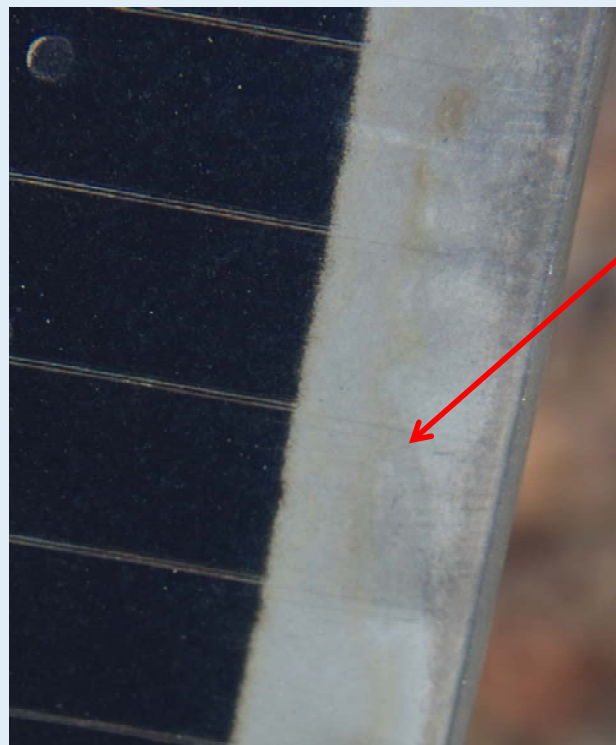


# 9. Frameless Edge Seal

9. Frameless Edge Seal: ☐ not applicable ☐ applicable

Bead of Silicone Around Module Edges

**Not an Edge Seal- NOT Applicable**



White or Gray Polymeric  
Sealant Around Module  
**Edge Seal- Applicable**



# 9. Frameless Edge Seal

## 9. Frameless Edge Seal: ☐ not applicable ☐ applicable

Appearance: ☐ like new ☐ discoloration (a.) ☐ visibly degraded

(a.) Fraction affected by discoloration:

☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)

Material problems:

☐ squeezed/pinched out ☐ shows signs of moisture penetration

Delamination: ☐ local only ☐ widespread

Fraction Delaminated: ☐ <5% ☐ 5--25% ☐ 50% ☐ 75% --100% (consistent overall)







# 10. Glass/Polymer (front)

## 10. Glass/Polymer (front):

Material: ☒ glass ☐ polymer ☐ glass/polymer composite ☐ unknown

Features: ☒ smooth ☐ slightly textured ☐ pyramid/wave texture  
☐ antireflection coating

Appearance: ☐ clean ☒ lightly soiled ☐ heavily soiled

Location of soiling:

☐ locally soiled near frame:

☐ left ☐ right ☐ top ☐ bottom ☐ all sides

☐ locally soiled on glass /bird droppings

Damage: ☐ no damage ☒ small, localized ☐ extensive

Damage Type (mark all that apply):

☒ crazing or other non--crack damage

☐ shattered (tempered ) ☐ shattered (non--tempered ) ☐ Cracked (a.)

☐ Chipped (b.) ☐ milky discoloration (c.)

(a.) Cracks (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

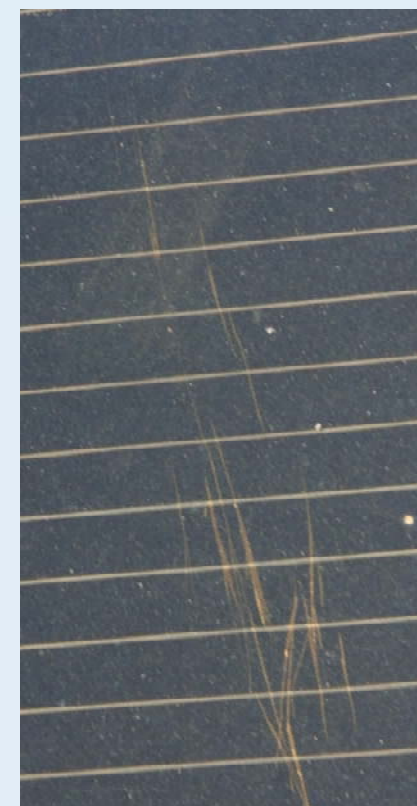
Crack(s) start from: ☐ module corner ☐ module edge ☐ cell ☐ junction box

(b.) Chips (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

Chipping location: ☐ module corner ☐ module edge

(c.) Fraction of area:

☐ <5% ☐ 5-25% ☐ 50% ☐ 75% -- 100% (consistent overall)



Localized scratches  
(non-crack damage)



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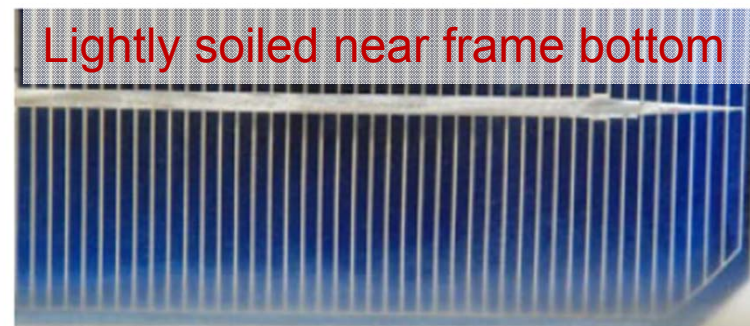
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(b.) Chips (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4--10 ☐ >10

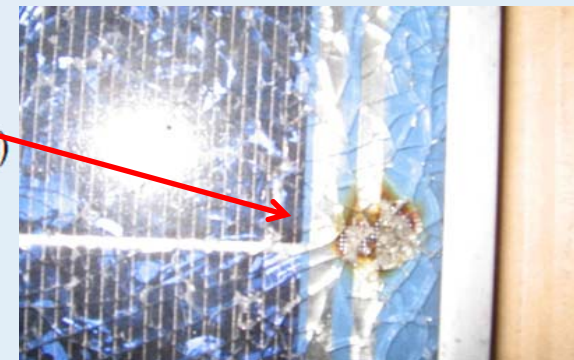
Chipping location: ☐ module corner ☐ module edge

(c.) Fraction of area:

☐ <5% ☐ 5-25% ☐ 50% ☐ 75% -- 100% (consistent overall)



Sanchez-Friera et al. Prog. Photovolt: Res. Appl. 2011



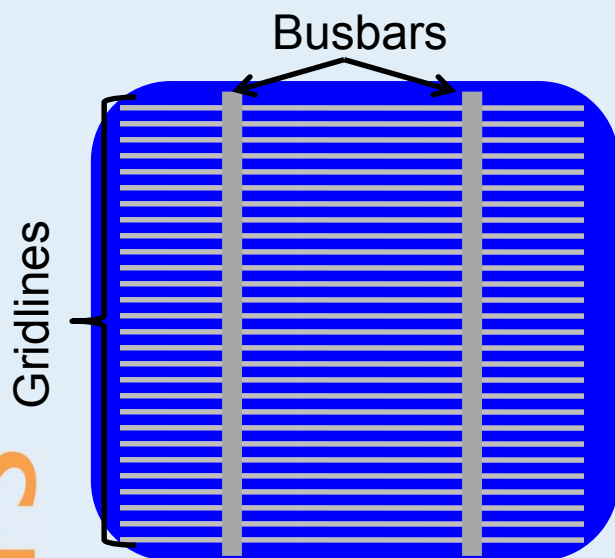


# 11. Metallization- Clarification of Terminology

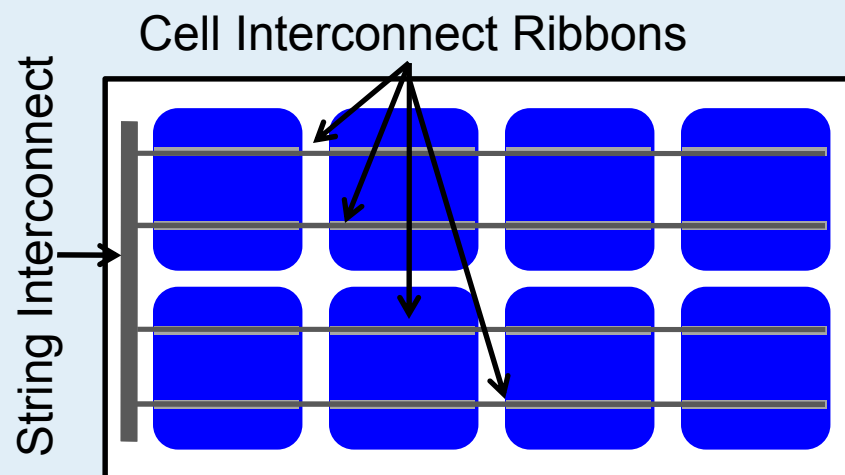
## Up to 4 levels of metallization and interconnects considered:

1. **Gridlines/Fingers**- finest level of metallization, <1mm thick
2. **Busbars**- connect gridlines/fingers within a single cell; often obscured by cell interconnect ribbon
3. **Cell Interconnect Ribbon**- connects multiple cells into a string
4. **String Interconnect**- connects multiple strings of cells

### *On an individual silicon cell*



### *On a silicon module*



**Note:** The condition of the busbars is often unobservable due to the overlap of the cell interconnect ribbon

**For thin film modules-**

Consider function of metallization; generally will not use all 4 levels





# 11. Metallization

## 11. Metallization:

**Gridlines/Fingers:** ☐ not applicable/barely observable ☒ applicable

Appearance: ☐ like new ☒ light discoloration(a.) ☐ dark discoloration(a.)

(a.) Fraction of discoloration:

☒ <5% ☐ 5-25% ☐ 50% ☐ 75% - 100% (consistent overall)

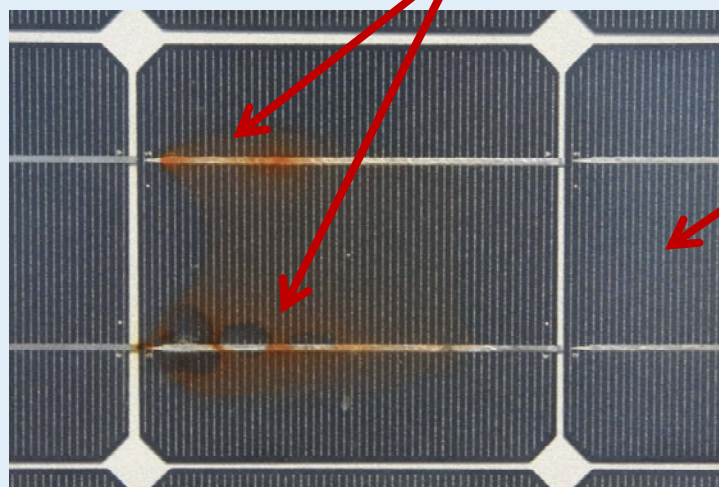
**Busbars:** ☐ not applicable/not observable ☒ applicable

Appearance: ☐ like new ☐ light discoloration(a.) ☒ dark discoloration(a.)

(a.) Fraction of discoloration:

☒ <5% ☐ 5-25% ☐ 50% ☐ 75% - 100% (consistent overall)

(mark all that apply): ☐ obvious corrosion ☒ diffuse burn mark(s) ☐ misaligned



Gridlines



# 11. Metallization

**Cell Interconnect Ribbon:** ☐ not applicable/not observable ☒ applicable

Appearance: ☒ like new ☐ light discoloration(a.) ☐ dark discoloration(a.)

(a.) Fraction of discoloration:

☐ <5% ☐ 5-25% ☐ 50% ☐ 75% - 100% (consistent overall)

(mark all that apply): ☐ obvious corrosion ☐ burn marks ☐ breaks

**String Interconnect:** ☐ not applicable/not observable ☒ applicable

Appearance: ☐ like new ☐ light discoloration(a.) ☒ dark discoloration(a.)

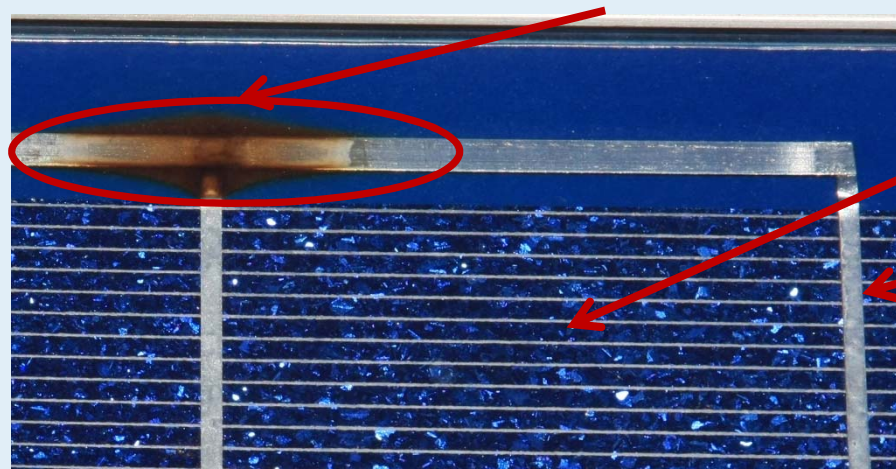
(a.) Fraction of discoloration:

☒ <5% ☐ 5-25% ☐ 50% ☐ 75% - 100% (consistent overall)

(mark all that apply): ☐ obvious corrosion ☒ burn marks ☐ breaks

☐ arc tracks (thin, small burns)

Dark Discoloration on String Interconnect



Gridline

Cell  
Interconnect  
Ribbon





# 12. Silicon Module: Cells

**12. Silicon (mono or multi) module:** ☐ not applicable ☐ applicable

Number of:

Cells in module \_\_\_\_\_

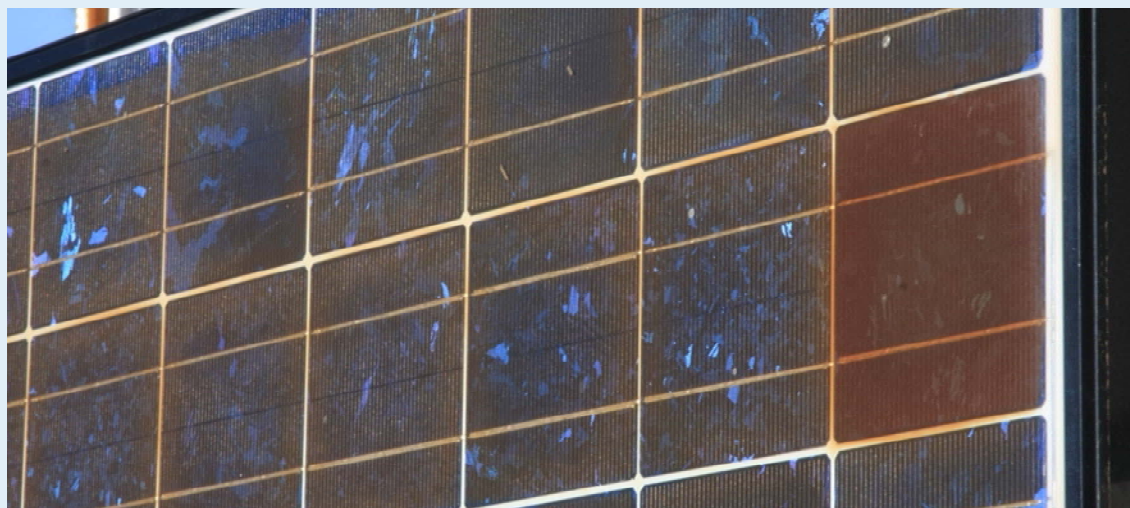
Cells in series/string \_\_\_\_\_

Strings in parallel \_\_\_\_\_

Cell size: Width \_\_\_\_\_ cm Length \_\_\_\_\_ cm

Distance between frame and cell: ☐ >10 mm ☐ <10 mm

Distance between cells in a string: ☐ >1 mm ☐ <1 mm





# 12. Silicon Module: Discoloration

**Discoloration:** ☐ none/like new ☐ light discoloration ☐ dark discoloration

Number of cells with any discoloration: \_\_\_\_\_

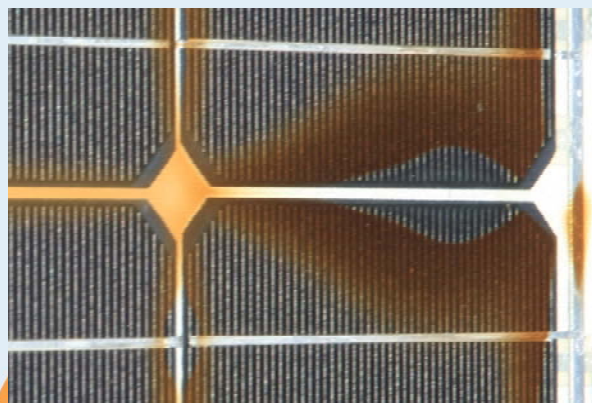
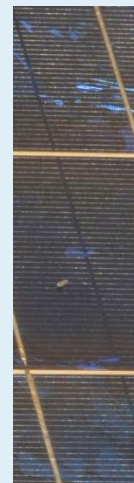
of those, average % discolored area:

☐ <5% ☐ 5-25% ☐ 50% ☐ 75% ☐ 100% (consistent overall)

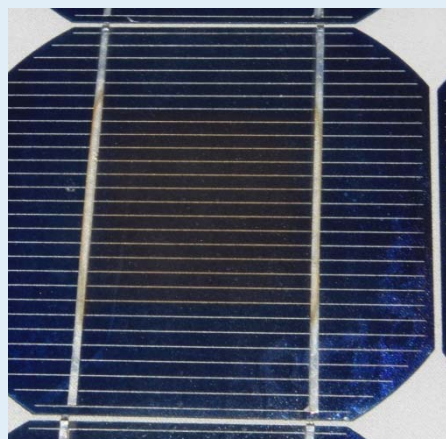
Discoloration location(s) (mark all that apply):

☐ module center ☐ module edges ☐ cell centers ☐ cell edges  
☐ over gridlines ☐ over busbars ☐ over tabbing ☐ between cells  
☐ individual cell(s) darker than others ☐ partial cell discoloration

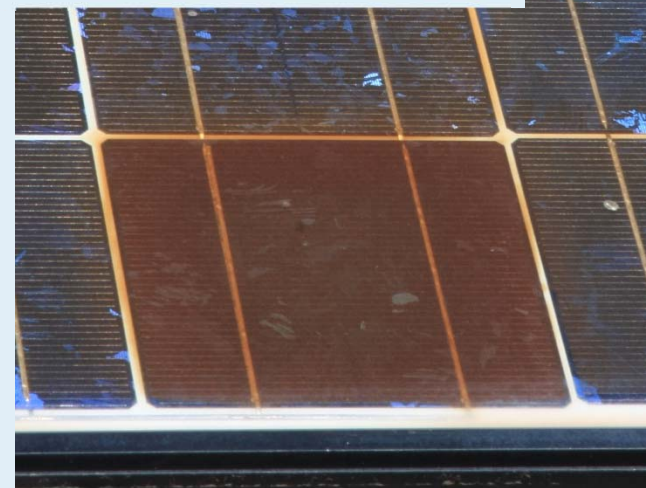
Junction box area: ☐ same as elsewhere ☐ more affected ☐ less affected



Dark discoloration at cell edges, between cells, and over gridlines and busbars



Light discoloration at cell center



Light and dark discoloration with one individual cell darker than others





# 12. Silicon Module: Discoloration

**Discoloration:**    ☐ none/like new    ☐ light discoloration    ☐ dark discoloration

Number of cells with any discoloration: \_\_\_\_\_

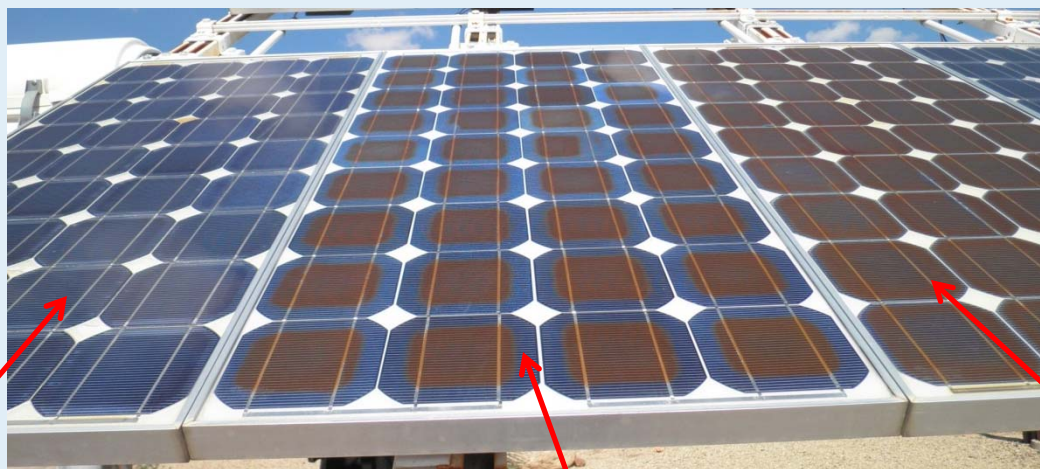
of those, average % discolored area:

☐ <5%    ☐ 5-25%    ☐ 50%    ☐ 75%    ☐ 100% (consistent overall)

Discoloration location(s) (mark all that apply):

☐ module center    ☐ module edges    ☐ cell centers    ☐ cell edges  
☐ over gridlines    ☐ over busbars    ☐ over tabbing    ☐ between cells  
☐ individual cell(s) darker than others    ☐ partial cell discoloration

Junction box area:    ☐ same as elsewhere    ☐ more affected    ☐ less affected



No discoloration

Discoloration over Center Of Cells

Discoloration over whole cell



# 12. Silicon Module: Damage

Damage: ☐ none

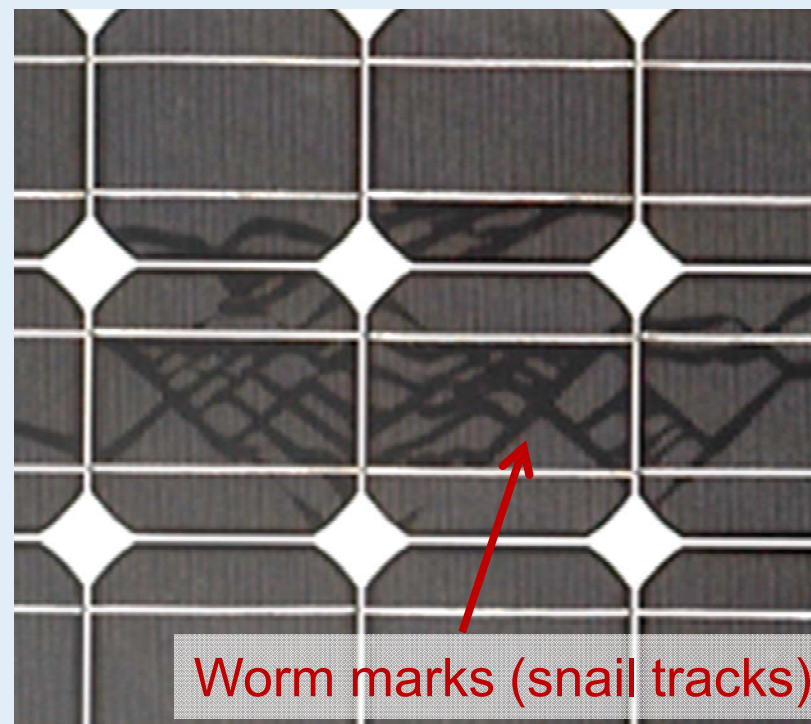
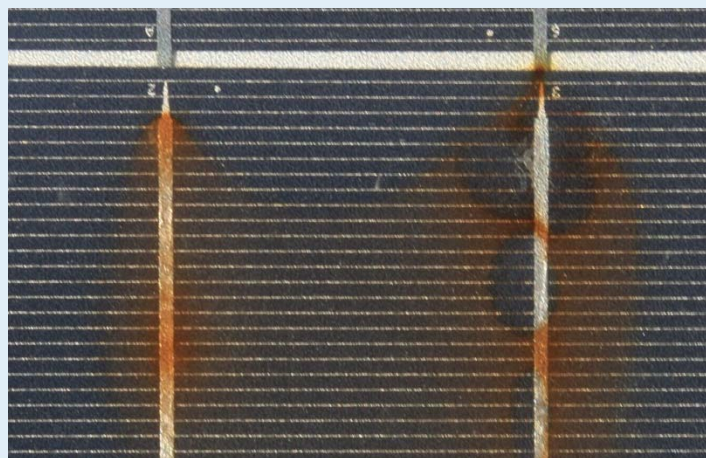
(mark all that apply): ☐ burn mark (a.) ☐ cracking (b.) ☐ moisture

☐ worm marks/snail tracks (c.) ☐ foreign particle embedded

(a.) Burns (#): ☐ 1 ☐ 2 ☐ 3 ☐ 4-10 ☐ >10

(b.) Number of cells cracked: \_\_\_\_\_

(c.) Number of cells with worm marks/snail tracks: \_\_\_\_\_



Worm marks (snail tracks)





# 12. Silicon Module: Delamination

**Delamination:** ☐ none ☐ from edges ☐ uniform ☐ corner(s) ☐ near junction box  
☐ between cells (a.) ☐ over cells (b.) ☐ near cell or string interconnect

(a.) Fraction delamination between cells:

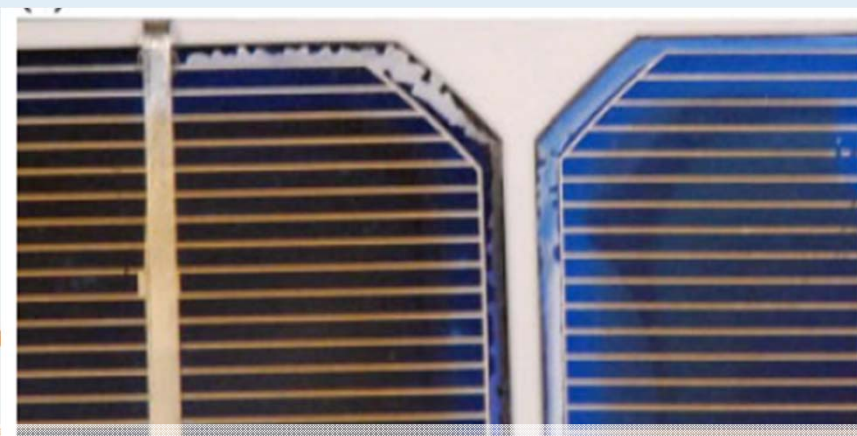
☐ <5% ☐ 5-25% ☐ 50% ☐ 75-100% (consistent overall)

(b.) Fraction delamination over cells:

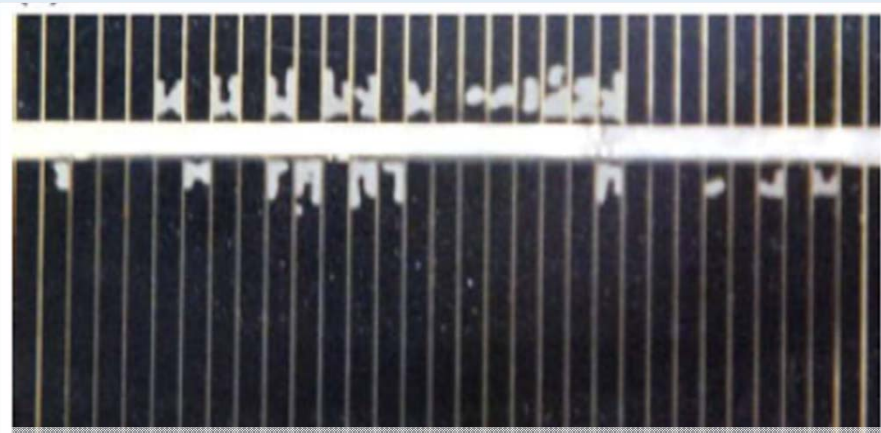
☐ <5% ☐ 5-25% ☐ 50% ☐ 75-100% (consistent overall)

Likely interface (choose 2):

☐ glass ☐ semiconductor ☐ encapsulant ☐ back sheet ☐ busbar



Semiconductor/Encapsulant delamination  
near edges



Semiconductor/Encapsulant delamination  
near busbar



# 13. Thin Film Module

13. Thin film module: ☐ not applicable ☐ applicable

Number of cells:

Number of cells in module \_\_\_\_\_

Number of cells in series/string \_\_\_\_\_

Number of strings in parallel \_\_\_\_\_

Cell size: Width \_\_\_\_\_ cm Length \_\_\_\_\_ cm

Distance between frame and cell: ☐ >10 mm ☐ <10 mm

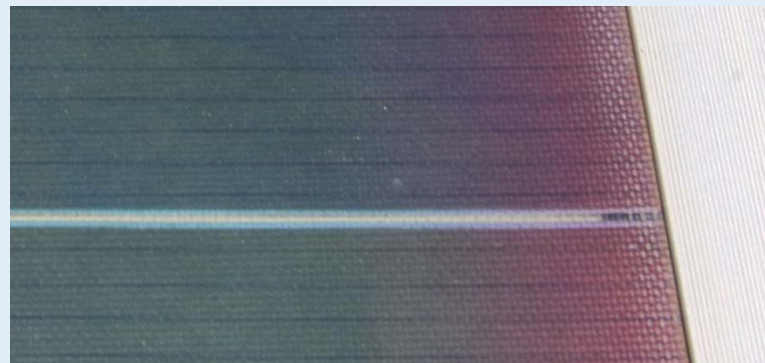
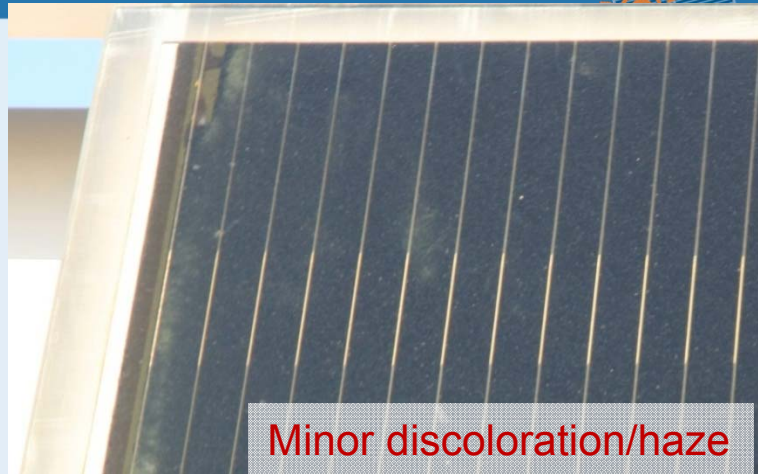
Appearance: ☐ like new ☐ minor/light discoloration ☐ major/dark discoloration

Discoloration type (mark all that apply):

☐ spotted degradation ☐ haze (encapsulant browning) ☐ other

Discoloration location (mark all that apply):

☐ overall/no location pattern ☐ module center ☐ module edge(s)  
☐ cell center ☐ cell edges ☐ near crack(s)



Major discoloration/spotted degradation/no pattern

Major discoloration/other/module edges





# 13. Thin Film Module

**Damage:** ☐ no damage ☐ small, localized ☐ extensive

Damage Type (mark all that apply): ☐ burn mark(s) ☐ cracking

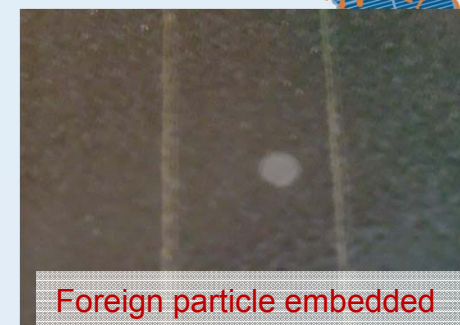
☐ possible moisture ☐ foreign particle embedded

**Delamination:** ☐ no delamination ☐ small, localized ☐ extensive

Location: ☐ from edges ☐ uniform ☐ corner(s) ☐ near junction box ☐ near busbar

☐ along scribe lines

Delamination Type: ☐ absorber delamination ☐ AR coating delamination ☐ other



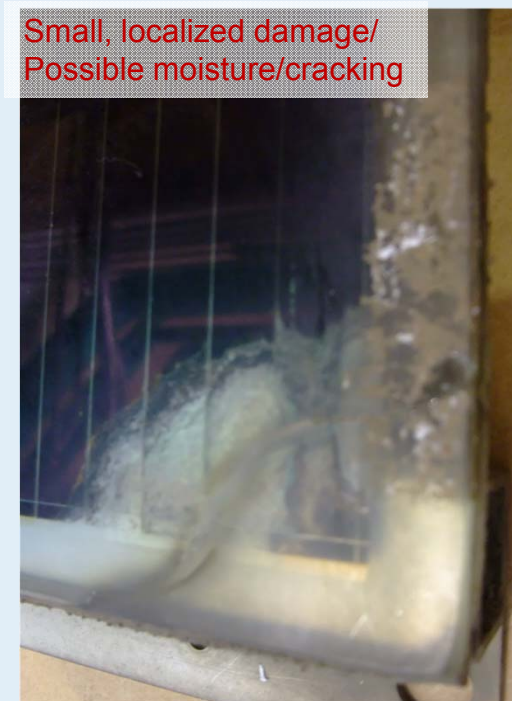
Foreign particle embedded



Absorber delamination



Small, localized damage/  
Possible moisture/cracking





# 14. Electronic Records

Photos taken of ☐ front and defects

**14. Electronic Records** ☐ applicable ☐ not applicable

Photographs and I--V curves recorded electronically--list file names in blanks

Photo files \_\_\_\_\_

I--V curve \_\_\_\_\_

Connector function: ☐ functions ☐ no longer mates ☐ exposed

Irradiance \_\_\_\_\_ Sensor \_\_\_\_\_

Temperature \_\_\_\_\_ Sensor \_\_\_\_\_

EL picture \_\_\_\_\_

IR picture \_\_\_\_\_

Bypass Diode Test: ☐ applicable ☐ not applicable

Number of diodes:

In total \_\_\_\_\_, shorted \_\_\_\_\_, open \_\_\_\_\_

**OTHER**





# Preliminary Data

## Site 1: Tempe, Arizona, USA

49 modules

83% Silicon (mono + multi)

18% Thin film

## Site 2: New Delhi, India

14 modules

17% Silicon (mono + multi)

83% Thin film

| Observation                        | % of Modules | Observation  | % of Modules |
|------------------------------------|--------------|--|--------------|
| Glass (front): Lightly soiled      | 55%          | Glass (front): Small, localized damage                   | 50%          |
| Glass (front): Bird droppings      | 24%          | Wires: Pliable but degraded                              | 43%          |
| Connectors: Pliable but degraded   | 22%          | Glass (front): Lightly soiled                            | 43%          |
| Encapsulant: Major discoloration   | 20%          | Junction box: seal will leak                             | 36%          |
| Backsheet: Small, localized damage | 20%          | Thin film module: Distance between frame and cells <10mm | 36%          |



# Summary & Conclusion

- Data collection tool has been created and is available for use

Additional detail can be found in the full NREL report TP-5200-56154

***Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded PV Module Condition***

*C.E. Packard, J.H. Wohlgemuth, S.R. Kurtz*

- Long form and short form data collection tools available, along with report detailing intended data collection procedures
- Collection of uniform, detailed data from multiple climate zones is one part of understanding module degradation and failure