National Laboratory of the Rockies

PV ModuleTech
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Reducing Glass Breakage Risk in Modern Utility Glass-Glass Modules

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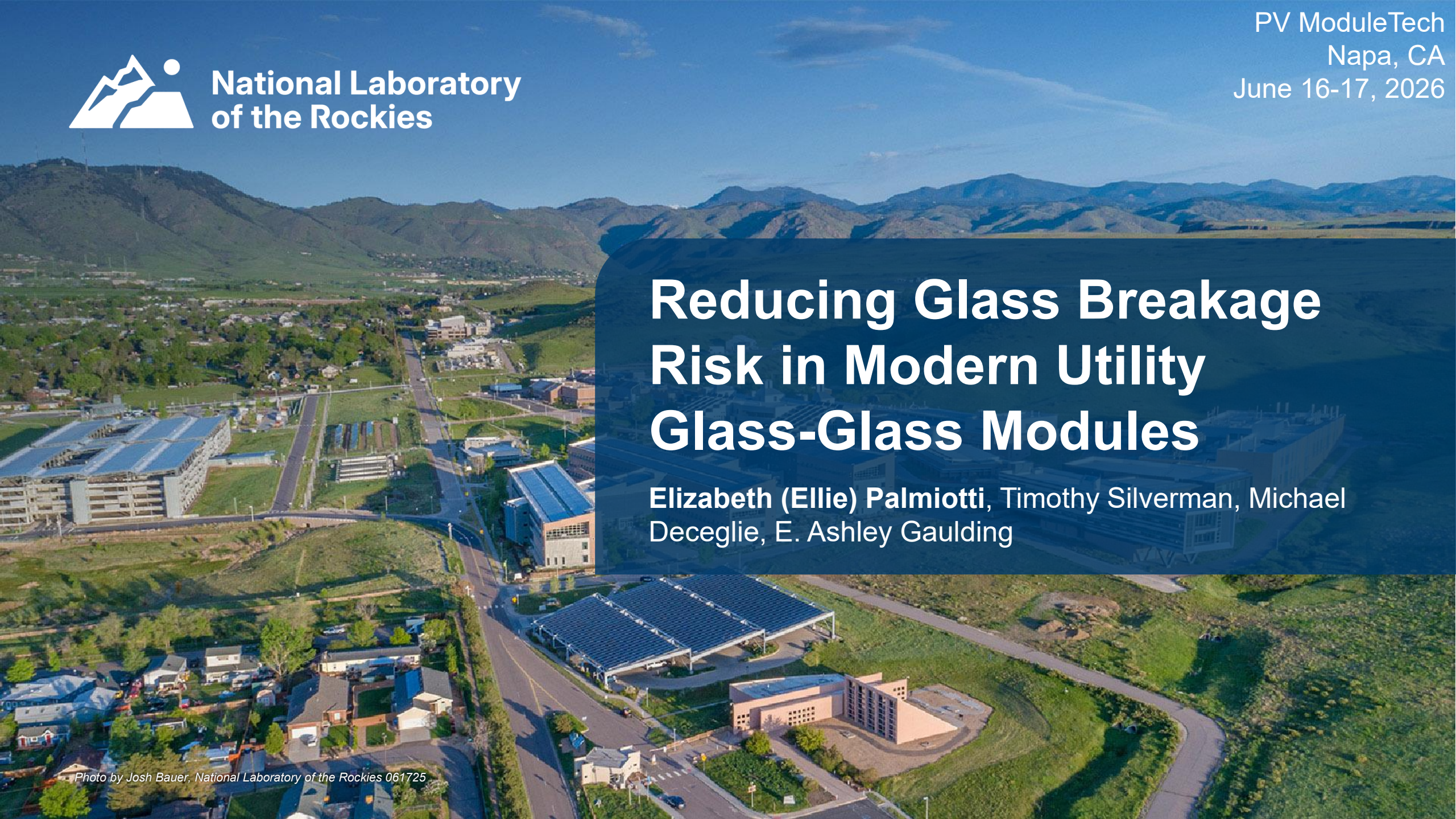


Photo by Josh Bauer, National Laboratory of the Rockies 061725

How do we assess risk?

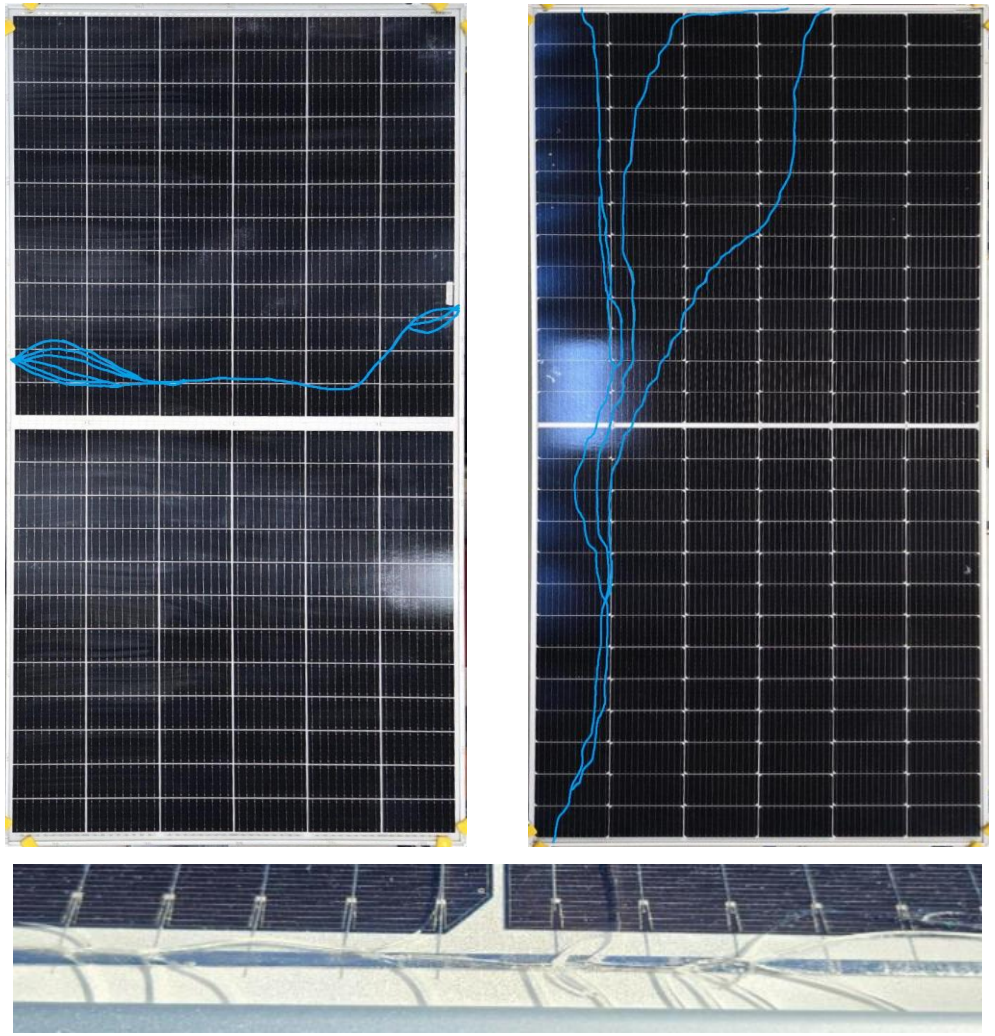
- Lightning can cause serious injury or death
- Lightning kills thousands per year

- Factors can increase risk
  - Outside during a thunderstorm
  - On top of a hill
  - By a tree
  - Holding an umbrella

- Lightning is random, but you are in control
- Every situation has different risk factors
- Reduce your risk by reducing the factors

Various risks put PV glass on the brink of breakage

- Broken PV glass is an electrical hazard
- A broken module can disable megawatts
- Glass breaks by brittle fracture and is random, but you are in control
- Every situation has a different mix of risk factors
- Reduce your risk by reducing risk factors



E. Palmiotti, PVRW, 2025

Recommendations to reduce glass breakage risk

- We will make recommendations
  - Improve the glass
  - Improve the module assembly
  - Improve the system design and operation
- We've studied glass breakage in >150 modules, six manufacturers, six global PV systems
- Following the recommendations will reduce breakage risk
  - How much? Nobody knows. It depends.
- We recommend doing what is practical

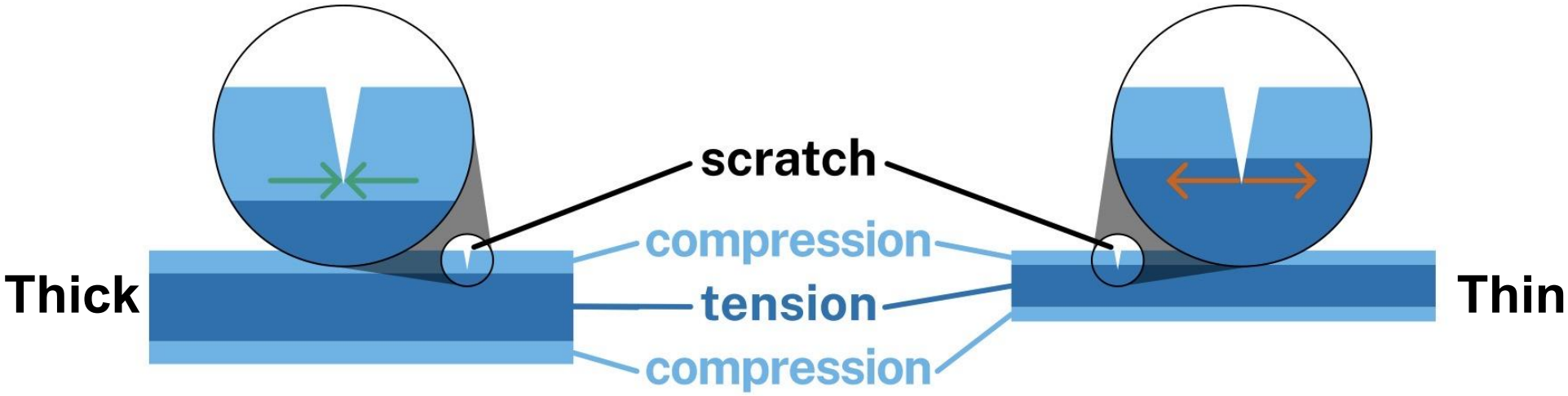
Improve the Glass

- Use thicker glass
- Use glass with more strengthening
- Remove more edge flaws with finer polishing
- Inspect for edge flaws
- Control coatings
- Control texture

Improve the Glass

Use thicker glass

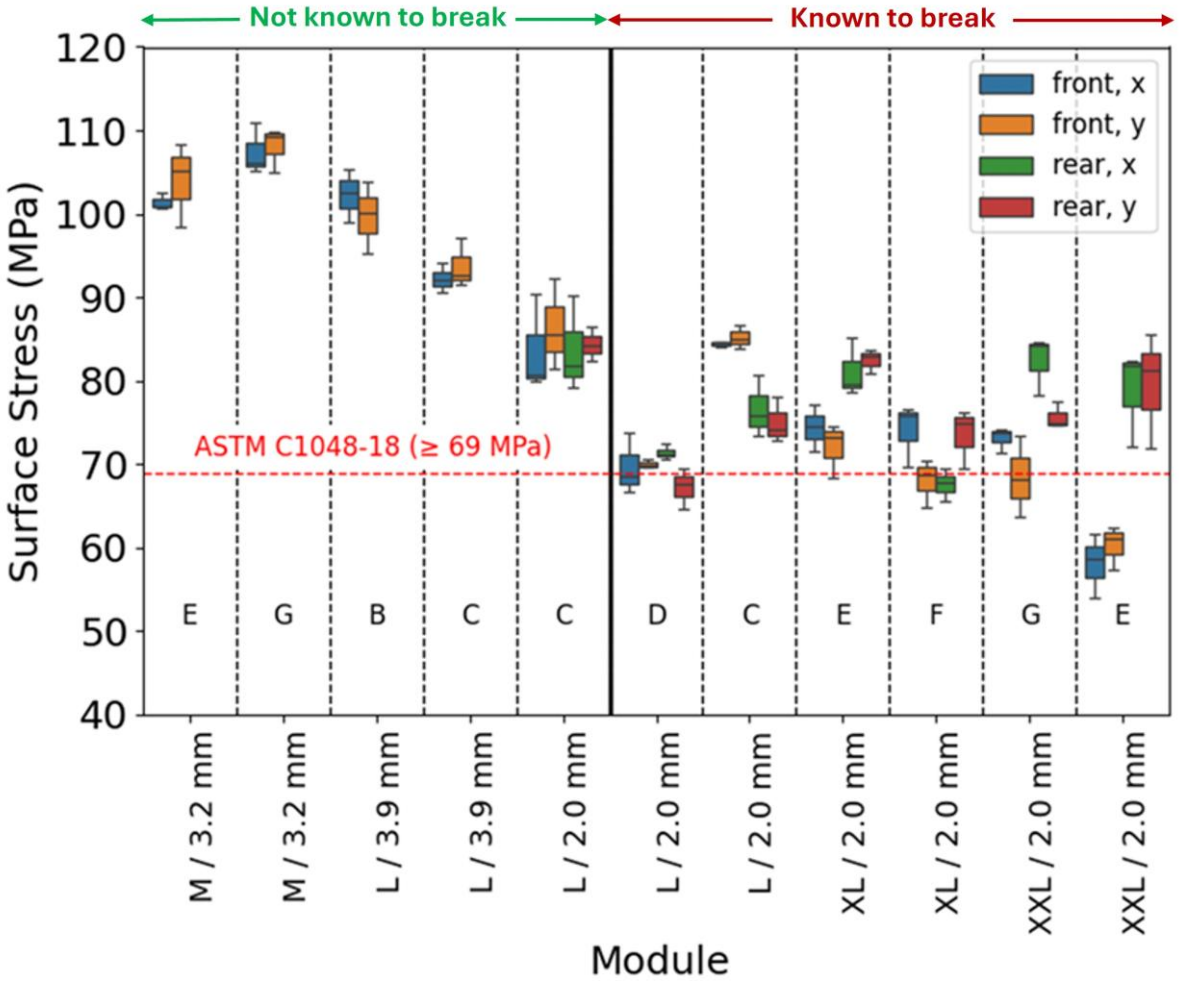
- Thin glass saves cost and weight, but experiences more stress for a given load
- Thinner compression depth in thin glass
- Thicker glass withstands larger flaws before unloaded breakage
- Thicker glass systematically has more thermal strengthening



Thinner glass and larger areas have worsened module sag. Have you seen degradation or failures due to sag? Let's talk!

Improve the Glass

Use glass with more strengthening



- Most PV glass is thermally strengthened
- Different levels of strengthening are possible
- Higher strength increases the stress at which glass breaks
- Higher strength can require thicker glass, special equipment, or more expensive processing
  - Directly reduces breakage probability

E. C. Palmiotti, T. J Silverman, M. G. Deceglie, I. L. Repins and E. A. Gaulding, "Surface Stress Characterization and Trends in Thermally Strengthened Photovoltaic Module Glass," in *IEEE Journal of Photovoltaics*, doi: 10.1109/JPHOTOV.2026.3668779.

Improve the Glass

Remove more edge flaws with finer polishing

- Glass fractures start at a flaw, often on an edge
- PV glass edges are coarsely ground
- Grinding to a finer finish reduces chance for cracks to start at an edge flaw
- Quantitative control of the process and the final finish is important
- Keeping track of edge finish may help

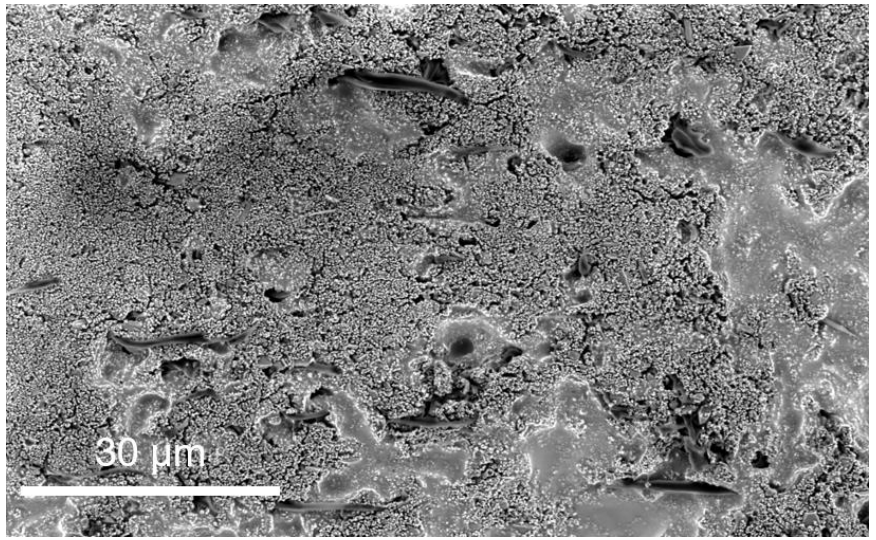
Glass Edge

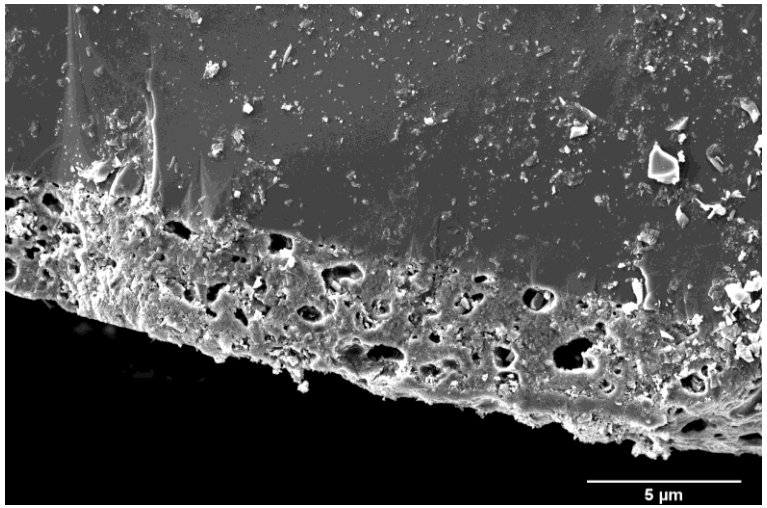
Improve the Glass

Check that coatings don’t reduce strength

- White coatings on third surface are common
- These coatings firmly attach to glass and have microscopically rough or porous texture
- Roughness in coatings may serve as starting points for glass cracks
- Coating roughness may be controllable through materials and process
- Eliminating rough coatings may also reduce breakage risk

Figure credit: EPRI and the DuraMAT Consortium



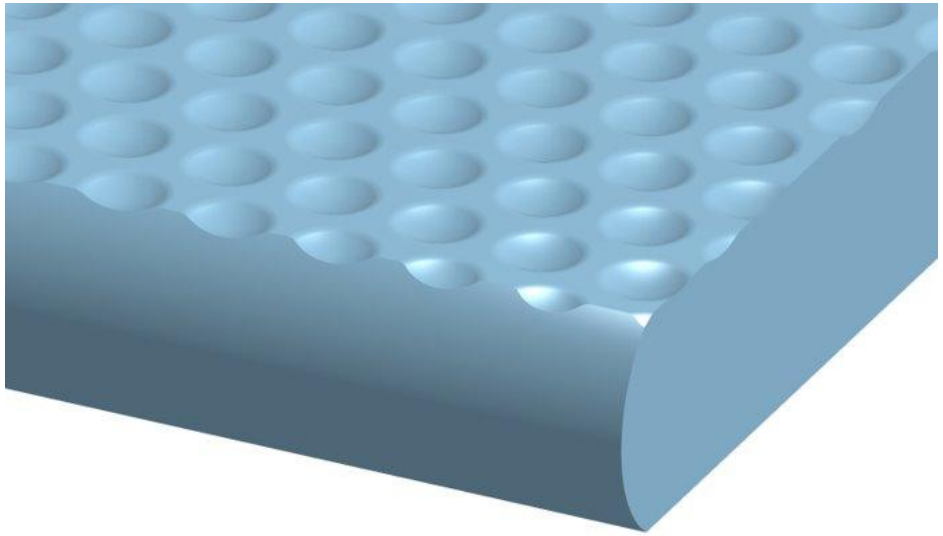


T. J. Silverman et al., “Tough Break: Many Factors Make Glass Breakage More Likely,” National Renewable Energy Laboratory, Golden, CO, NREL/TP-5K00-91695, 2024.

Improve the Glass

Check that patterning does not reduce strength

- Rolled PV glass is usually finely textured on first surface
- Regularly dimpled on second surface
- These features may reduce effective thickness of glass
- They may act as starting points for cracks



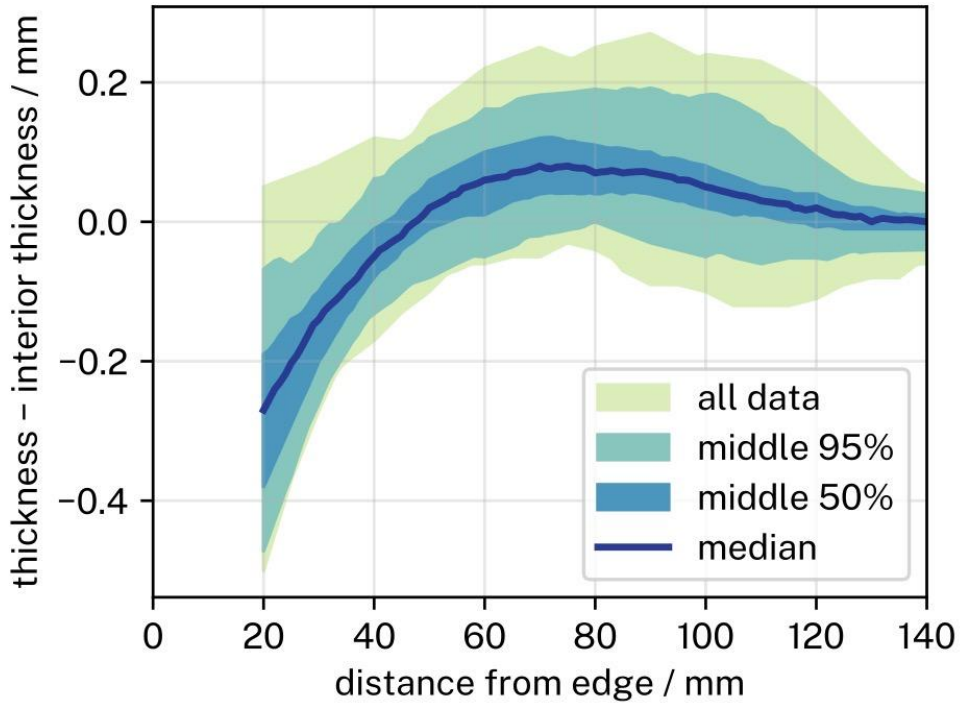
Is there a market for float glass for c-Si? Let's talk!

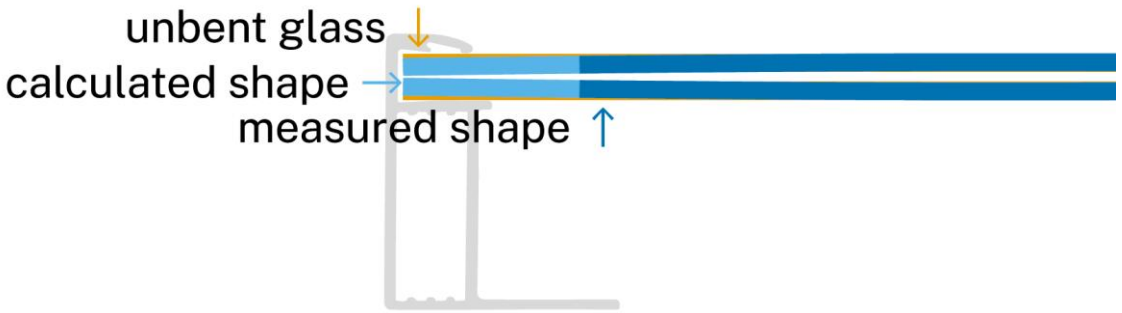
Improve the Module Assembly

- Reduce edge pinch
- Avoid internal glass contact
- Use a stiffer frame
- Apply frame adhesive more carefully

Improve the Module Assembly

Reduce edge pinch





- Most glass-glass modules we have measured have edge pinch
  - This results in bending glass
  - Bending introduces tensile stresses, reducing the benefits of thermal strengthening
- Reducing edge pinch by changing the lamination process
  - Different lamination equipment
  - Add extra encapsulant at the edges
  - External perimeter frame during lamination

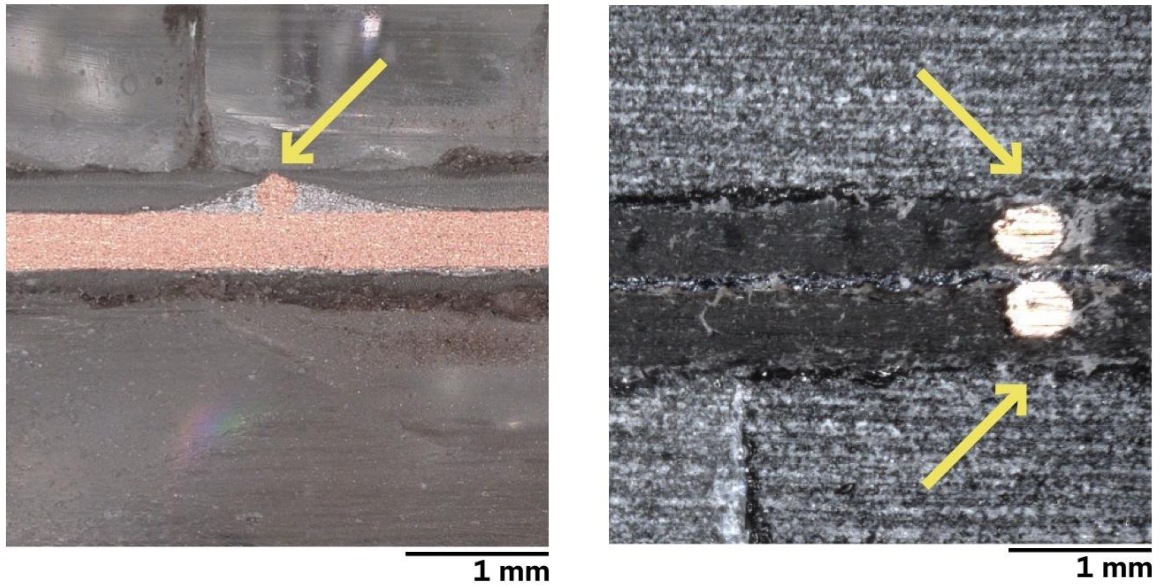
T. Silverman, PVRW, 2026

Improve the Module Assembly

Avoid internal glass contact

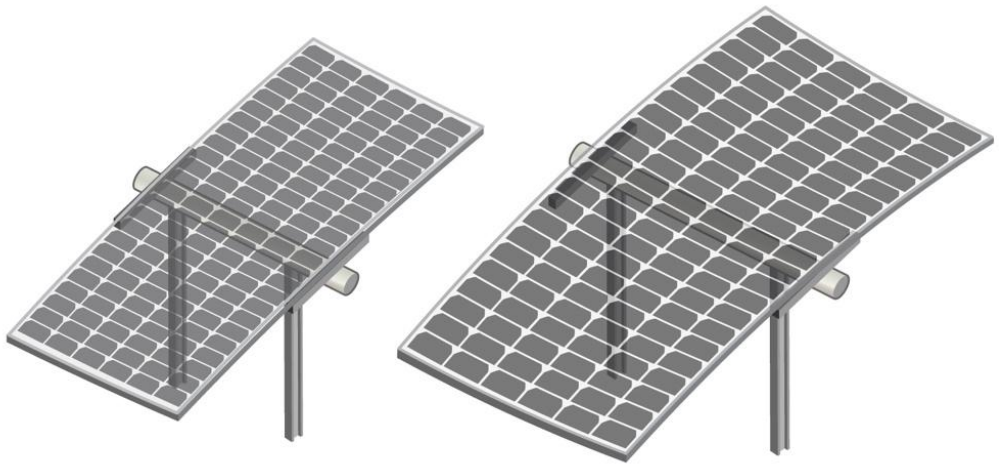
- The stack is often thicker where wires overlap with each other or bus ribbons
- If there is not enough encapsulant, tabbing wires can approach or contact the glass
  - During laminate cooling, glass bends at this point
  - Causes extra tensile stress
  - Increases risk
- Can be exacerbated by edge pinch
- Use thick encapsulant to avoid this

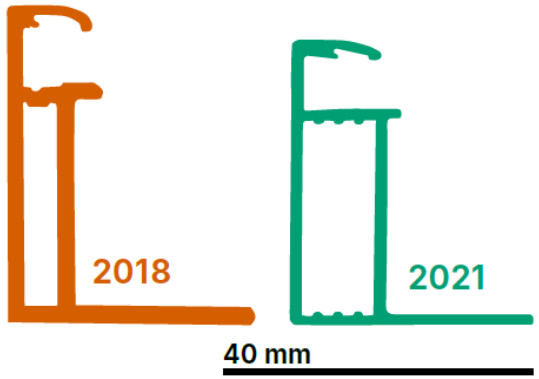
T. Silverman, PVRW, 2026



Improve the Module Assembly

Use a stiffer frame





- Frame stiffness has decreased
- Newer frames uses 30% less material and have 40% less bending stiffness
- For the same mechanical loads, glass deflects more, increasing breakage risk
- Stiffer frames reduce deflection
  - Reduced deflection reduces driving force for cracks to start and grow

E. Palmiotti, PVRW, 2025

Improve the Module Assembly

Apply frame adhesive more carefully

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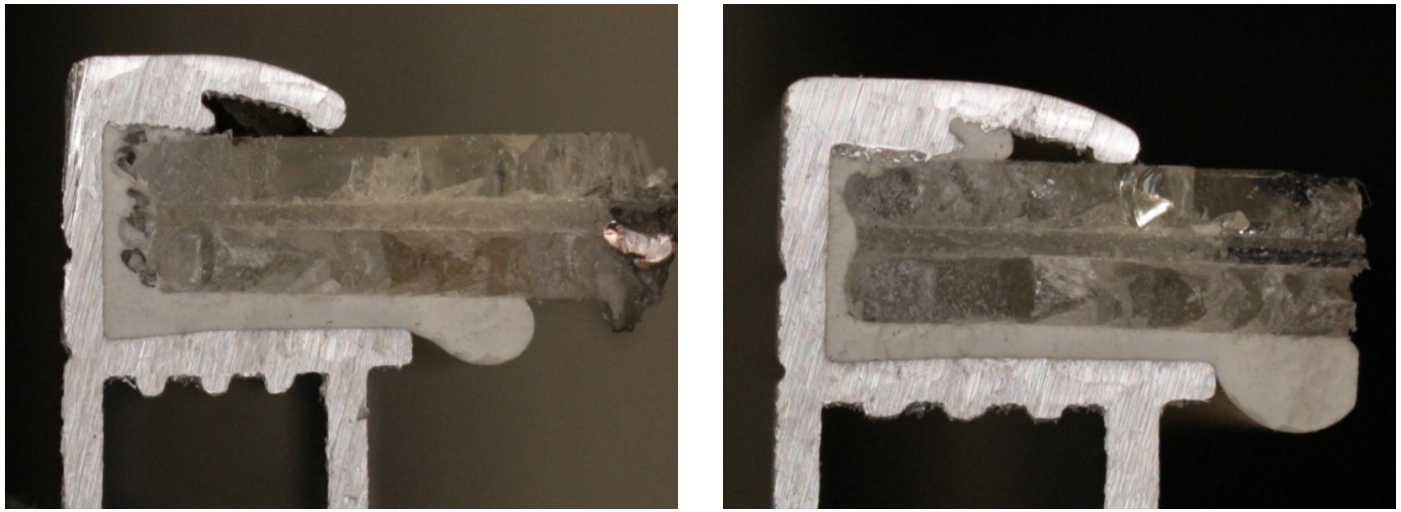


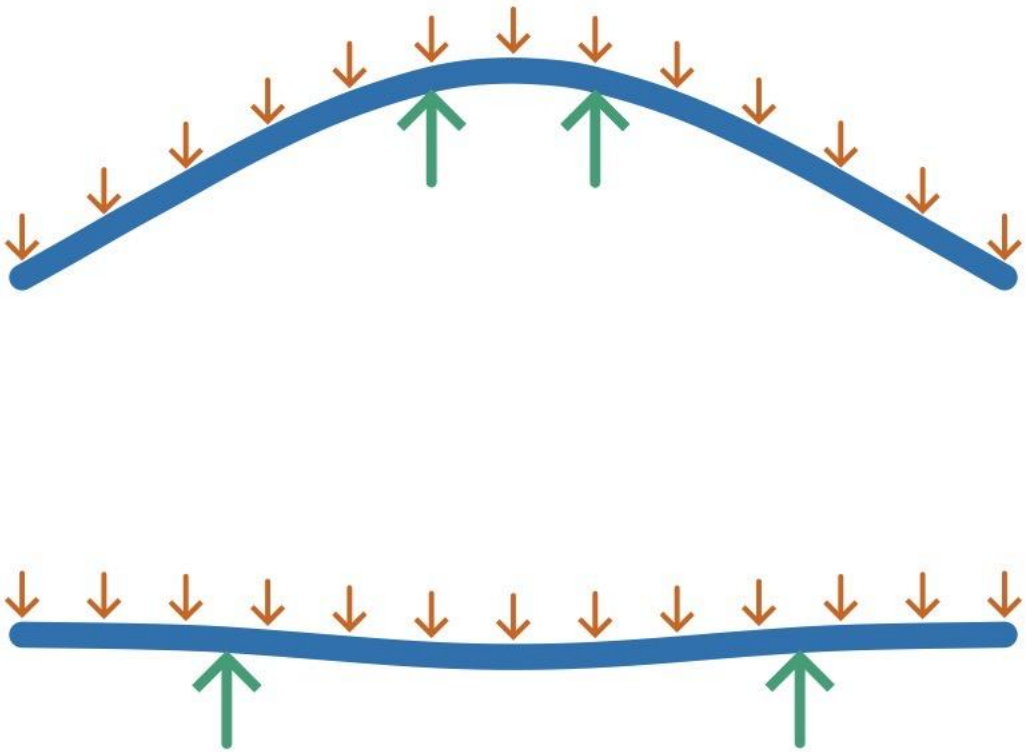
- Direct contact between glass and the frame causes high stress and wear
- A bead of silicone adhesive protects the glass
- The bead very often does not protect the glass
- Improving adhesive application reduces risk of glass-metal contact

Improve the System Design and Operation

- Use stiffer mounting structures
- Reduce accidental projectiles
- Don’t let the clamp chomp the glass

Improve the System Design and Operation

Use stiffer mounting structures

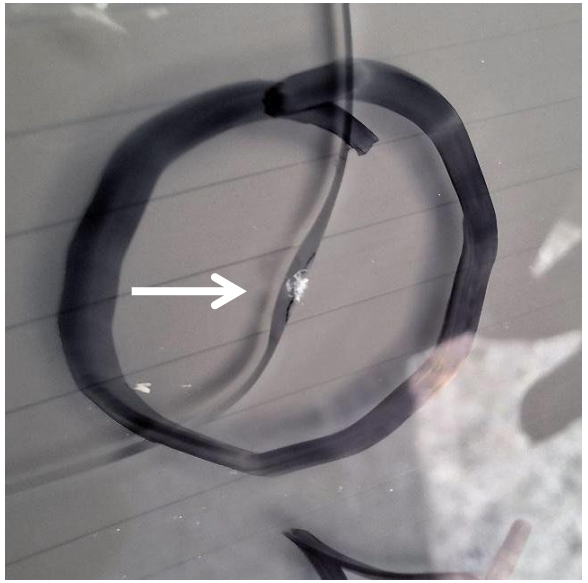


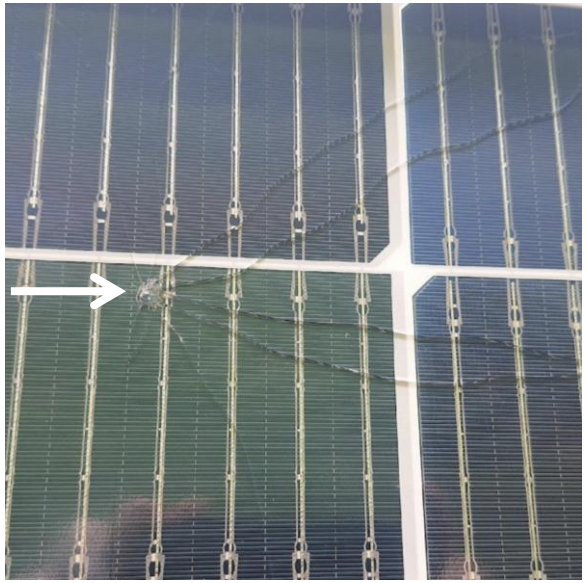
- Compliant mounting structures allow modules to deflect more
- More deflection increases breakage risk
- Stiffer structures reduce deflection
- Reduced deflection reduces driving force for fracture

Improve the System Design and Operation

Reduce accidental projectiles

- Vehicle activity and vegetation management can send flying debris into modules
- Debris may cause invisible mechanical damage that reduces glass strength
- Reduce size and availability of projectiles
- Change practices that launch them



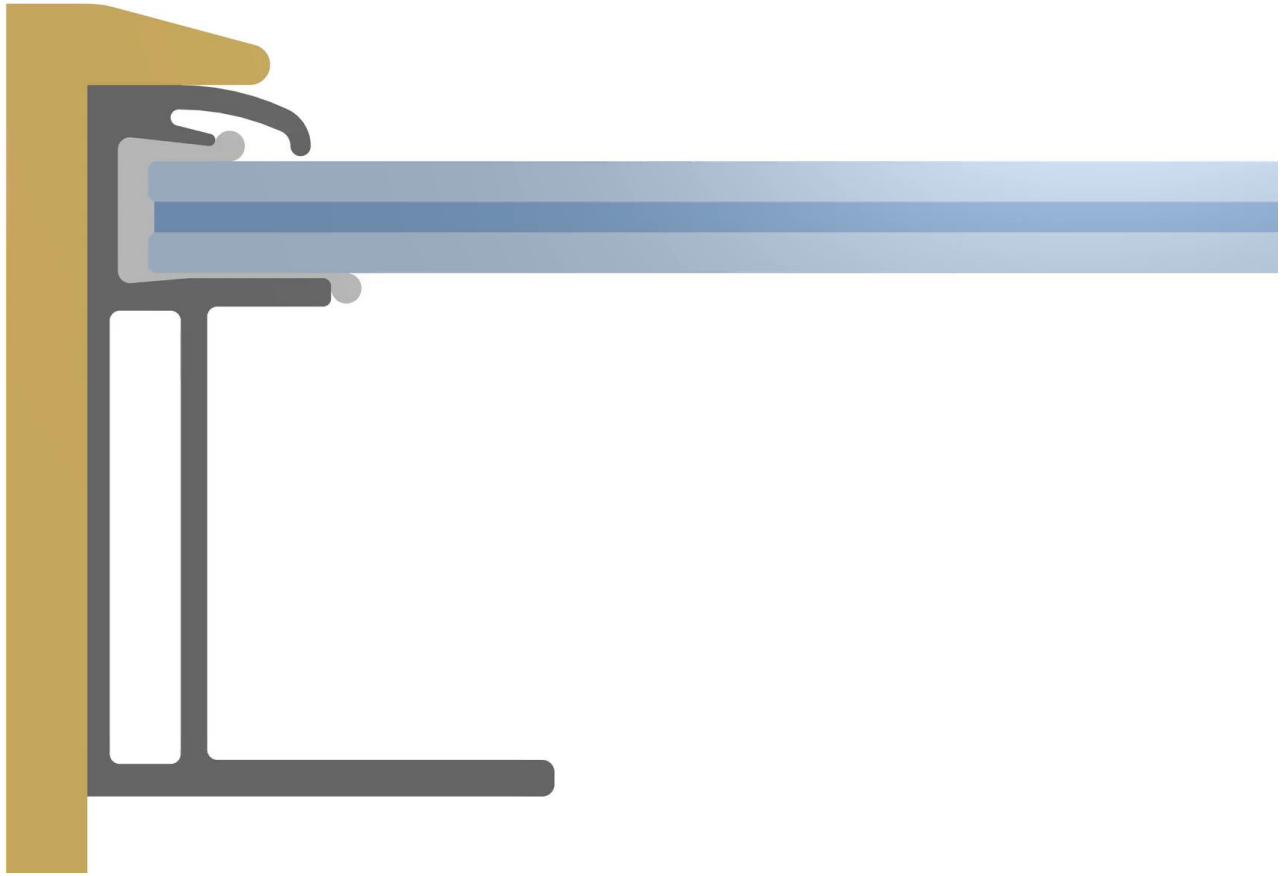


Gaulding, et al. PVRW 2026

Improve the System Design and Operation

Don’t let the clamp chomp the glass

- Module clamps, even torqued to spec, can push the frame into the glass
- This can introduce defects and stress
- Defects can turn into cracks



Conclusion

- Every PV system has a mix of risk factors for glass breakage
- Address the factors to reduce the risk
- The most effective subset is unknown
- We recommend following whichever recommendations are practical

Publications

Tough Break: Many Factors Make Glass Breakage More Likely
tinyurl.com/tough-break

Growing Panes: Investigating the PV Technology Trends Behind Frequent Early Failures in Modern Glass-Glass Modules
tinyurl.com/growing-panes

Surface Stress Characterization and Trends in Thermally Strengthened Photovoltaic Module Glass
tinyurl.com/surface-stress

Thank you!

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