



Resilient Power Report



Executive Summary

In June 2025, we published our 7th Annual Solar Risk Assessment, which details risks identified by industry experts to solar and battery energy storage system (BESS) assets. But after years of compiling that report, we recognized that something was missing from the industry conversation. While understanding risks is essential, we also need to celebrate and learn from our successes. That's why I'm proud to introduce the inaugural Resilient Power Report - a companion publication to our annual Solar Risk Assessment that is focused on what happens when renewable energy infrastructure is designed, operated, and protected with best practices in mind.

Understanding what works becomes increasingly important as we scale. The [IEA](#) predicts that the world will add more than 4,600 gigawatts of new renewable energy capacity by 2030, doubling current capacity. We're not just building incrementally anymore; we're now one of the primary sources of electricity on the grid. At the same time, 54% of renewable energy developers now cite weather damage as their top operational concern¹. As extreme weather events become more prevalent and asset value continues to increase, the gap between vulnerable assets and resilient ones has never been more consequential.

Resilience, however, is not theoretical. The four case studies in this report prove that when we combine smart engineering, proactive protocols, and strategic risk management, renewable energy can withstand nature's worst. An Arkansas municipal utility cut its insurance deductible in half by deploying automated hail stow, and when the storms came, the system automatically protected itself. In the Caribbean, a small island project on Mayreau demonstrated how targeted engineering improvements can withstand repeated hurricanes, turning field lessons into practical design innovations. NREL's satellite analysis of over 11,000 systems confirms that proper mounting and strategic design choices prevent damage even during record-breaking hail events.

These cases aren't isolated miracles; they're the result of deliberate choices. The technology exists. The data validates it. The question is whether we'll deploy these solutions before the next storm makes that choice for us. The assets we're building today need to operate reliably for 30+ years in a climate that's becoming less predictable. We can and should learn from the projects that are getting natural catastrophe resilience right and scale those solutions across the industry. That requires honesty about current gaps, adoption of proven strategies, and collaboration between manufacturers, asset owners, brokers, insurers, and lenders.

Rising energy requirements and costs demand that we succeed, and the case studies in this report prove we can. By documenting and scaling what works, we can build renewables infrastructure that's worthy of a long and sustainable energy future.

Sincerely,



CEO, kWh Analytics



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When Insurance Drives Innovation: How Hail Stow Tech Cut Deductible by 50%

By: Nikky Venkataraman, kWh Analytics

Hail is becoming an increasingly perilous issue for solar project owners, even outside of Texas. Some owners own only a few small solar projects, and as a result, are not aware of the latest innovations that are coming to market. As extreme weather events become more frequent and severe, traditional insurance carriers protect themselves by withdrawing coverage or imposing prohibitive terms and conditions, leaving asset owners with limited options to protect their investments. This dynamic has created an unexpected catalyst: insurance requirements driving technological innovation.



The Challenge

A municipal utility in Arkansas struggled to find hail coverage for its 13 MW solar project. The 2022 installation is located in a high-hail hazard region and provides power to surrounding homes. Traditional carriers could only provide expensive insurance options, leaving the utility to seek an innovative coverage solution.

This highlighted a broader problem: as hail damage to solar becomes more prevalent, the gap between available insurance and actual project needs widens. Small asset owners, lacking the risk management resources of commercial developers, are particularly vulnerable to these risks.



The Resolution

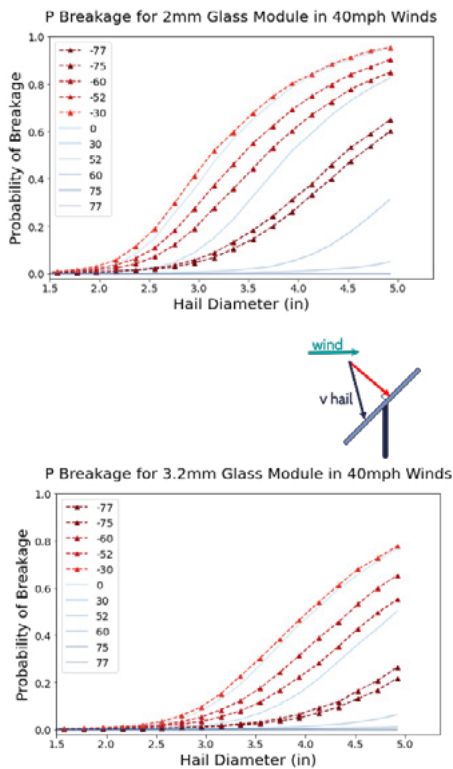
Rather than accepting poor coverage options, the utility opted for a tech-driven solution. Working with kWh Analytics, with support from their broker and racking manufacturer Nextracker, they upgraded existing racking systems with automated hail stow capability. This technology automatically tilts panels to a protective angle when severe weather approaches.

The upgrade included installation of a control system server and firmware updates, integration with weather forecasting services, and automated protocols triggered by hail size, proximity, and impact probability. The upgraded system has stow capabilities up to 60 degrees of tilt, an angle which



has been proven to reduce the kinetic energy of hail impact, and thus reduce the probability of damage. System settings also prioritize hail stow over wind stow, and will automatically set the system to stow away from the wind when hail is predicted or detected. The system operates autonomously during storms, and regular testing protocols have been established to verify reliability .

Figure 1



The Outcome

Results were measurable across multiple areas. kWh Analytics structured an innovative policy that reduced deductibles by 50% upon implementation of the auto stow program. The utility gained access to comprehensive coverage previously unavailable.

Recent hail events provided real-world proof. When severe weather approached the site, the system activated automatically, and inspections revealed no damage. This validated both the technology's reliability and the insurance assumptions. The region has seen 14 hail events of greater than 1 inch hail in 2025, and 3.25 inch hail was observed in the region in March, 2025.

Operationally, the system eliminated the need for storm staffing, reducing costs and human error. "This is so much easier, and lets us sleep better at night," noted the operations manager. "When storms roll through, we want to focus on keeping the lights on."

This partnership demonstrates how innovative insurance structures can incentivize technological improvements that benefit all stakeholders, reducing risk for insurers while enhancing project resilience for asset owners.



Extreme weather resilience lessons from satellite imagery

By: Dirk C. Jordan, Kirsten Perry, Quyen Nguyen, National Renewable Energy Laboratory

Satellite imagery analysis of extreme weather events reveals that strategic design choices and operational protocols can dramatically reduce solar asset damage. Recent studies of hurricane and hail events demonstrate that while weather severity matters, resilient design practices often determine whether a solar installation survives intact or suffers catastrophic losses. The data shows that proper mounting systems, component selection, and operational protocols can protect solar assets even during record-breaking weather events.



The Challenge

For energy security and grid reliability, PV systems need to withstand extreme weather events such as hurricanes and hail. Hurricane winds generate devastating uplifting forces, particularly for modules mounted near building edges, where strong uplift forces can lead to severe damage. Meanwhile, hailstorms present equally destructive risks - the September 2023 Austin event produced hailstones over 4 inches in diameter and caused over \$600 million in regional damages, marking the highest hailstorm damage in Austin area history. Despite over 11,000 PV systems being in the hail path, damage patterns varied dramatically even among neighboring installations, suggesting that weather severity alone doesn't determine outcomes.



The Resolution

To understand how extreme weather affects PV, two notable events and their associated damages to PV sites were examined in detail. Hurricane-related damage was evaluated by analyzing the impacts of Hurricanes Maria and Irma on roughly 1,500 PV sites in Puerto Rico and the U.S. Virgin Islands. PV

vulnerability to hail was assessed through the 2023 Austin hailstorm, which affected more than 11,000 systems. Satellite analysis identified key resilience strategies that differentiated between surviving and damaged installations. For hurricane protection, proper mounting systems proved critical, as shown in Figure 1, which highlights three specific locations (Sites 1, 2, and 3) that faced high hurricane winds. Site 1 experienced significant damage despite relatively low wind gusts, as the modules were mounted on a structure contiguous with the edge of the building. It is well known that modules mounted close to a building edge will experience strong uplifting forces that can more easily lead to severe damage.¹ In a similar vein, Sites 2 and 3 are approximately 1 mile apart, yet they sustained approximately two orders of magnitude different damage due to a known mounting problem. The most heavily damaged site shown in Figure 1 was still under construction when Hurricane Maria brought wind gusts of 180 km/hr, leaving many modules improperly secured and resulting in greater levels of damage.

1. SEAOC Solar Photovoltaic Systems Committee, *Wind Design of Solar Arrays*, Technical Report (Structural Engineers Association of California, 2017).



Figure 1

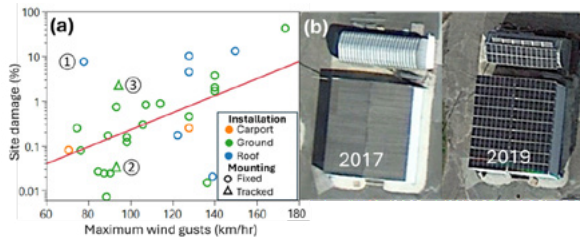


Figure 1. (a) Hurricane site damage as a function of maximum wind gust speeds, color coded by the type of installation and symbol coded by the type of mounting. Sites labeled 2 and 3 are around 1 mile from each other but show very different site damage. (b) Images of Site 1 in 2017 and 2019.

The second case study of extreme weather resilience focuses on hail exposure. Figure 2 (a) shows the impact of an extreme hailstorm that impacted the greater city of Austin, TX in September 2023, when the city saw hailstones over 4 inches in diameter. More than 11,000 PV systems were in the hail area at the time of the storm, yet only 5.5 % sustained damage, with damage concentrated in the regions predicted by radar to have the largest hail sizes (Figure 2a). Further, the results of this study indicated that sites that had an installation azimuth facing primarily into the direction of the wind suffered higher damage amounts than those facing primarily away from the wind. This finding supports the concept of hail stow, in which tracker-equipped sites tilt panels to a steep angle to reduce hail impact energy and improve survival rates.

For hail stow to be effective, the wind direction needs to be known so that modules can be tilted away from the wind, which is not always identical to the storm movement, as shown in Fig. 2(b). In this case, the wind direction did not change within 2 hours prior to the onset of the hail, indicating that hail stow may have been effectively employed if the weather situation was closely monitored. Our investigation also revealed that modules installed after 2020 showed significantly more damage than modules of earlier vintage (Figure 2.c). Newer modules are typically larger and may have thinner front glass that can make them more vulnerable to hail, indicating a need for more robust testing, smart protective tracker orientation, and proactive standards.⁷

Figure 2

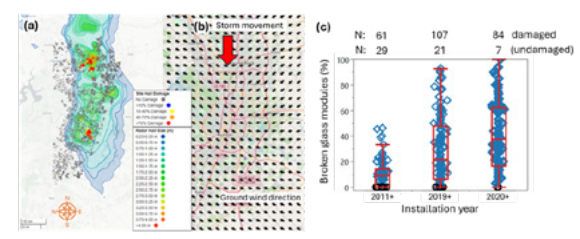


Figure 2. (a) Hailstorm in the Austin, TX, USA, area in September 2023. Contours indicate hail sizes detected by radar and damage to PV system color-coded by severity of damage. (b) Storm direction, movement, and ground wind speed direction measurements. (c) Broken glass module percentage for different installation periods for the same hail size and orientation.



The Outcome

The satellite data prove that resilience investments pay off: well-designed systems can survive extreme weather that destroys poorly planned installations. The analysis established a clear resilience framework—proper mounting systems, thicker glass modules, strategic placement away from building edges, more rigorous test standards, and proactive hail stow protocols. Most significantly, the research demonstrates that asset owners have concrete, actionable strategies to protect their investments rather than simply accepting weather-related losses as inevitable. These findings provide the solar industry with evidence-based guidelines that can substantially reduce catastrophic damage rates during extreme weather events.

1. R. McAtee, "Solar Photovoltaic Reliability After Hurricanes," *Military Engineer* 110, no. 713 (2018): 64–66.
2. Christopher Burgess, Frank Oudheusden, Chris Needham, and Fidel Neverson, *Solar Under Storm III: Updated best practices for resilient ground-mount PV systems with hurricane exposure*, RMI, 2025, <https://rmi.org/insight/solar-under-storm>.
3. J. Elsworth, O. Van Geet, C. Kurnik, et al., *Solar Photovoltaic (PV) Damage Assessment After Typhoon Mawar: Findings and Recommendations for Resilient PV on Guam*. Technical Report NREL/TP-5R00-89629 (National Renewable Energy Laboratory, 2024), <https://doi.org/10.2172/2479116>.
4. R. Segal, *September Hail Storm Caused 600 Million in Damage to Austin Area*, NWS Estimates (KXAN Austin, 2023).
5. D. C. Jordan, K. Perry, R. White, and C. Deline, "Extreme Weather and PV Performance," *IEEE Journal of Photovoltaics* 13, no. 6 (2023): 830–835, <https://doi.org/10.1109/JPHOT.OV.2023.3304357>.
6. E. C. Palmiotti, M. Springer, J. Zuboy, et al., "Growing Panes: Investigating the PV Technology Trends Behind Frequent Early Failures in Modern Glass–Glass Modules," *IEEE Journal of Photovoltaics* 15, no. 2 (2025): 297–308, <https://doi.org/10.1109/JPHOT.OV.2025.3526170>.

Tech Review of New Defensive Hail Stow System Confirms 100% Success Across Multi-Day Severe Convective Storm Outbreak in Arkansas

By: Jonathan Ostrom Allen, Director of Hail Risk Services - VDE Americas

Rare but expensive catastrophic solar losses are on the rise as project development activities expand to hail-exposed regions in Africa, Australia, Europe, and North and South America. Earlier this year, climate insurance provider kWh Analytics reported that hail accounts for 6% of its solar project insurance claims by volume but roughly 73% of total dollar losses.¹ Meanwhile, specialty insurer GCube has noted that its average solar hail claim expense is over \$58 million.² Automated stow protocols are increasingly deployed in utility applications to prevent physical damage and financial losses.



The Challenge

Proving these hail defense systems work reliably in advance of extreme weather events remains a critical technology verification gap. In a post-event forensic investigation explained in the 2025 Solar Risk Assessment, VDE Americas found that defensive hail stow protocols successfully prevented widespread physical damage at three utility-scale solar farms in Fort Bend County, Texas, during multiple one-in-500-year hail events in mid-March 2024. Given that PV module hail damage at the exposed sites was isolated to a small portion of one PV power plant that did not achieve hail stow due to a pre-existing tracker motor issue, investigators concluded that overall site damages could have been much worse if not for operational hail stow protocols.³

Though the Fort Bend County forensic investigation's findings are promising, many in the insurance, investor, and technical due diligence community invariably ask: "How can project stakeholders have confidence that operational hail stow measures will work as intended when needed?"



The Resolution

VDE Americas and GameChange Solar, a single-axis tracker manufacturer, collaborated on a real-world hail stow verification study for a hail-exposed solar site in Johnson County, Arkansas (Figure 1). The investigators reviewed system and meteorological data for April 2025, focusing on three consecutive days during which severe convective storms passed near the site. Researchers examined data from every step of the defensive hail stow operation: weather service alerts, automated master controller activation, and hail stow confirmation using controller status as a proxy for in-field tracker position.

Figure 1

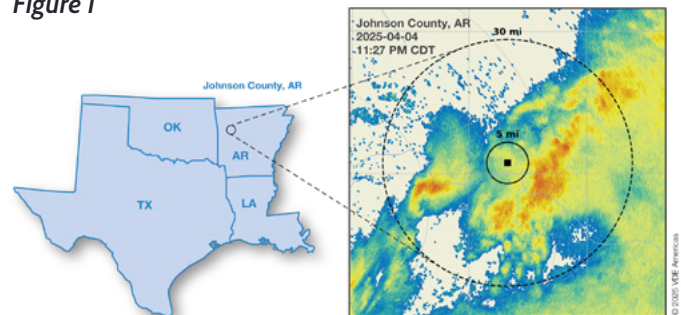


Figure 1. The approximate location of the study site in Johnson County, Arkansas, and a snapshot of weather radar data at the start of a severe convective storm approximately 20 miles to the west-southwest of the site. Note that the project (black square) is centered within 5- and 30-mile radii with different triggering alert criteria.

1. Fagan, R., "Hail Accounts for 73% of Total Losses by Damage Amount, Despite Representing Only 6% of Loss Incidents," *Solar Risk Assessment 2025*, kWh Analytics
2. *Hail No! Defending solar from nature's cold assault, Q4 2023 Report*, GCube
3. Previtali, J., "Study Shows 100% Hail Stow Success Despite Severe Storm Exposure," *Solar Risk Assessment 2025*, kWh Analytics



The Outcome

In early April 2025, Arkansas experienced a tumultuous weather pattern marked by severe storms, record-breaking rainfall, and deadly flooding. Severe thunderstorms generated hail as large as 3 inches in diameter.⁴ The site discussed in this study was prepared (Figure 2). As the storms drew near, weather alerting services from DTN and Vaisala XWeather merged Next Generation Weather Radar (NEXRAD) data with meteorological models to rapidly predict the size and location of hailfall. GameChange Solar processed these alerts and directed the trackers to stow at a steep angle within minutes.

Weeks later, VDE Americas examined engineering and meteorological data to verify that this complex real-time system worked as designed. The study verified that the automated system operated as designed; it

- 1 queried the weather service APIs every 2 minutes,
- 2 signaled hail stow activation within a minute of receiving a triggering alert,

- 3 executed the hail stow command, and
- 4 maintained the defensive stow position until the storms had passed.

During the study period, six systems of severe thunderstorms generated hail within 30 miles of the site, with the nearest hail observation only 4.4 miles from the site. Hail was observed within 30 miles of the site on every occasion that the system went into hail stow; thus, the system had no false activations. The minimum buffer between radar-based hail observations and stowed trackers was 14.4 miles.

Automated hail alerting and stow requires the coordinated operation of weather radars, meteorological modeling, alert retrieval and processing, and tracker positioning in real-time. Since communication or hardware issues could compromise this system, periodic testing and maintenance are critical to reliable operations.⁵ Independent technical due diligence, including engineering and meteorological verification of these complex systems in operation, can provide evidence that hail stow systems perform as designed to mitigate catastrophic hail losses. Moreover, case studies have shown that solar assets with properly implemented and documented hail defenses can qualify for evidence-based insurance premium reductions.⁶

Figure 2

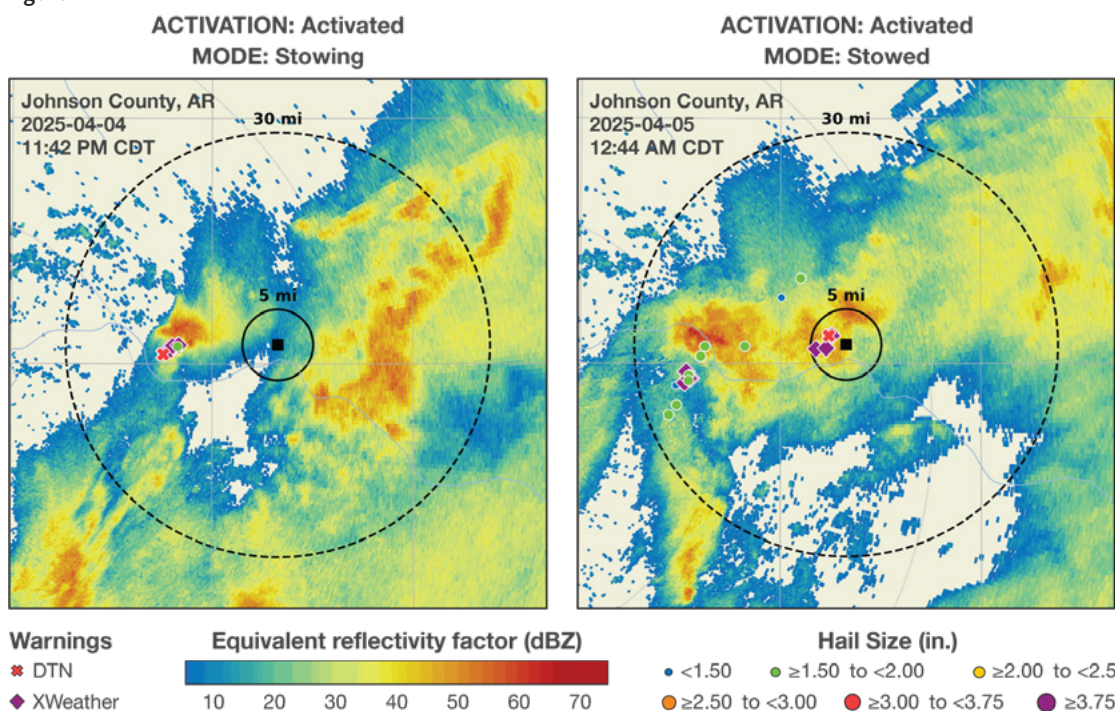


Figure 2. This sequence shows that the tracker controller has properly activated hail defenses in response to triggering alert criteria (left), and 62 minutes later, the system remains in hail stow when the storm system generates hail alerts within 5 miles of the site (right). Note the record of hail observations to the west of the site.

4. "NWS Little Rock, AR – April, 2025 Monthly Summary," National Weather Service, <https://www.weather.gov/lzk/apr2025.htm>

5. Bostock, P., et al, "Best Practices for Hail Stow of Single-Axis Tracker-Mounted Solar Projects," VDE Americas & Wells Fargo, February 2024

6. "Case Study: Resilient Assets Command Better Coverage," kWh Analytics, September 2024

Building Wind Resiliency on the Frontlines: Lessons from Mayreau

By: Frank Oudheusden, Azimuth Advisory Services and Resilient Solarworks

The Caribbean is one of the most demanding proving grounds for solar energy, where high winds and corrosive environments make long-term performance an extraordinary challenge. On the small island of Mayreau, repeated Category 4–5 hurricanes have revealed both vulnerabilities and opportunities in solar design.

For the past eight years, Azimuth Advisory Services (AAS) has provided boots-on-the-ground forensic analysis only weeks after major hurricane landfalls. Those lessons learned have culminated in the Solar Under Storm I (2017), II (2020), and III (2025) reports on solar resiliency, co-authored and funded by RMI.



The Challenge

Following the devastating Category 5 hurricanes Irma and Maria in 2017, a solar site on Mayreau was constructed using the guidance of Solar Under Storm I, establishing a testbed for resiliency based on the earliest set of recommendations. That system performed admirably through multiple years of exposure, until Category 4 Hurricane Beryl in 2024 introduced the next-generation failure mode.

Azimuth Advisory Services was dispatched by sailboat to analyze these outcomes in the field. The most critical failure observed at the Mayreau site was low-cycle fatigue in module frames. While industry-standard testing emphasizes ultimate strength, field performance showed that as manufacturers reduce aluminum use to cut costs and weight, frame cross-sections have become thinner and more flexible, reducing tolerance to cyclic stresses and accelerating crack initiation at bolted joints.

While flat washers are designed to spread a uniform load, module-frame connections rarely behave uniformly under stress. Under wind-induced deflection, the frame tends to roll, turning the washer into a knife-edge that digs into the thin aluminum

frame. Over time, this localized stress concentration has led to significant module loss in the field, even under moderate wind speeds.

Figure 1



Figure 1. Cyclical Fatigue Loading Failure Seen on Mayreau – Photo Credit: Azimuth Advisory Services





The Resolution

In response to this challenge, AAS collaborated with partners to develop and test a stainless-steel reinforcement that replaces the conventional flat washer with an engineered fastener tailored for solar performance. Rigorous modeling and testing confirmed that Stormplate reduced load transfer into the module frame by 50% and extended cycle life by more than 450 times.

Figure 2

Fatigue Life 2 Elements from Edge A (Cycles)			
Model	Applied Load		
	1068 Pa 40% Rated	1335 Pa 50% Rated	1602 Pa 60% Rated
1.1mm Thick Extrusion	198,427	14,730	607
1.5mm Thick Extrusion	2,298,817	283,000	38,958
RSW StormPlate™ SP0 1.1mm Thick Extrusion	4,144,299	1,015,000	283,169

Figure 2. Results of fatigue cycles performance from non-linear FEA analysis

The updated fastener, StormPlate®, geometry spreads clamping pressure more evenly across the module frame, preventing localized stress concentrations that typically drive crack propagation. In addition, Stormplate provides reinforcement against frame tear-through by flexing in concert with the module frame. This “Goldilocks” balance delivers enough stiffness to strengthen the connection without creating new stress risers, while still offering the compliance needed to meaningfully extend fatigue life.

Figure 3



Figure 3. The StormPlate® SP1 engineering fastener



The Outcome

These advancements form part of a broader framework AAS is advancing to ensure solar is not only cost-competitive but storm-hardened. By commercializing targeted product innovation from field forensic analysis, we’re shifting the industry’s focus from “can the system survive a storm?” to “can the system continue to thrive after multiple storms?” Although only a 100 kW system, Mayreau was re-powered in summer 2025, ready for round three and prepared for nature’s next test.



Contributors

kWh Analytics, a leading Climate Insurance provider, underwrites property insurance and revenue firming products for renewable energy assets. Our proprietary database of 300,000+ zero-carbon projects and \$100B in loss data fuels advanced modeling and insights, enabling precise underwriting decisions. This data-driven approach incorporates resiliency measures in risk evaluation, promoting sustainable practices in the renewable energy sector. kwhanalytics.com

National Renewable Energy Laboratory (NREL) leads energy systems innovation and integration—enhancing existing technologies and developing new, cutting-edge solutions that unlock economic opportunity and fuel America’s global competitiveness. NREL bridges foundational research with practical applications to integrate various energy sources, storage, buildings, transportation, and emerging technologies. nrel.gov

VDE Americas provides technical advisory and risk mitigation services to equipment manufacturers and those who develop, finance, construct, own, operate, and insure large-scale solar power generation and energy storage facilities. The company’s products and services have facilitated the financing of over \$15 billion in operating renewable energy assets. VDE Americas is the world’s leading expert in solar project hail risk intelligence and loss prevention. vde.com/en/vde-americas

Azimuth Advisory Services (AAS) is a consulting firm specializing in technical due diligence, forensic analysis, and field investigations of PV design and mounting systems, with nearly a decade of post-storm expertise captured in the Solar Under Storm reports. Resilient Solarworks (RSW) builds on these lessons by commercializing targeted solutions like the StormPlate™, ensuring solar projects achieve both cost competitiveness and lasting resiliency. azimuth-ventures.com

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