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Failure Modes of Crystalline Si Modules

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Outline

- Review list of failure modes from yesterday's talk.
- Provide some detail on each of the failure mechanisms.
- Discuss methods utilized to either eliminate the failure itself or to minimize its effect of the module's long term performance.

Failure Modes of Crystalline Si Modules

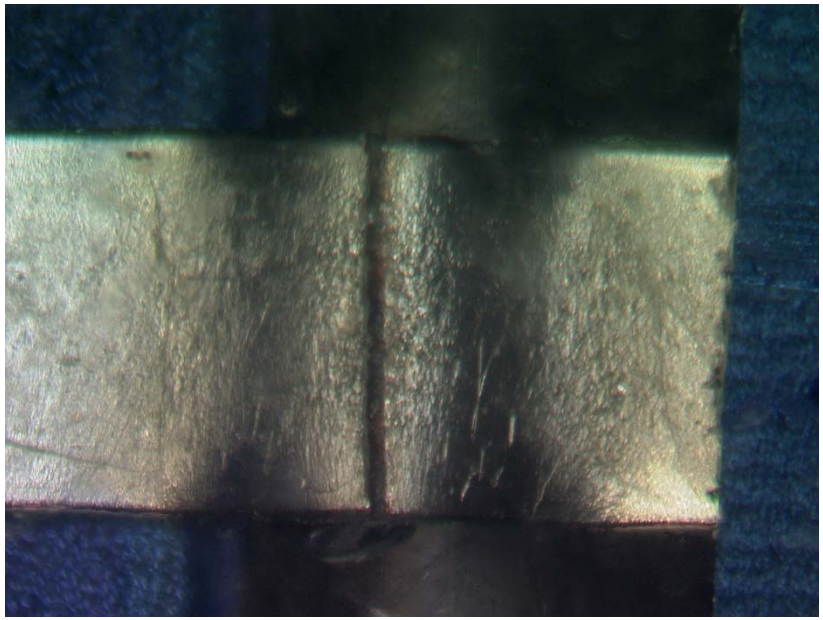
- Broken interconnects
- Broken Cells
- Corrosion
- Delamination and/or loss of elastic properties
- Encapsulant discoloration
- Solder bond failures
- Broken glass
- Hot Spots
- Ground faults
- Junction box and module connection failures
- Structural failures

Equal Opportunity Presentation

- This is an equal opportunity presentation
- Examples of module failures have been taken from many different module manufacturers, from most regions of the world.
- Many of these examples occurred during the early years of PV module manufacturing.
- It was this experience that lead to the reliable products we have today.

Broken Interconnects

- Interconnects break due to stress caused by thermal expansion and contraction or due to repeated mechanical stress.
- Early modules suffered open circuits due to broken interconnects.
- What makes it worse
  - Substrates with high thermal expansion coefficients
  - Larger cells
  - Thicker ribbon
  - Kinks in ribbon

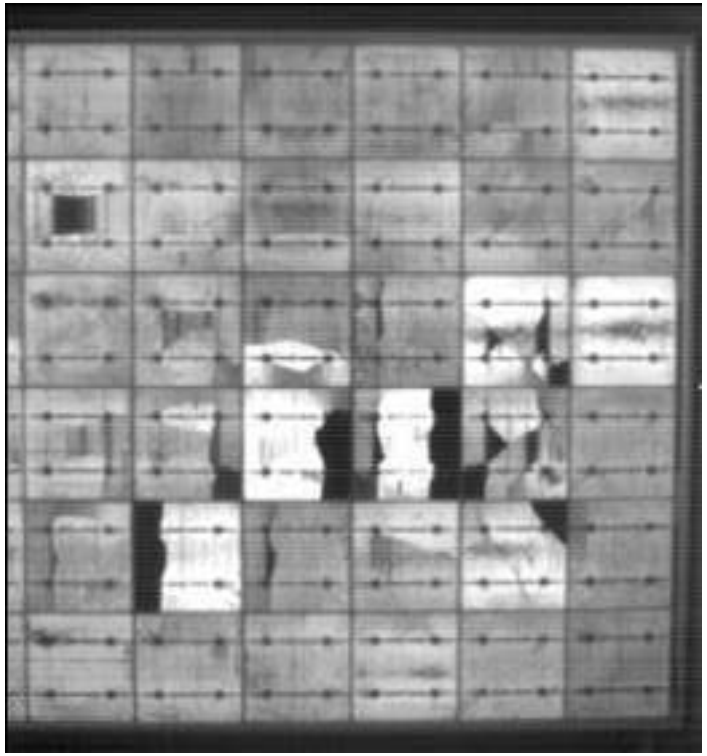


Solutions to broken interconnects

- Substrates with lower thermal expansion coefficients – that is one of the reasons why glass superstrate modules are so popular.
- Built in stress relief (But not kinks because they concentrate stress)
- Built in redundancy – if one fails the module continues to operate
- Thinner ribbon
- Softer more pliable material
- Discrete bonds versus continuous attachment

Broken Cells

- Crystalline Si cells can (and will) break due to mechanical stresses.
- Early modules suffered open circuits due to broken cells since there was only one attachment point for each polarity.
- What makes it worse
  - thinner cells
  - Single crystal especially if cleave plane is oriented along bus bar
  - Pre-stressed or chipped cells
  - Larger cells in large modules



Solutions to Broken Cells

- Build in crack tolerance using redundant interconnects and multiple solder bonds on each cell.
- Do not orient cleave planes along tabbing ribbons.
- Presorting of cells to remove those with cracks or chips.
- IR and NIR inspection.
- Dynamic mechanical load testing of new designs to determine the potential for cell breakage and whether the breakage leads to power loss.

Corrosion

- **Moisture induced corrosion of cell metallization.**
- **Key to survival is to minimize the ionic conductivity in the package, especially the encapsulant.**
- **Field failures of PVB encapsulated modules in 1980's was due to high ionic conductivity in moist PVB.**
- **What makes it worse**
  - **Metallization sensitivity to moisture**
  - **Encapsulant with humidity dependent conductivity**
  - **Encapsulant that absorbs a lot of moisture.**

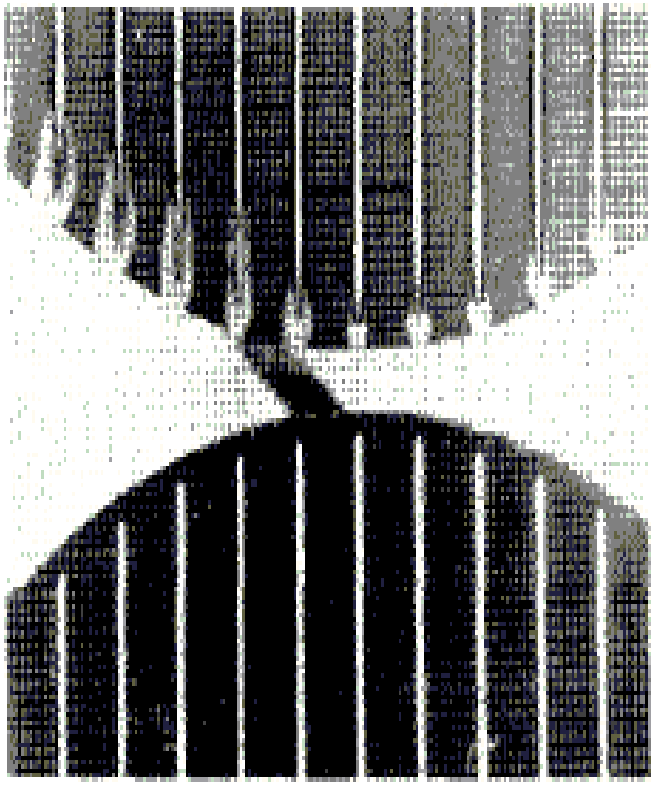


Figure 2. Solar-Cell Electrochemical Corrosion

Power Loss Due to Corrosion in PVB (JPL Picture and Data)

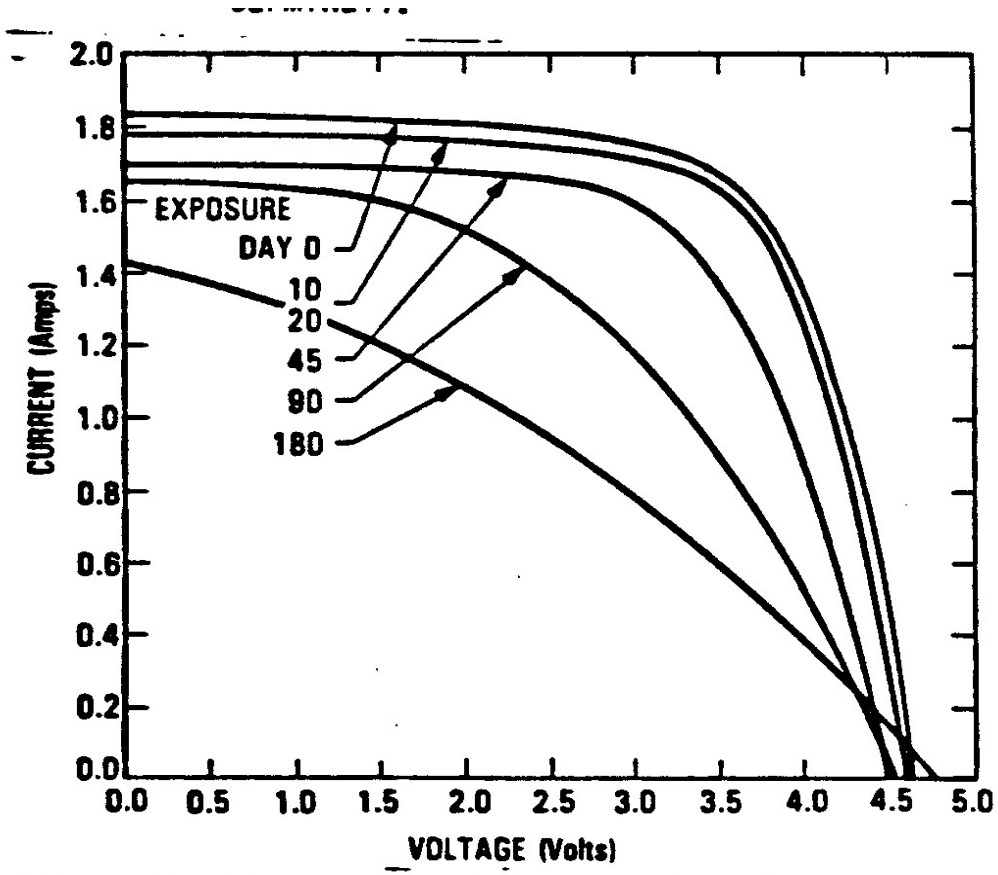


Figure 6. Module current-voltage data illustrating series resistance increase with exposure in 85/85/voltage-bias environment.

Corrosion

- For crystalline Si corrosion of front contacts is dependant on both the metallization system and the encapsulation system.
- Experience – with same cell metallization system, one EVA passed 1000 hours of damp heat (< 5% power loss) while modules with 2nd type of EVA degraded in power by close to 50% after 1000 hours.
- Performed testing of competitor's (IEC 61215 certified) crystalline Si modules through 1250 hours of damp heat testing (versus 1000 hours from IEC 61215). 8 out of 10 failed due to power loss in excess of 5%.

Solutions to Corrosion

- Utilize an encapsulant that does not increase in conductivity when it absorbs water vapor.
- Incorporate moisture barriers in superstrate and substrate.
- Utilize a metallization system that is compatible with the encapsulation system chosen.
- Do damp heat testing beyond 1000 hour.

Delamination

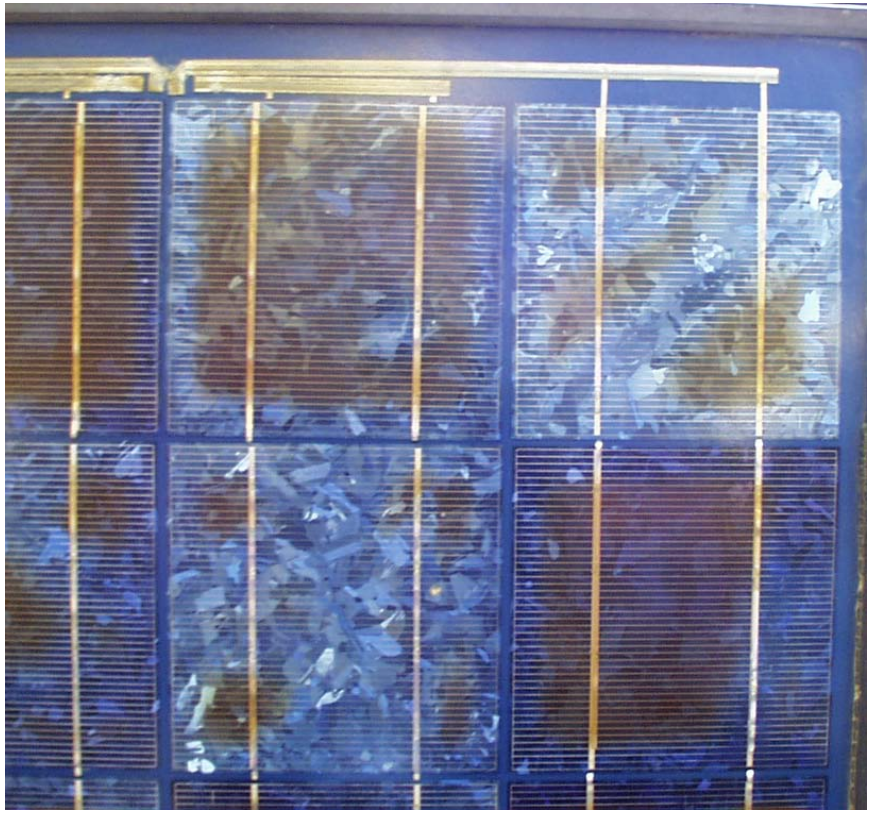
- Delamination observed to varying degrees in a small percentage of PV module types.
- Delamination can be between superstrate (ie. glass), substrate (ie. Backsheet) and encapsulant or between encapsulant and cells.
- Usually the result of an adhesive bond that is sensitive to UV, humidity, or contamination from the material (Excess Na in glass or dopant glass left on cell)

Solutions to Delamination

- Careful selection of adhesives and primers – Stable to UV and moisture.
- Control of raw materials and processes.
- Module testing to detect and eliminate any changes in materials or processes.

Encapsulant discoloration

- Will result in some loss of transmission and therefore reduced power.
- Worst reported case was in slow cure EVA caused by low concentration system at Carissa Plains.
- Standard cure EVA formulation A9918 does discolor.
  - Caused by heat and UV.
  - Bleached by oxygen
  - So with breathable backsheet center of cells discolor while outside ring remains clear.
  - Without concentration it takes 5 to 10 years to see discoloration and longer to start appreciably reducing output power.
- It was not EVA itself that discolored, but additives in the formulation



Eliminating encapsulant discoloration

- Make sure actual encapsulant package is tested to UV exposure at high temperature.
  - BP Solar does 6 months of UV testing for all encapsulants, backsheets and even labels.
- Original EVA yellowing alleviated via changes in EVA additive package and adding UV absorber (Cerium Oxide) to low iron glass.
- Most glass manufacturers have now removed Cerium Oxide from low iron glass so it is important to verify that the encapsulant being utilized is not sensitive to UV induced discoloration.

Solder bond failures

- Solder bonds can fail due to stresses induced by thermal cycling.
- Solder can creep when loads are applied at elevated temperatures.
- Solder fatigue can be caused by cyclic loading, e.g. thermal, mechanical or electrical repetitive stress.
- Early modules typically only had 1 solder bond per interconnect per cell so failure of this solder bond resulted in an open circuit failure of the whole module.
- Even today non-cell solder bonds often have no redundancy so failure of one of these bonds can lead to drop out of a cell string, a whole module or even a whole string of modules.

Alleviating Solder Bond Failures

- Utilize multiple solder bonds on each tabbing ribbon.
- Utilize softer ribbon and leave stress relief.
- Perform periodic pull tests to assure quality of solder bonds being made.
- Perform thermal cycle tests well beyond the 200 cycles from IEC 61215.
- Implement training and QA inspections to assure that non-cell solder bonds are being fabricated correctly.
- In critical areas (like termination wires) use both solder and mechanical connections.
- Do not rely on pottants as second attachment for termination wires. This can lead to arcing danger.

Broken glass

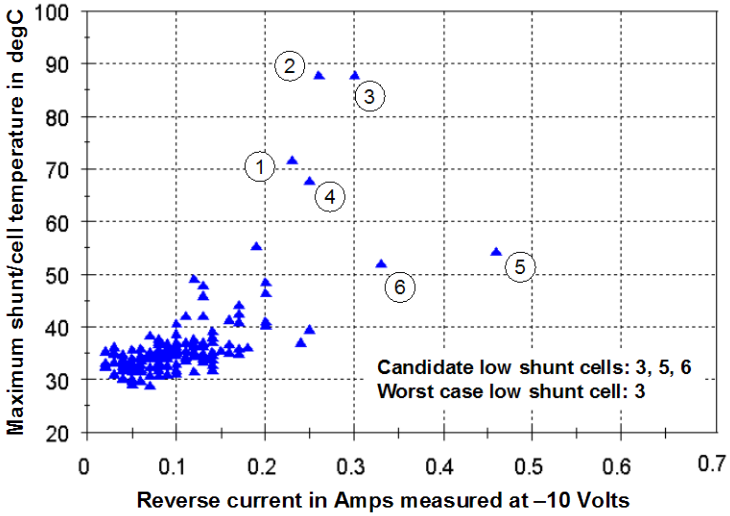
- Type of glass breakage is dependent on the type of glass used. (tempered, heat strengthened or annealed)
- High impacts like hail, rock or bullet will break glass. Can almost always identify spot where object hit.
- Mechanical loading from snow and/or wind can break glass.
- Failure of or misuse of support structure can lead to glass breakage
- High temperature (hot spot or arc) can break glass.
- Annealed glass can also break due to:
  - Stress built into the package during manufacture.
  - Stress applied by the framing/mounting system.
  - a temperature difference of as little as 25 C from center to edge.

How to keep glass from breaking

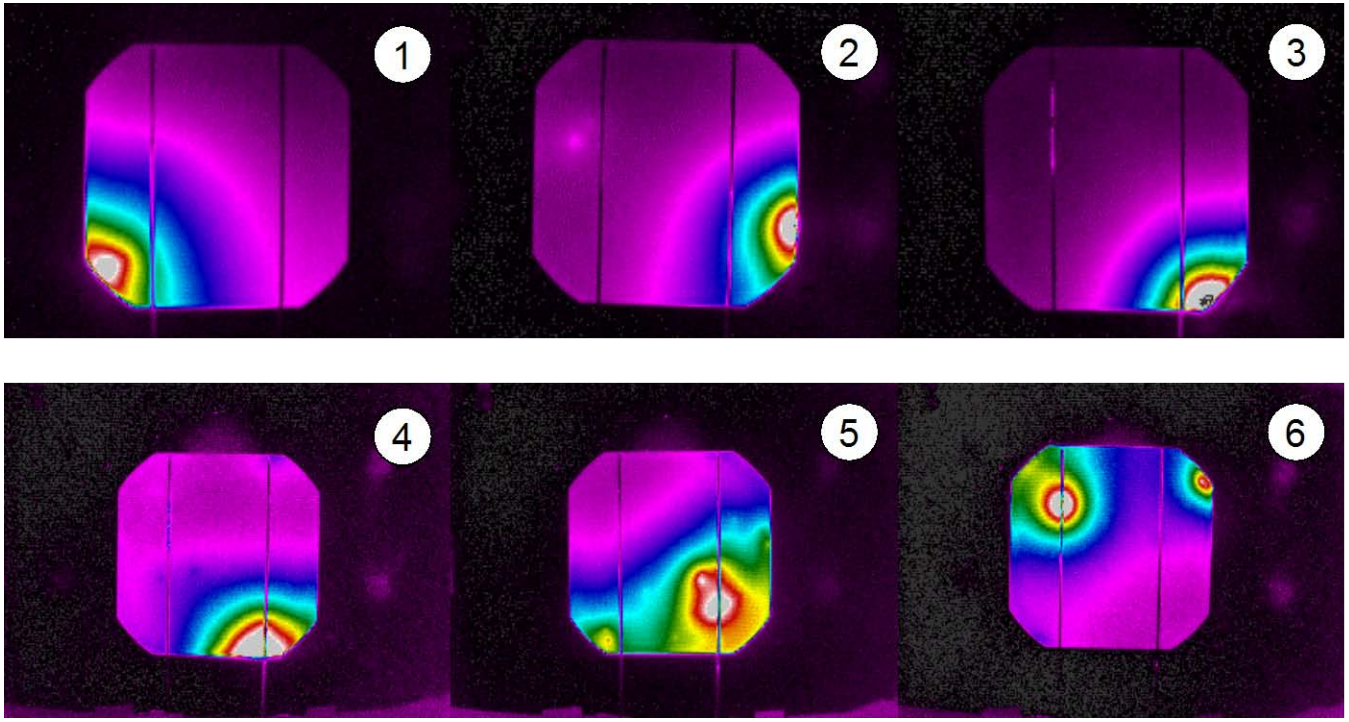
- Use tempered glass wherever possible.
- Pay attention to mounting method and mounting points.
- Test mounting system for snow load per IEC 61215.
- In high traffic areas try to protect glass (or any other superstrate) from direct impacts.
- Minimize hot spots and arcs.

Hot Spots

- Hot-spot heating occurs in a module when its operating current exceeds the reduced short-circuit current (Isc) of a shadowed or faulty cell or group of cells.
- When such a condition occurs, the affected cell or group of cells is forced into reverse bias and must dissipate power.
- If the power dissipation is high enough or localized enough, the reverse biased cell can overheat resulting in melting of solder and/or silicon and deterioration of the encapsulant and backsheet.



Hot Spots in Cells (From TUV)



How to avoid hot spots

- Most cells can be adequately protected by use of bypass diodes (say 1 diode every 20 cells).
- Still may have some cells with localized shunts that will heat excessively at the reverse bias level allowed by the bypass diodes.
- Solution is to screen out low shunt cells.

Ground faults

- PV modules are suppose to have high resistance stand-off between the electric circuit and the ground plane.
- Occasionally this protection is compromised.
- The consequences can be serious as there is nothing to stop the PV current from flowing in ground loops until one component gets so hot it melts or burns.
- Many ground faults are the result of poor installation practices.
- In picture the installer mounted modules with clips that penetrated the module insulation and contacted the solar cells at numerous locations.

Roof Fire Caused by Installer Ground Fault

Alleviating Ground Faults

- Mounting modules within the cell area should be avoided or done with extreme caution (and probably the addition of significant additional electrical insulating material like use of a glass substrate).
- Grounding of the array circuit actually increases the potential for this type of fault.
  - In a grounded array it only takes 1 ground fault to cause current flow in a ground loop.
  - For an ungrounded circuit it takes 2 ground faults to cause a problem, giving the system operator a chance to detect the first one and fix it before the second one occurs.

Junction box failures

- Single point for potential failure that can often be attributed to poor workmanship.
- Water ingress and subsequent corrosion can be a problem.
- How well is the J-box attached to the module back sheet?
- Some adhesive systems are good for short term pull but poor at maintaining long term adhesion.
- Picture from UL report.

Addressing junction box issues

- Use only qualified materials and boxes.
- Make sure boxes pass same set of tests that modules pass – damp heat, humidity freeze, thermal cycle, robustness of termination and wet high pot.
- Test adhesion well beyond qualification requirements.
  - At BP Solar we perform a boiling water test to verify adhesion under worst case conditions.
- Evaluate worst case failures – what happens if a wire comes detached?
- Quality control during manufacture.

Structural failures

- Often it is the way the module is mounted that determines whether it can survive a particular load.
- You want me to follow the manufacturers installation instructions?
- Snow load can deform the frame and break the glass.
- Sometimes the entire array structure is not capable of surviving high winds.

Difference in Mounting Method

Wind damage
(Hans Urban, from his presentation at TUV Sponsored Module Workshop, 2006)

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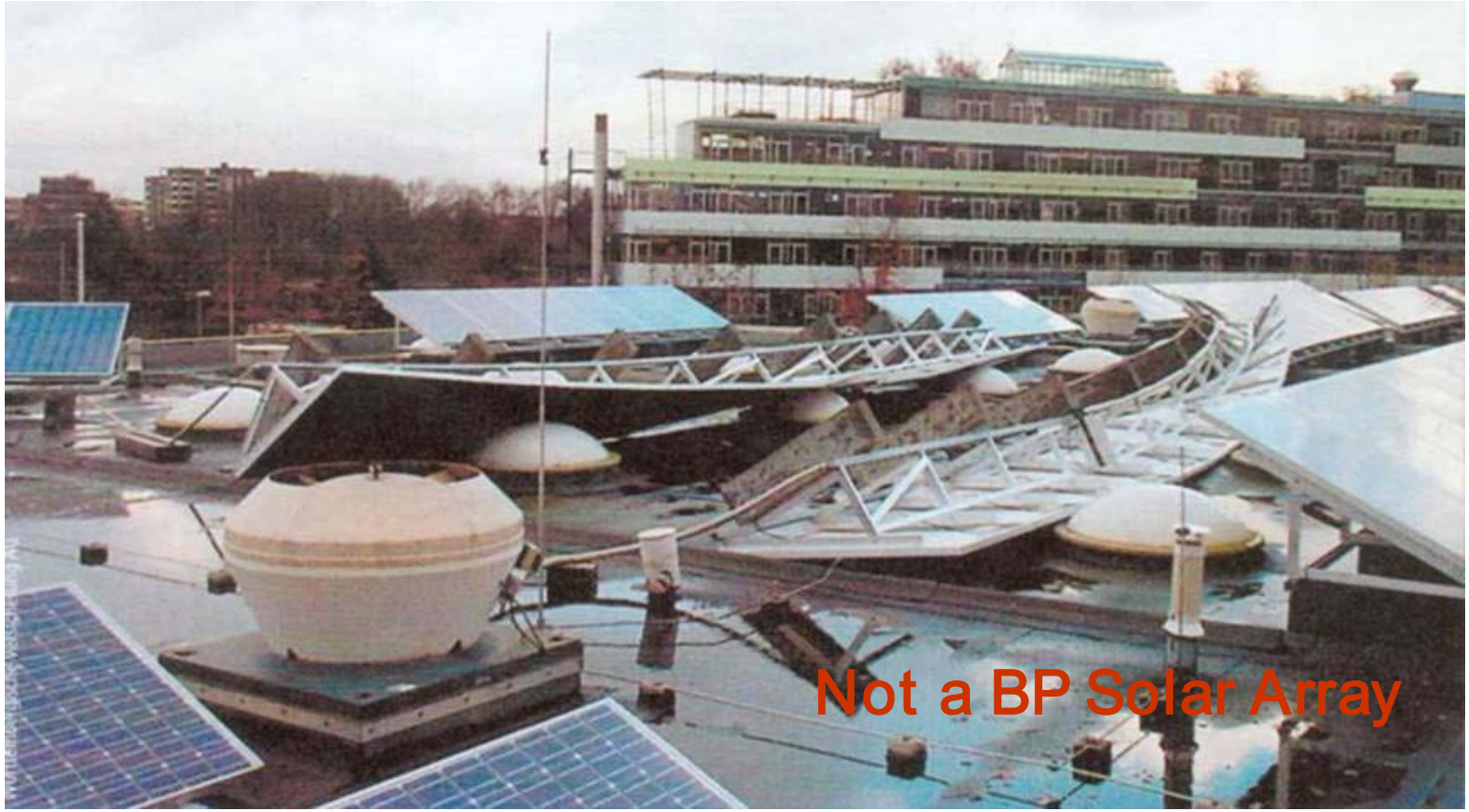

Avoiding Structural Failures

- Follow the module manufacturer's installation instructions.
- Follow local building codes where available as they are usually based on local weather history.
- Test new approaches (for example in a wind tunnel) before using them in the field.
- The best designed system built using the highest quality components will not work well and may be unsafe if it is installed improperly.
- Installer training and certification programs like the one run by BP Solar are critical to achieving highly reliable and safe PV systems.

Summary

- Crystalline Si Module reliability and performance
  - Very good but still with room for improvement
  - Not all modules are created equal, poor material selection, improper assembly and processing will yield different degradation rates and lifetimes
- New Module Technology
  - Can’t test for 25 years before releasing commercial products
  - Strong accelerated test programs required.
  - Process controls required to assure production modules perform as well as test modules.