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DuraMAT
Durable Module Materials Consortium

Accelerating a sustainable, just, and equitable transition to zero-carbon electricity generation by 2035.

# Analyzing hail impacts on PV modules using computational simulation

James Hartley, Jen Braid, Farhan Rahman **(Sandia National Laboratories)**; Colin Sillerud, James Richards **(CFV Labs)**

Multi-Scale, Multi-Physics Model

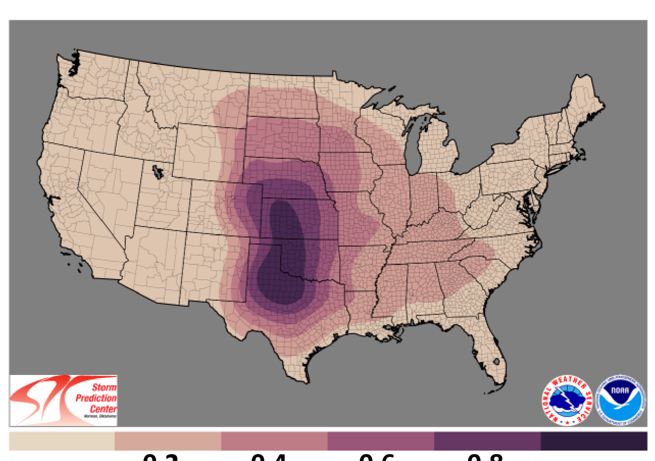
**Awarded FY22 Core Modelling Call**

**Period of Performance: 36 Months**
**Funding: $936,500**

## Contributing to DuraMAT Consortium Goals

- Using simulations to fully characterize the mechanisms leading to or preventing hail damage would reduce premature failures by ensuring that deployed module designs have sufficient margin to survive 20, 30, or 50-year-frequency hail events.
- Module material choice could be optimized by identifying the features which are advantageous, neutral, or detrimental to hail robustness.
- A capability to identify the critical, module-specific hail size which could lead to widespread cell damage could help to identify or exclude historical hail events as the trigger for observed wear-out failures in the field.

## Project Overview and Motivation



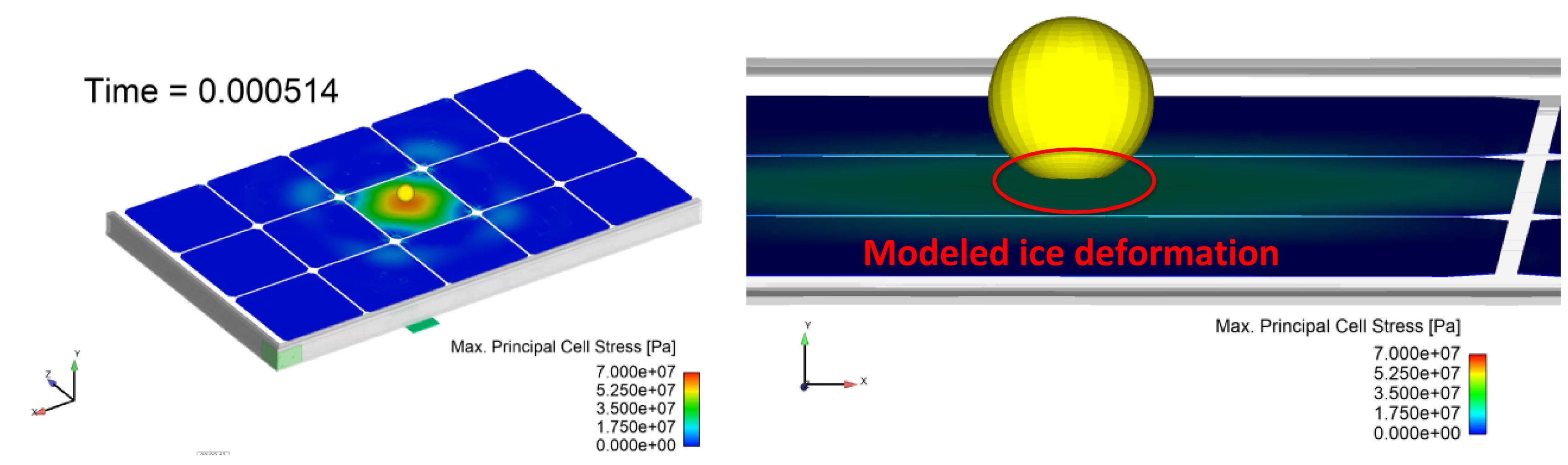

**Mean days per year with a hail size >2 inches**


**Can damage likelihood be quantified, beyond pass or fail?**

- Longer module life means larger probability of experiencing a large hail event
- Pass/fail qualification tests provide poor resolution for detailed risk assessments
- Simulating hail impacts could enable quantification of damage risk on a continuum– **to inform efficient insurance decisions** and **identify features that improve robustness**

## Simulating a hail impact against a PV module

### Year 1 Q1 Goal




**A hail impact vs. PV module simulation was successfully demonstrated using the SIERRA solid mechanics code**

- The hail ice ball and PV module are fully coupled and both modeled in simulation
- Results can be analyzed frame-by-frame to quantify internal stresses, and rank the influence of parameter changes such as module materials or hail size

## Outcome & Impact

### Quantitative, module-specific hail damage predictions enable:

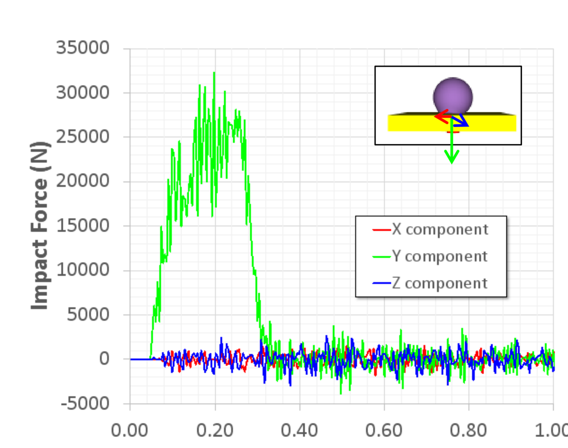
- Optimized decisions throughout the module life cycle: from material selection and robustness vs. cost, to acceptable insurance coverage during deployment
- More efficient and representative qualification tests

## Accomplishments & Publications

- Testing capabilities for standardized hail from 25 mm to 85mm sizes were developed **(CFV Labs)**
- A computational hail ice material model was exercised and is pending validation and publication **(Sandia)**
- A test methodology for measuring module displacement during impact using high speed video and digital image correlation was confirmed **(Sandia)**

## Hail Ice Model Validation

### Year 1 Q3 Goal




**50 kHz impact force sensor**

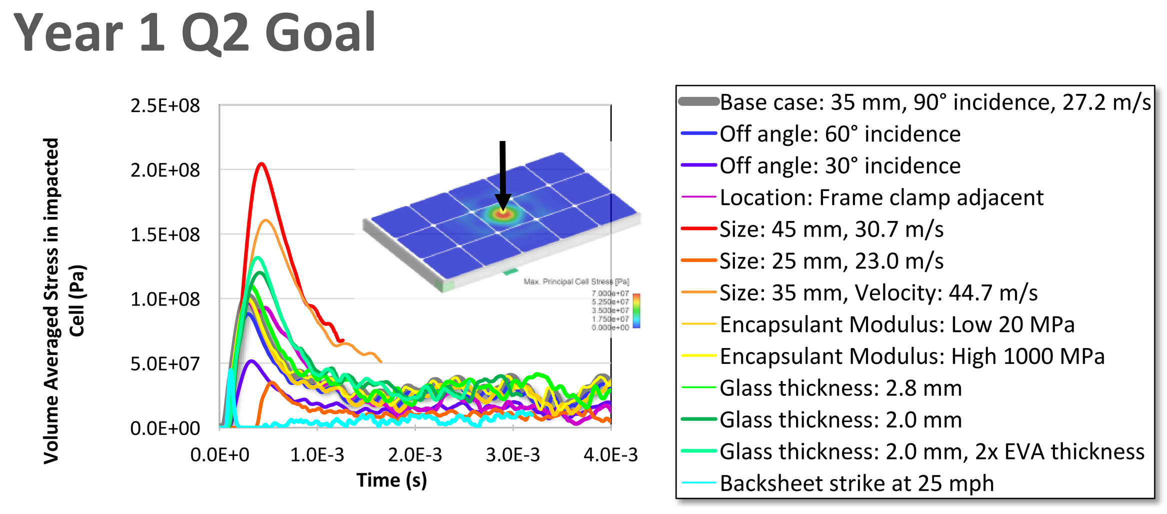
**Testing non-ideal ice addresses real hail variability**

**Simulated impact force vs. time produced by hail ice will be validated against measurements**

- Ice strength and failure characteristics must be modeled correctly to impose correct impact forces
- Matching simulated results to measurements using a high speed force sensor will validate material model
- Measurements of other ice types can provide insight into the range of impact force variability in real hail

## Initial Parametric Simulations

### Year 1 Q2 Goal

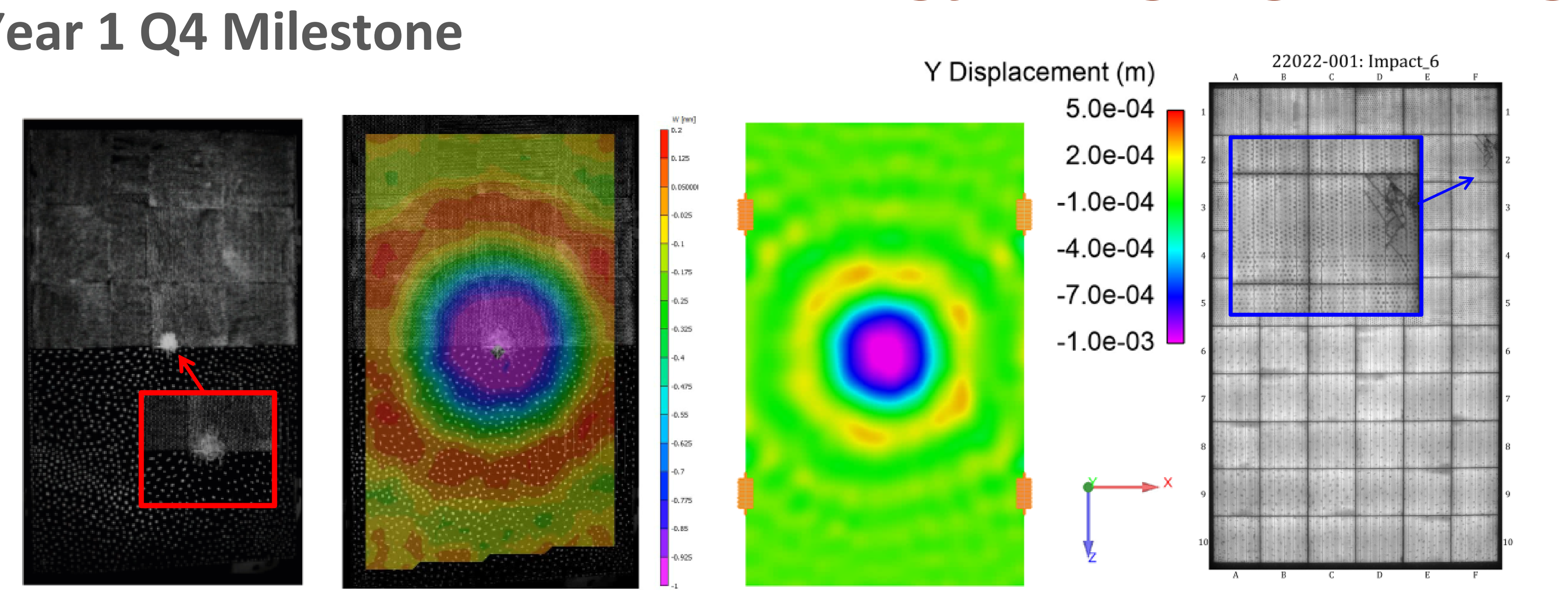



**Initial parametric studies show how cell stress during impact is affected by hail and module characteristics**

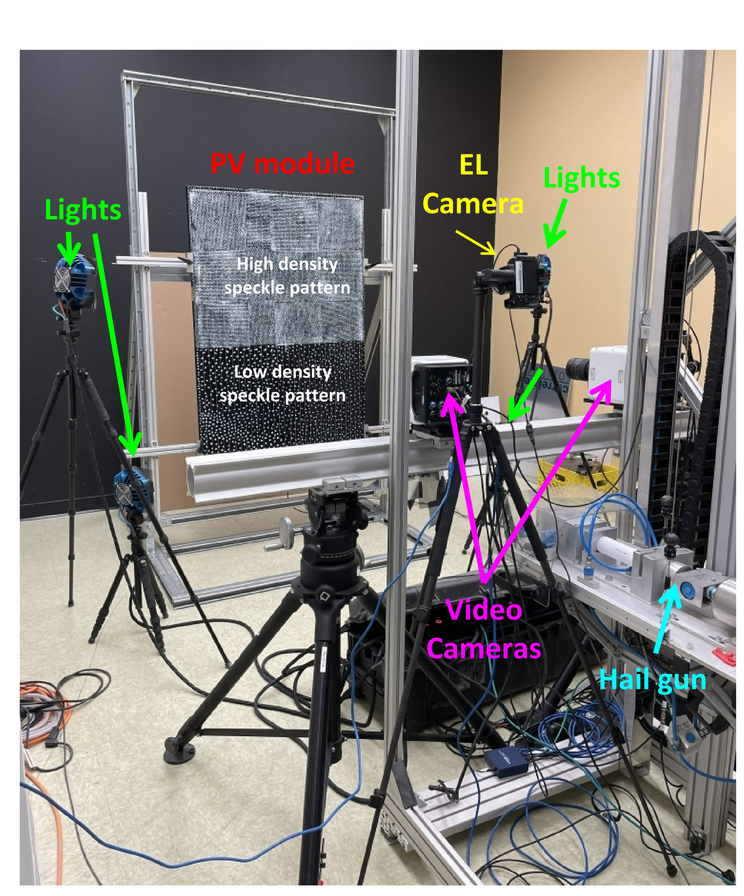
- Parametric studies were conducted using existing models to rank potentially influential design features
- Hail size and impact angle were most important, followed by glass thickness. Module encapsulant did not appear to be influential.
- Results will be used to define which module types are of most interest for Year 2 testing

## Model Validation Methodology Using Digital Image Correlation (DIC)

### Year 1 Q4 Milestone




**Visual impact video** | **Displacements from DIC** | **Displacements from simulation** | **Cell cracks detectable thru speckling**

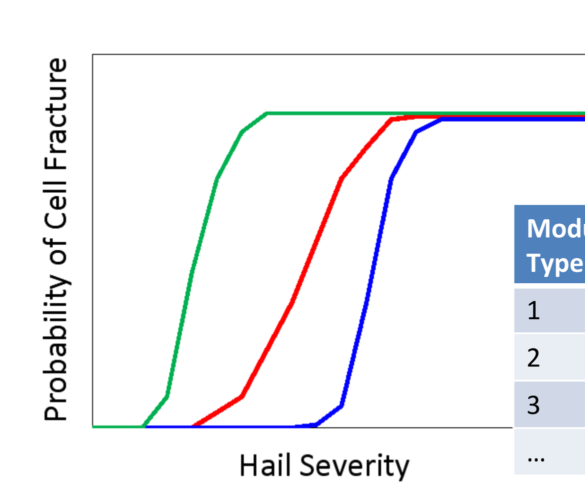



**Hail test setup with video and EL cameras @ CFV Labs**

- The process for conducting a hail test, collecting video, processing video to deflections vs. time, and checking for cracking was demonstrated
- Deflections vs. time will be used to validate simulations, while failure statistics will be used to validate simulated failure metrics

## Testing for failure statistics

### Year 2 Objectives




**Testing and modeling diverse module designs to collect and validate failure metrics**

| Module Type | Glass Thickness | Cell size | Interconnection | … |
|---|---|---|---|---|
| 1 | 3.2 mm | M2 | Smartwire | … |
| 2 | 2.0 mm | M10 | Ribbon | … |
| 3 | 2.8 mm | M12 | Ribbon | … |
| … | … | … | … | … |

**Testing a suite of module designs and samples will provide data for validation and damage probabilities**

- Year 2 will focus on testing various module types for model validation, with sufficient repeats to gather damage statistics
- With confidence in model applicability, detailed parametric studies can be conducted (Year 3)

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