SOLARGRADE

BY HELIOVOLTA

# THE SOLARGRADE PV HEALTH REPORT

## Second Edition

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# INTRODUCTION

Since founding HelioVolta, we have dedicated our careers to digitizing renewable energy site visits with our software platform, SolarGrade. **Our efforts have yielded a >100,000-record database of PV health, safety, and reliability metrics.**

Our team built this database by logging thousands of hours of PV system inspections with the SolarGrade mobile app. The second edition of our PV Health report gleans a story of opportunity from this data.

**While a staggering 72% of project inspections found critical or major safety or reliability risks, almost all issues we observed were preventable.**

But substantial risk reduction requires project stakeholders to find and fix latent problems as projects are built, and before they become costly failures.

In an effort to make this report as actionable as possible, we are publishing insights from newly constructed and build-stage site inspections for the first time. We also share our internal matrix for calculating the severity of safety risks.

We publish this report so that EPCs, O&M providers, and asset owners and operators can leverage our findings for their training, quality standards, and O&M protocols.

Our hope is that the data we share here is used to build and operate assets that fulfill the promise of solar power as responsible and reliable clean energy sources far into the future.

**David Penalva and James Nagel**
Co-founders of HelioVolta and SolarGrade

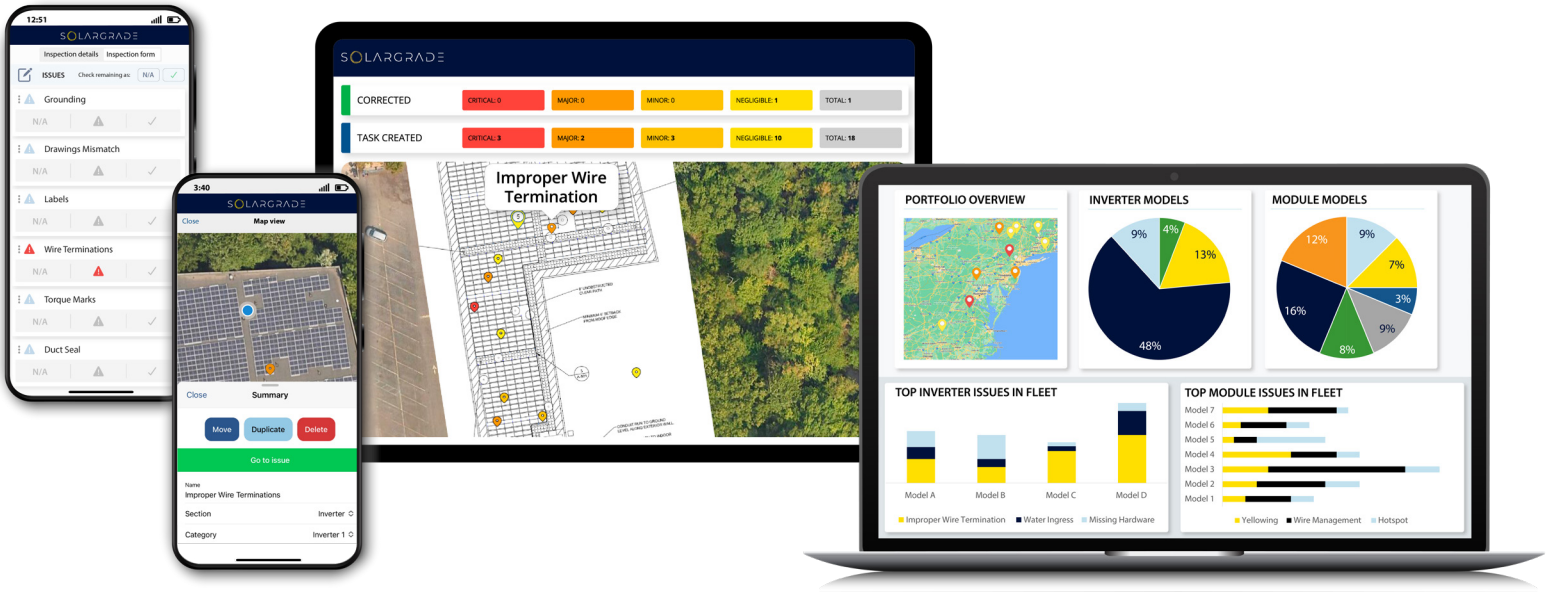
## KEY FINDINGS

- **11% of inspections found critical safety issues requiring partial or total system de-energization.***
  - 80% of critical issues were in operating assets.
- **72% of inspections found critical and/or major safety issues, an increase from 62% reported last year.**
  - The increase is partially driven by nearly 2x growth of our database.
  - We highlight that 40% of our health audits took place at randomly selected projects in fleets with prior failures. Third-party construction QA/QC was not conducted at most of these sites.
- **Issues related to wiring and connectors were observed more frequently than any other issue type.**
  - 80% of inspections found wire-related issues.
  - 83% of inspections found connector-related issues.

* Findings from inspections conducted for root cause analyses of field failures are excluded from this statistic. When projects with critical issues identified during RCA inspections are included, the share of projects with critical issues increases to 13%.

# METHODOLOGY

Inspections analyzed for this report were conducted with SolarGrade, the field operations software for renewable assets. The platform generates field intelligence from site visits for project development, construction, and operations. SolarGrade analytics inform business strategies that increase profitability for EPCs, O&M providers, asset owners and operators, and technical advisors.




## HOW SOLARGRADE WORKS

### Faster, Better Site Visits and Reports

The mobile app guides technicians as they complete tasks, take photos, log observations, mark up drawings, and generate one-tap reports.

Our library of editable templates and records made for renewables streamlines onboarding, standardizes site visits and improves accuracy.

### A Single Source of Project Truth

Geo-referenced field records are saved in the project's history and stored in the cloud.

Issues are tracked, so latent problems are not forgotten or overlooked.

Users can auto-generate punch lists, build O&M schedules, and create work orders with data from prior site visits.

### Field Analytics that Boost ROI

Site visit informatics are stored in an analysis-ready database alongside equipment data and key project details.

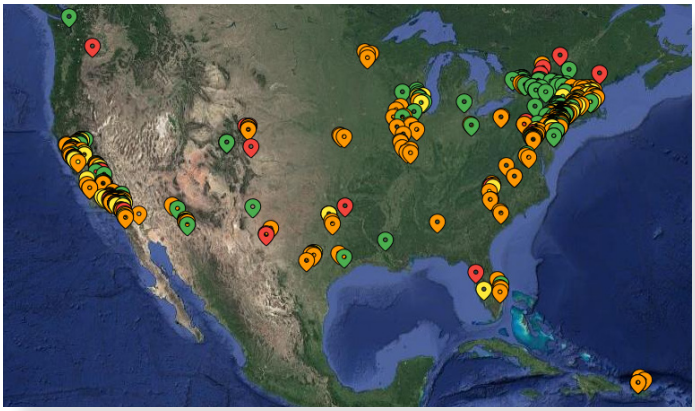
Users can analyze fleet- and project-level data by crew, equipment OEM, tickets, or any other attribute they opt to track.

**Learn more at solargrade.io >>**

# OUR DATA SET

This report is based on >100,000 PV system health data points from hundreds of HelioVolta's PV system inspections in the U.S. and Puerto Rico:

- Projects ranged in size from 50 kW to 350 MW. The **median system size is 500 kW and the mean is 69 MW**.
- **76% of projects are on commercial rooftops**, 19% of projects are ground-mounted, and 5% are carports.
- The inspections occurred from **May 2021 to March 2024**.
- **45% of inspections were for operating assets:**
  - Most of these inspections were health audits and end-of-EPC-warranty inspections, but 4% were site visits for failure root cause analyses (RCA).
  - RCA site visits typically include a health audit and a detailed review of failed components.
- **55% of all inspections were for new construction:**
  - EPC hand-off had not yet occurred when these projects were inspected. A final EPC punch list was a key deliverable.
  - These inspections include QA/QC at project milestones (i.e. golden row, substantial completion, final completion) and commissioning inspections.
  - Commissioning inspections occur about two weeks after permission to operate is received and systems are energized.



*Projects inspected by HelioVolta are shown as pins. Pin colors reflect the severity of unremediated issues at the site.*

## INDUSTRY PERSPECTIVE

"QA/QC for commercial solar assets plays a crucial role in transitioning from the EPC to the Asset Management phase of the asset lifecycle or when a transaction results in a change of ownership.

This service ensures compliance with code requirements and safety standards, verifies the accuracy of as-built drawings, and identifies installation deficiencies.

The QA/QC report provides a punch list of issues that need to be addressed before the project reaches final completion or ownership changes.

**This process ultimately helps maintain high quality and safety standards in solar projects, supporting better performance and return on investment for solar assets."**

**ANNA WATERS**

**Vice President of Commercial Operations**

OMNIDIAN

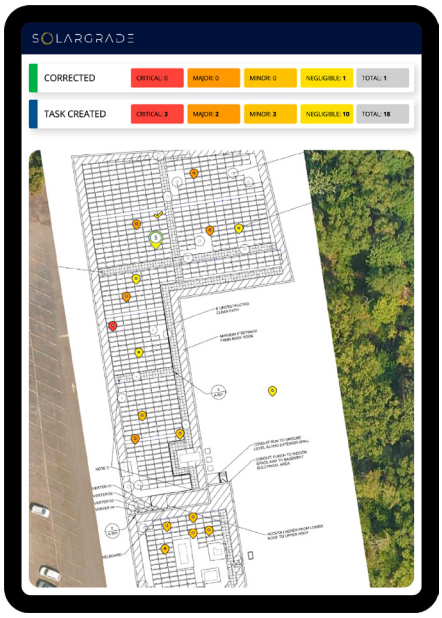
# QUANTIFYING RISK

Every issue logged in SolarGrade is ranked by severity. HelioVolta uses a Risk Assessment Matrix to objectively and consistently evaluate the safety and reliability risk of workmanship and equipment-related issues we observe.

**We are publishing this matrix for the first time in an effort to provide the market with an easy-to-use tool for ranking risks.** We hope you test our matrix online with your mobile device in the field or using the chart on the following page.

Please note: This matrix is an informational guide designed to assess common problems. It does not replace the expertise of trained professionals. It is the responsibility of users to appropriately designate severity risk.

Our aim is to collaborate with our peers to establish consistent and universally accepted definitions of risk. We expect this matrix to evolve. **Please share your feedback with us solargrade@heliovolta.com.**




**Use Our Risk Assessment Matrix online >>**

## THE SOLAR INDUSTRY NEEDS CONSISTENT STANDARDS

Most PV system issues do not impact safety, but many impact performance or cause downtime, and some dramatically increase the likelihood of costly, dangerous thermal failures and safety events.

**Yet the solar industry lacks unified, objective standards for assessing the risk of failure in PV systems.**

While it is common for solar professionals to use the same Failure Modes and Effects Analysis (FMEA) terms to describe risk, such as negligible, minor, major, and critical, but they often define them differently.

A few papers* have been published on this topic, but widely accepted guidelines have not reached professionals in the field.

**Inconsistent risk definitions have negative consequences:**

- When low risks are overstated, time and money is wasted on unnecessarily urgent corrective actions that can wait to be addressed.
- When high risks are understated, important corrective actions are not taken and safety incidents are more likely.
- When severity levels are disputed, delays in system construction and commissioning, stalled contractor payments, canceled project transactions, and even costly legal actions can occur.

*We recommend *Quantification of Technical Risks in PV Power Systems* published by the International Energy Agency: https://iea-pvps.org/key-topics/quantification-of-technical-risks-in-pv-power-systems/

Severity Assessment

## STEP 1 ELECTRICAL SAFETY: CALCULATE POINTS

Does this issue pose an **immediate risk*** to personnel, equipment, or property?
- YES → 15 points
- NO → Is the **equipment faulted** or operating **out of range**, AND it **poses a risk if energized**?
  - YES → 5 points
  - NO → Does the issue **compromise the integrity** of a component (assembly or circuit)?
    - YES → 3 points
    - NO → 1 point

**An immediate risk occurs when live parts are unintentionally exposed to personnel or moisture, OR there is a shock hazard if the part is contacted.*

## STEP 2 THERMAL: CALCULATE POINTS

Is there a **thermal anomaly* higher than the maximum rating** specified for the component (typically >90°C)?
- YES → 5 points
- NO → Is the relative temperature of the **thermal anomaly ≥15°C higher** than a similar component in the same conditions?
  - YES → 4 points
  - NO → Is the relative temperature of the **thermal anomaly 4°C to 15°C higher** than a similar component in the same conditions?
    - YES → 2 points
    - NO → 0 points

**A thermal anomaly is a high temperature reading on ANY component. They are often found on wire terminations, breakers, fuses, switches, cables, connectors, and PV module cells and junction boxes.*

## STEP 3 CODE & MFG. SPECS: CALCULATE POINTS

Does the issue involve **non-compliance with building code**?
- YES → 3 points
- NO → Does the issue involve **non-compliance with engineering drawings**, the equipment **warranty**, or instruction **manual**?
  - YES → 2 points
  - NO → Does the issue involve **non-compliance with industry best practices?**
    - YES → 1 point
    - NO → 0 points

Likelihood Assessment

## STEP 4 LIKELIHOOD OF CATASTROPHIC IMPACT: CALCULATE POINTS

Has a (thermal or mechanical*) **catastrophic failure occurred on-site**? This indicates a high likelihood of additional failures.
- YES → 5 points
- NO → Is there a **moderate likelihood*** of (thermal or mechanical) catastrophic failure?
  - YES → 4 points
  - NO → Is there a **remote likelihood*** of (thermal or mechanical) catastrophic failure?
    - YES → 2 points
    - NO → 1 point

**Signs of catastrophic thermal failure are deformed or charred components, sparks, and/or high energy discharge.*

*Signs of mechanical failure are loose, improperly attached, under/over torqued, improperly installed components and/or disengaged and malfunctioning equipment that interferes with site operations.*

**This issue previously caused a catastrophic failure in this portfolio, OR it is a known failure mode that occurs during the first ten years of operation.*

**This issue is known by industry professionals to cause failures at any point during the equipment's lifetime.*

## STEP 5 CALCULATE FREQUENCY POINTS

Is the issue **systemic** OR **present in >10%** of the system?
- YES → 2 points
- NO → Is the issue **present in 1-10%** of the system OR **endemic*** to a portion of the system?
  - YES → 1.5 points
  - NO → Is the issue **limited to 1 to 2 occurrences** OR **isolated to <1%** of the system?
    - YES → 1 point

**Endemic is defined as present in more than 10% of one portion or area of the system.*

## STEP 6 DETERMINE TOTAL SCORE TO ASSIGN RISK

**Add up points from Steps 1-4** → **Multiply sum by points found in Step 5** → **Use table below to assign severity level** → **Remediate immediately and/or report the issue for ongoing monitoring as appropriate.**

| SCORE | ASSESSMENT | ACTION |
|---|---|---|
| ≥23 | Critical: Extreme risk | Immediate self-isolation; remediate ASAP, ideally before leaving the site |
| 22 - 13 | Major: High risk | Remediate ASAP in operating assets or prior to handoff in new construction |
| 12 - 7 | Minor: Medium risk | Monitor; remediate during next scheduled site visit |
| <7 | Negligible: Low risk | Monitor; okay to skip remediation |

# SAME ISSUES, DIFFERENT RISKS

The table below illustrates how the same basic issue can appear at each level of severity.

## UNDER/OVERTORQUED CONNECTORS

### CRITICAL

An undertorqued back nut on a field-made homerun connector that was catastrophically damaged due to overheating was found. Undertorqued back nuts were systemic and there were multiple instances of overheating connectors.

### MAJOR

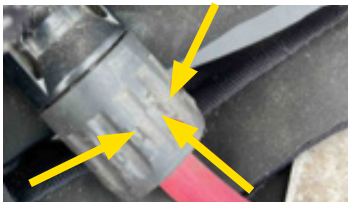
An undertorqued back nut on field made home run connector was found. Additionally, the connector pair is cross-mated, which is a systemic issue at the site.

### MINOR

Two isolated instances of undertorqued back nuts on field-made homerun connectors were found. No other workmanship or thermal issues were observed.

### NEGLIGIBLE

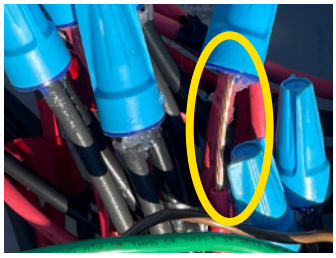
An isolated instance of an over torqued connector with signs of improper tooling was found. Excessive marks on the back nut indicate pliers were most likely used to tighten the back nut.



## WIRE TERMINATIONS

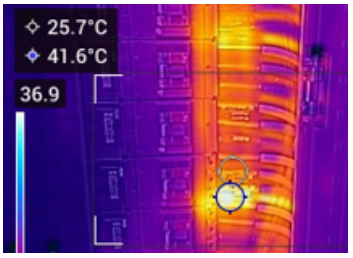
### CRITICAL

DC homerun conductors were spliced with wire nuts in a pull box. One of the conductors had an exposed section of bare copper. Additionally, the installation was non-compliant with the engineering drawings, which prohibited splicing DC conductors. This is a shock and fire hazard.



### MAJOR

A hotspot on an AC distribution breaker measured approximately 15°C warmer than adjacent terminations. This issue is typical of under torqued terminations. Due to regular thermal cycling, these hot spots can quickly escalate to high impedance faults and cause component failure.




### MINOR

Light conductor scoring was found on the copper DC homerun terminations. This issue results from improper tooling or procedures to strip conductors. The scoring reduces the cross-sectional area of the conductor and compromises the integrity of the termination over time.

### NEGLIGIBLE

Over-stripped conductors were found at negative terminals on a string inverter. Over-stripping insulation can expose live conductors to unintended current paths.

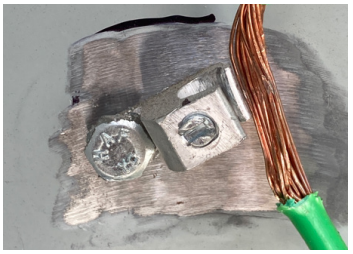

## IMPROPER GROUNDING

### CRITICAL

Improper grounding resulted in unintended current paths and component thermal failures on site. Thermal failures began to occur as soon as the project began operating.

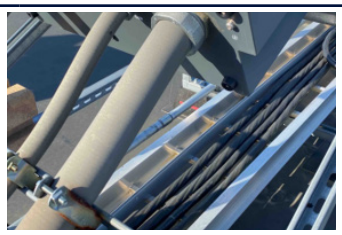
### MAJOR

The equipment ground conductor was not terminated on the racking in the PV array. The sub array is not properly grounded per the National Electrical Code and the manufacturer's specifications. This issue presents a safety hazard for personnel if there is a fault in the specific sub array.



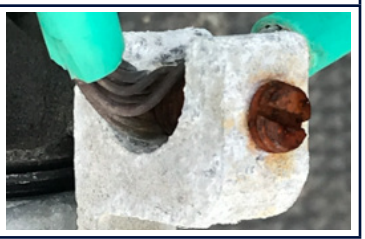
### MINOR

The equipment rack is missing bonding to the inverter and is electrically isolated. This issue may be hazardous for personnel if there is a fault at the inverter.



### NEGLIGIBLE

The ground lug on the conduit bushing is experiencing corrosion and may compromise the integrity of the grounding circuit over time.



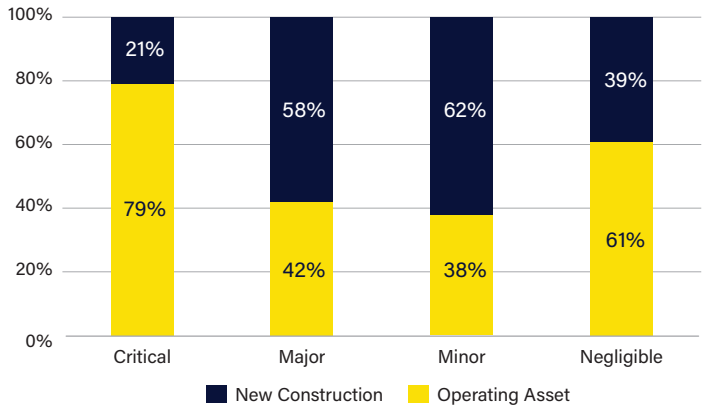
# ISSUES BY PROJECT STAGE

Nearly 80% of all critical issues were in operating assets: as components degrade in the field, the risk of catastrophic failure increases.

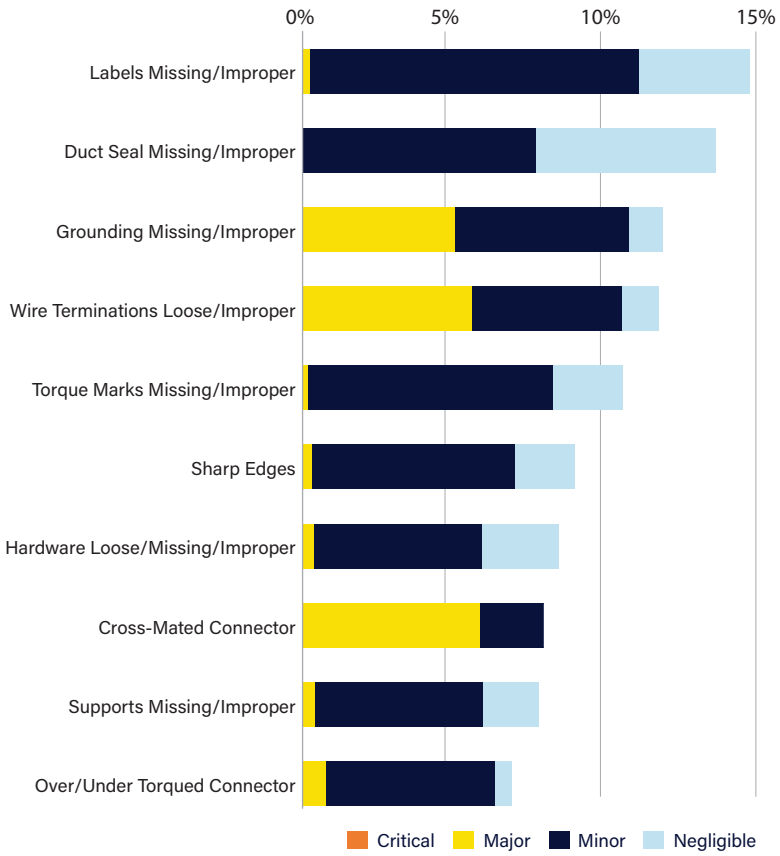
While there is significant overlap in the top ten most common issues in new construction and operating assets, three unique issues appear on each stage's list:

- New construction: Missing/improper duct seals, missing/improper grounding and supports.
- Operating assets: Exposure to sunlight/water, hotspots, and wires resting on roofs.

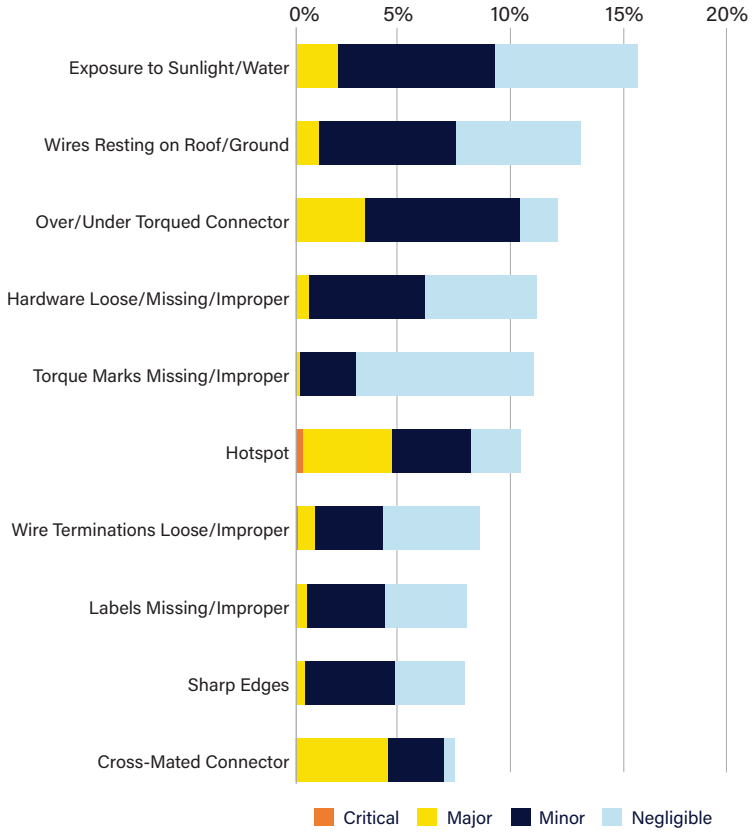
**Issue Severity by Project Stage**




**Top 10 Most Common Issues in New Construction**




**Top 10 Most Common Issues in Operating Assets**




## WHAT YOU SHOULD KNOW

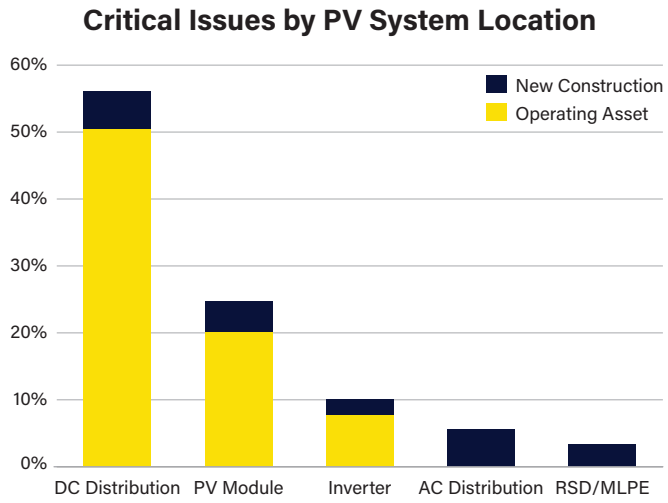
Critical issues that take time to develop, such as thermal anomalies, are more common in operating assets. Periodic thermal inspections help stakeholders decide when to prioritize remediation to avoid unacceptable levels of risk. When workmanship issues appear in operating assets, it suggests that construction QA/QC was limited or absent, that remediation was not required prior to project hand-off, or that the issues were simply not tracked or forgotten over time.

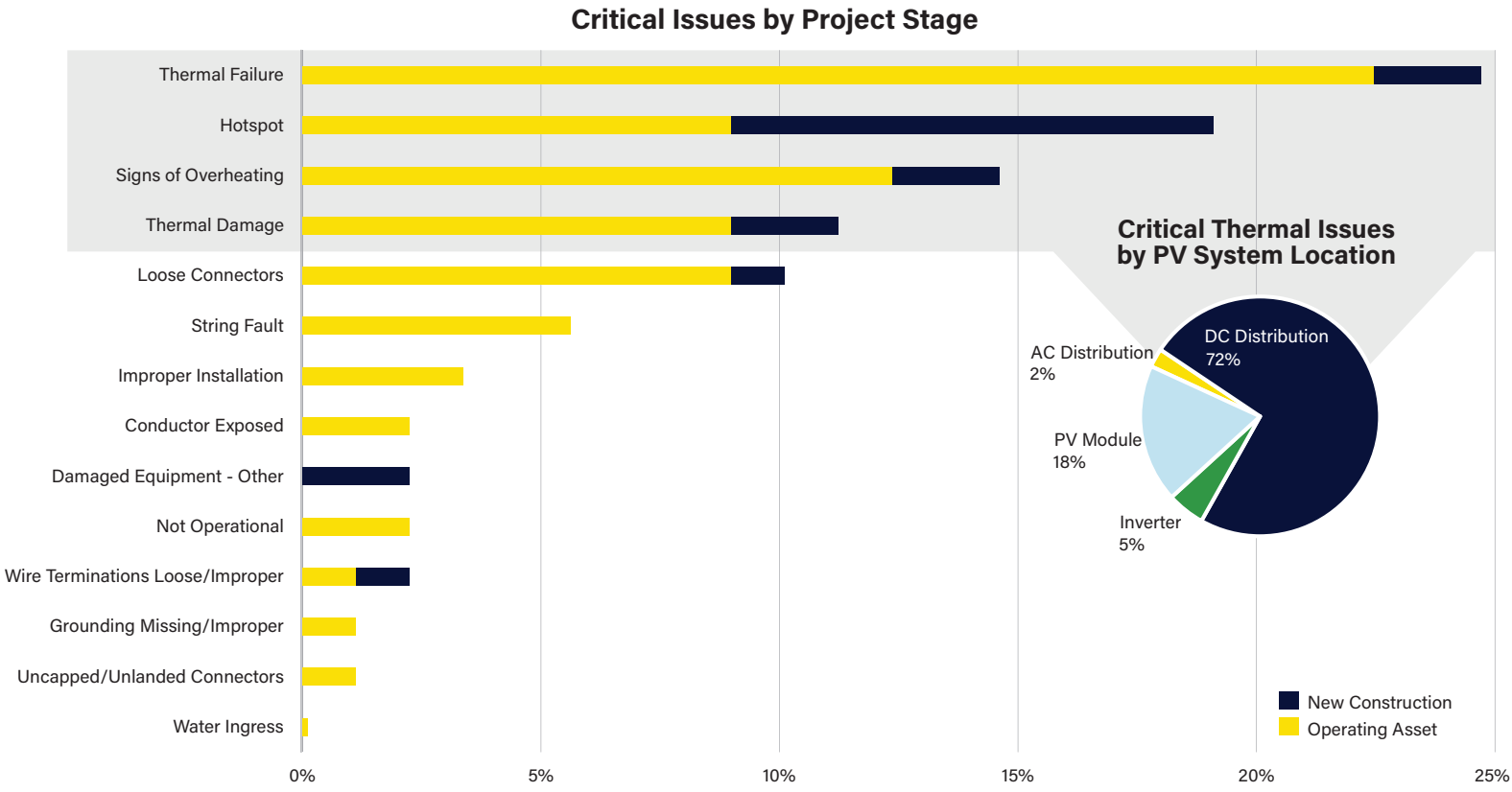
# CRITICAL ISSUES

70% of all critical issues are directly related to thermal failures and high temperature operation: these types of issues present the greatest safety risks in a PV assets.

56% of critical risks were located in DC distribution*, followed by PV modules at 25%, and inverters at 10%.

*Previous SolarGrade publications classified issues with factory-made PV module connectors as located in the DC distribution section of the system. Based on client feedback, we now assign these issues to the PV module section of the system. Field-made homerun connectors remain associated with DC distribution. Similarly, RSD/MLPE issues were associated with PV modules in past reports but are now analyzed separately.




## WHAT YOU SHOULD KNOW

Hotspots, or high-temperature system components, can occur on any electrical component. While aerial flyovers are a rapid and cost-effective thermal scanning option, on-the-roof inspections that cover connectors, combiner boxes, electrical panels, and wire terminations are periodically necessary, especially on commercial rooftops where the consequences of safety events may be severe. Thermal imaging should be conducted on PV systems on a periodic basis.

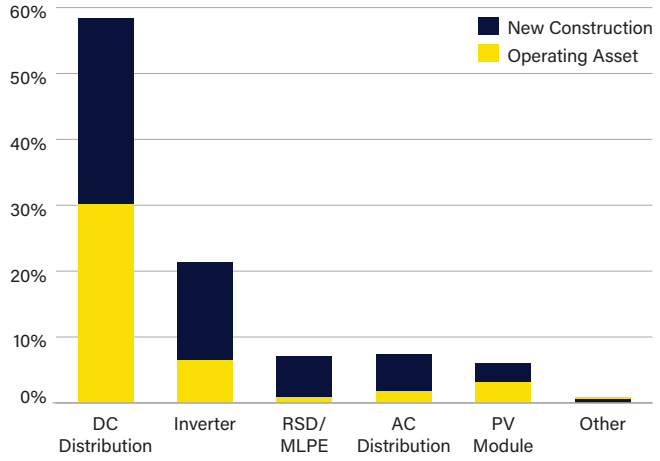
# MAJOR ISSUES

56% of major issues were found in DC distribution: as with critical issues, they are by far the largest driver of issues at this severity level.

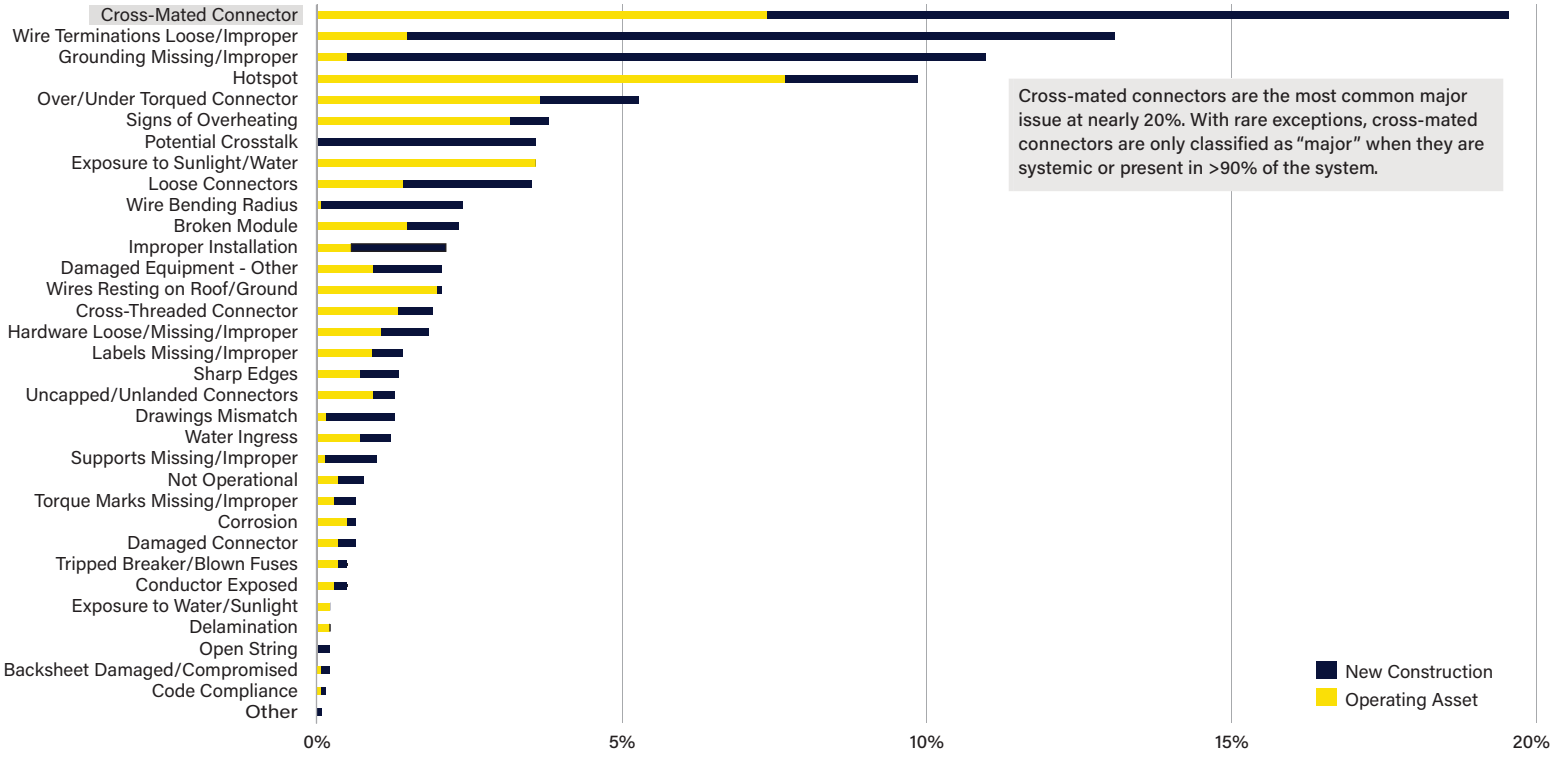
Inverters were the second most common source of major issues at 21%, with the bulk of major inverter issues (15%) found in new construction.

Major issues are found somewhat more frequently in new construction than operating assets. These issues, especially loose and improper wire terminations and thermal issues like hotspots and signs of overheating, have a relatively high likelihood of progressing to critical severity levels if they are not addressed prior to handoff.

**Major Issues by PV System Location**




**Major Issues by Project Stage**




## WHAT YOU SHOULD KNOW

The top three most common major issues are loose/improper wire terminations, missing/improper grounding, and cross-mated connectors, and they account for 40% of the total share of major issues. They are also far more prevalent in new construction than operating assets.

Focusing on grounding requirements, wire terminations, and connector compatibility might help EPCs reduce rework substantially during installation and construction QA/QC.

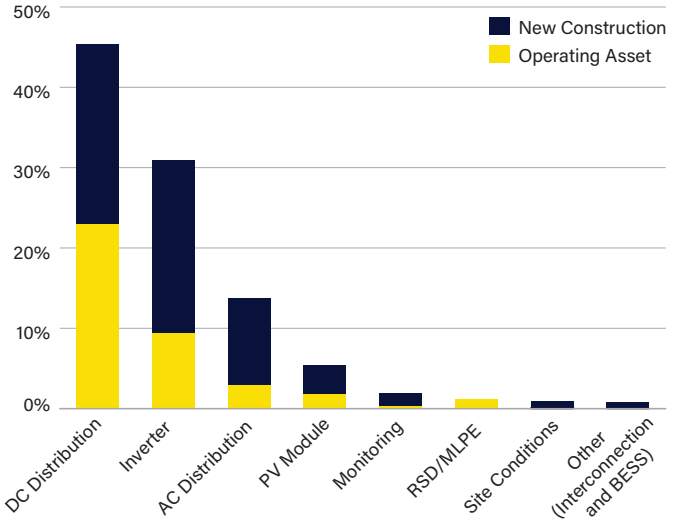
# MINOR ISSUES

In the minor category, DC distribution and inverters again emerge as the most common issue sources.

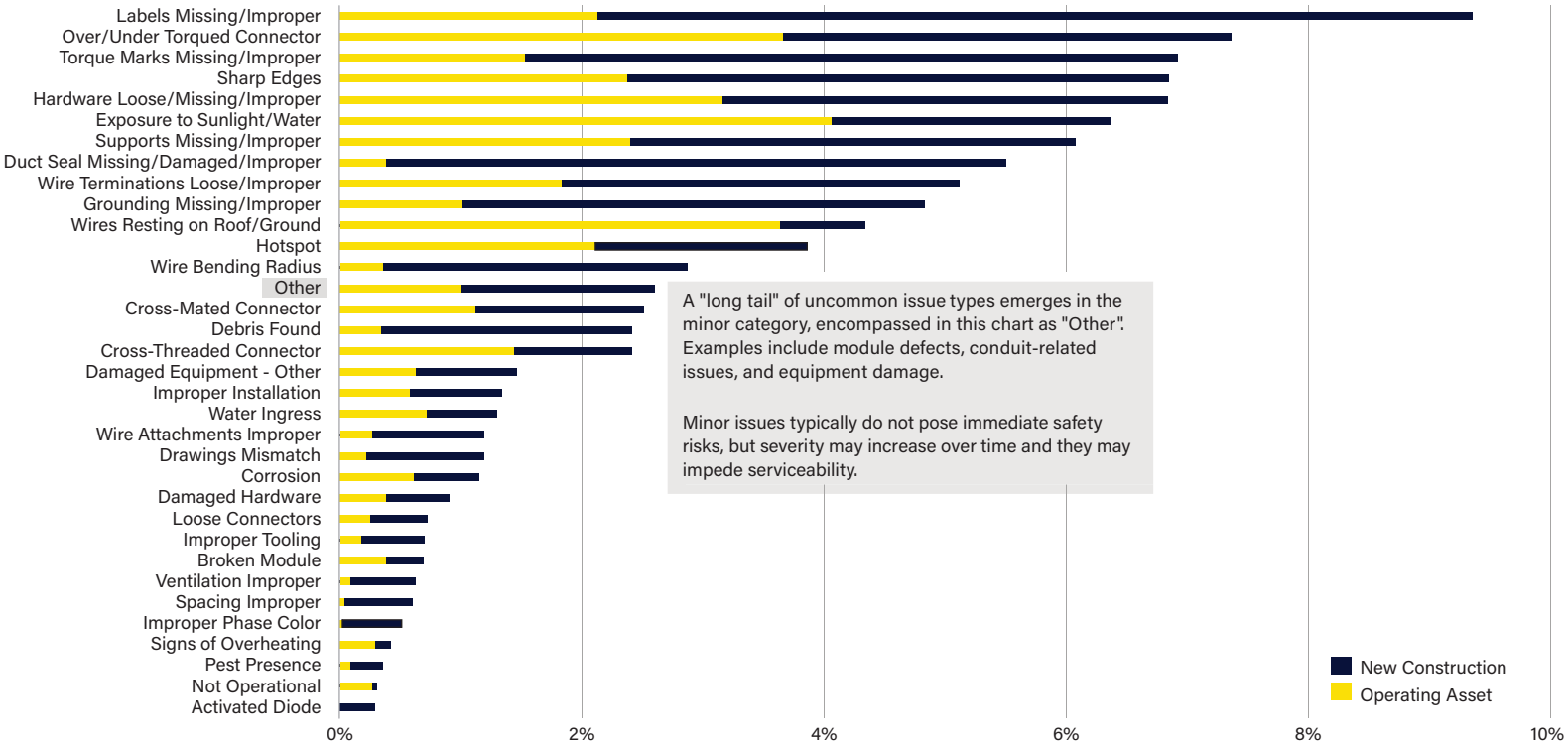
As with the major category, most minor issues were found in inspections conducted before EPC handoff. Labeling, the most frequently observed minor issue, is usually - but not always - addressed prior to handoff.

While labels are often an afterthought, proper documentation for all breakers, AC/DC switches, panels, and combiner boxes are vital to technician safety in the field and facilitates O&M.

**Minor Issues by PV System Location**




**Minor Issues by Project Stage**




A "long tail" of uncommon issue types emerges in the minor category, encompassed in this chart as "Other". Examples include module defects, conduit-related issues, and equipment damage.

Minor issues typically do not pose immediate safety risks, but severity may increase over time and they may impede serviceability.

## WHAT YOU SHOULD KNOW

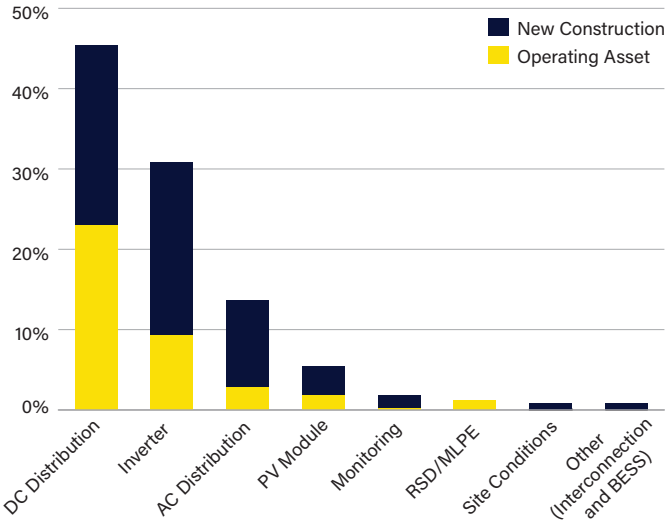
Minor issues are often overlooked by EPCs before handoff and can easily be forgotten. When minor issues are left unresolved, they tend to escalate over the project's lifetime, evolving into major concerns. For example, if sharp edges are not addressed, wires in contact with abrasive surfaces may suffer insulation damage due to thermal expansion and contraction over time. This can lead to compromised conductors and increased risk of system failure or safety hazards.

# NEGLIGIBLE ISSUES

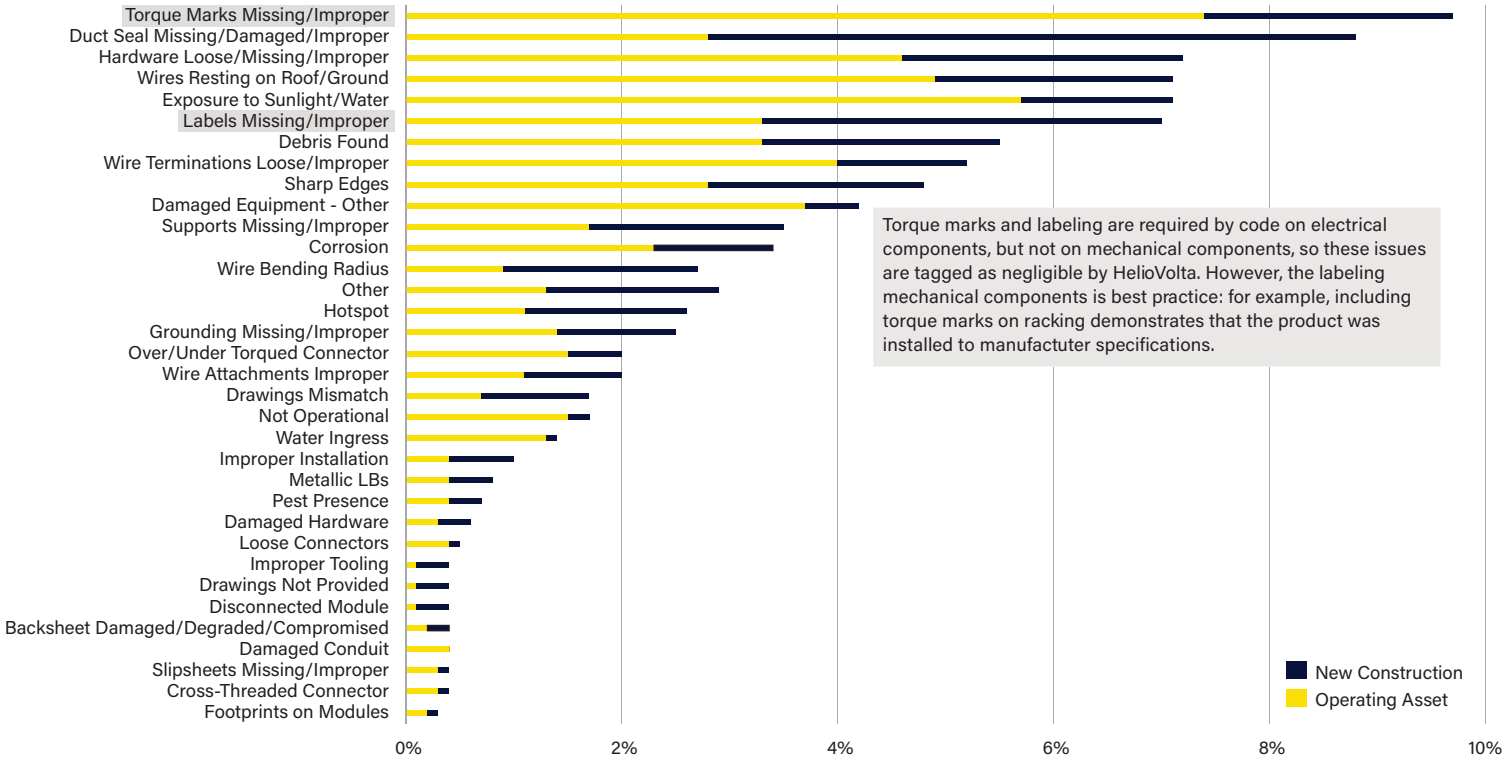
Negligible issues are not urgent concerns, but they should be tracked because they can progress into more serious problems. This category of issues is more common in operating assets than new construction. They are often the result of wear and tear on system components over time but exceptions exist.

For example, footprints on PV modules - an uncommon negligible issue (just 0.03% of all negligible issues found) - are usually the result of insufficient workforce training. While the negligible footprints observed by HelioVolta did not present a significant risk at the time of inspection, they can damage PV cells and create hotspots over time.

**Negligible Issues by PV System Location**




**Negligible Issues by Project Stage**




## WHAT YOU SHOULD KNOW

Negligible is the lowest risk severity HelioVolta assigns to issues, but these issues are still important to track. While the cost of remediating every small problem may not be justified, seemingly insignificant problems can affect serviceability or lead to failures over time, especially in harsh environments. Documenting each negligible issue in a structured, geo-referenced database ensures asset managers and O&M providers know which areas of a system to monitor. As time passes, these monitoring efforts can identify issues when remediation is appropriate, but before costly failures occur.

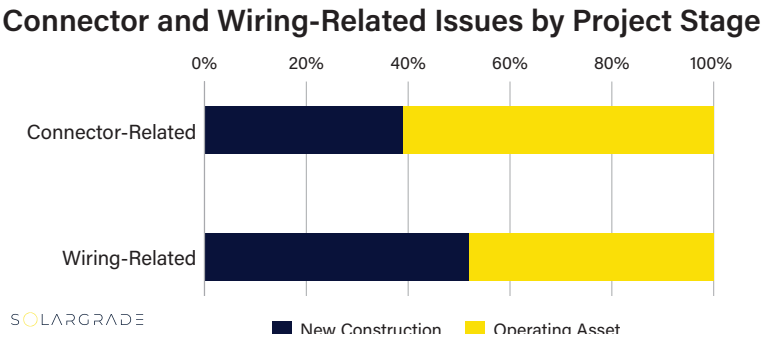
# CONNECTORS AND WIRING

Issues related to connectors and wiring are among the most common in our dataset:

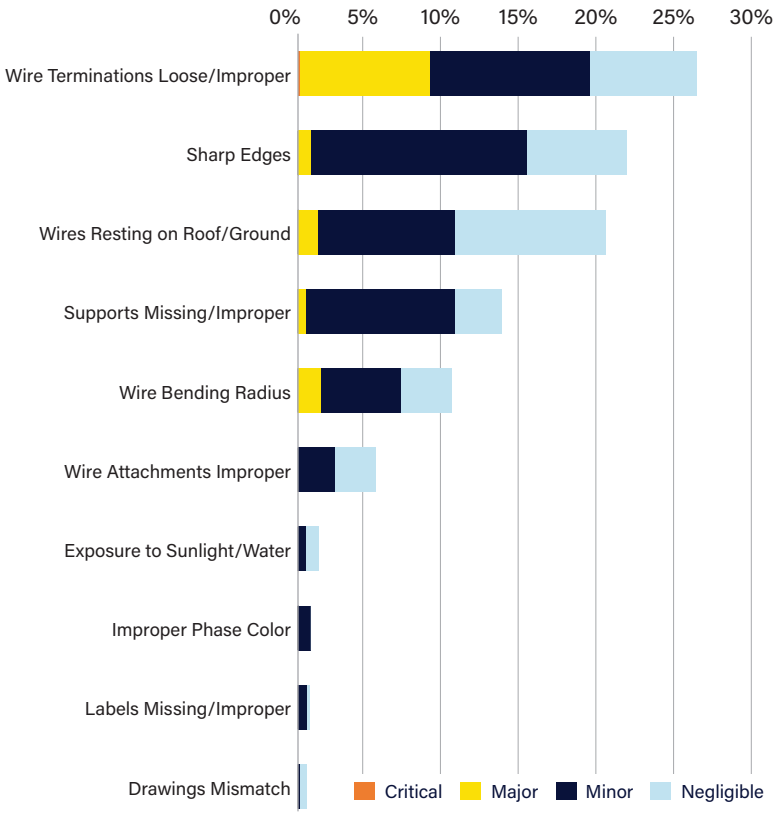
- 80% of projects had issues related to wiring.
- 83% of projects had issues related to connectors.

These ubiquitous components are often hidden from view and easy to overlook: inspecting them often involves physically crouching or even lying down, mirror in hand.

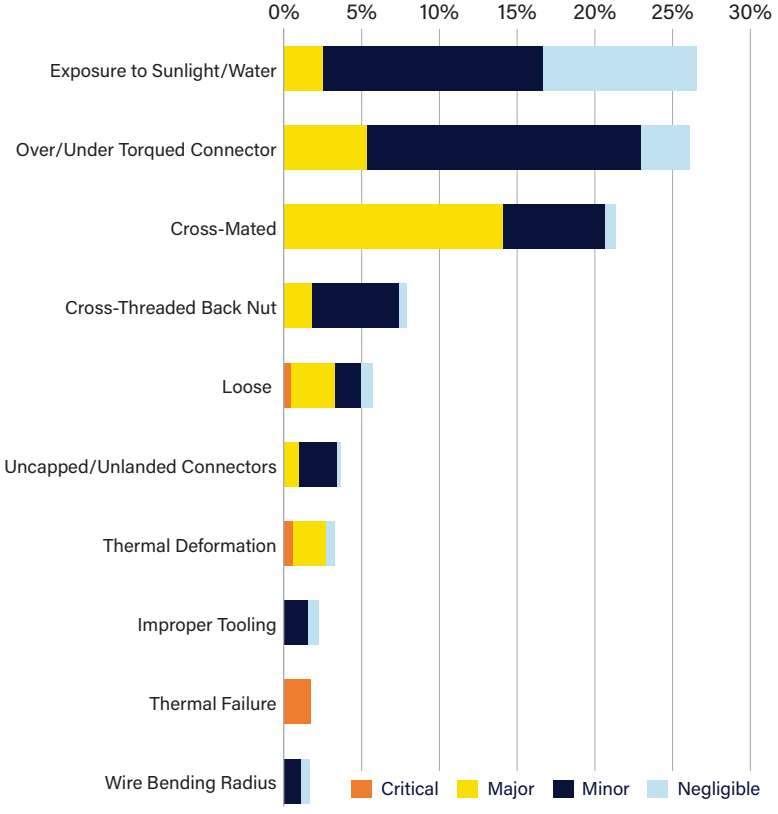
### Issues by Project Stage




### Top 10 Wiring-Related Issues




### Top 10 Connector-Related Issues




## WHAT YOU SHOULD KNOW

Overlooking connectors and wiring is a mistake. They are as important to project health and reliability as big-ticket components like inverters and PV modules. Potential safety and reliability risks are not the only reason these components merit close attention. Issues in connectors and wiring also directly impact system performance: when they malfunction, resistive losses increase.

**Download our white papers on connectors and wire management to learn more >>**

# CONCLUSION

The solar industry's collective work in the field is the foundation of PV system safety and reliability. No single organization can create the clean energy future that the next generation deserves.

We hope the second edition of the SolarGrade PV Health Report empowers project stakeholders to elevate asset care.

Solar power is fundamentally safe and reliable when systems are installed correctly — and they are not maintenance-free.

Taking action to identify and correct issues in the field is vital, especially as installed solar capacity expands.

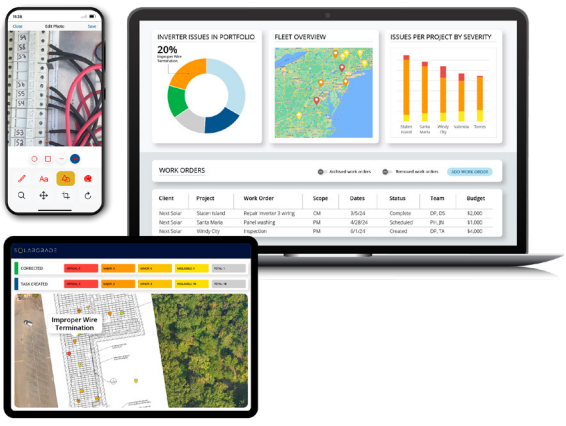
Based on the data in this report and our personal experiences in the field, the HelioVolta team recommends the following best practices for solar project stakeholders:


1. **Require Robust Installer Training**
2. **Conduct Construction QA/QC Inspections at Key Milestones**
3. **Require Inspections During O&M Visits 2x/Year**
4. **Standardize and Consistently Document Site Visits**
5. **Monitor Issues and Remediate When Necessary**

## TAKE THE NEXT STEP >>

Learn how SolarGrade helps teams in the field and beyond.

**Get in touch online or at solargrade@heliovolta.com**



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