CEA
Clean Energy Associates
INSIGHTS

BESS Quality Risks

A summary of the most common Battery Energy Storage System manufacturing defects

February 2024

The Past Several Years Have Shown That Thermal Runaway Poses a Significant Risk to the Energy Storage Industry

Data collected from CEA's factory quality inspections of BESS systems has found that these risks still exist:

26% **of inspected energy storage systems had quality issues related to the fire detection and suppression system.**

18% **of inspected systems had quality issues related to the thermal management system.**

The following report highlights the safety issues above as well as a host of other quality concerns.

CEA Has Conducted Factory Quality Audits On Over 30 GWh of Lithium-Ion Energy Storage Projects

- **320+ inspections in 52+ Battery Energy Storage System (BESS) factories**
- **64% of tier 1[*] BESS cell manufacturers audited worldwide**
- **1300+ total manufacturing issues identified**

Locations of CEA factory audits

Here are our key findings...

[*]*Tier 1: definition is based on BMI (Benchmark Mineral Intelligence)*

Our Audit Process: CEA Assigns a Severity to Each Finding Depending On the Risk Level of the Issue

A **finding** is an issue identified during inspection that indicates deviation from standard best practices, processes or product specifications.

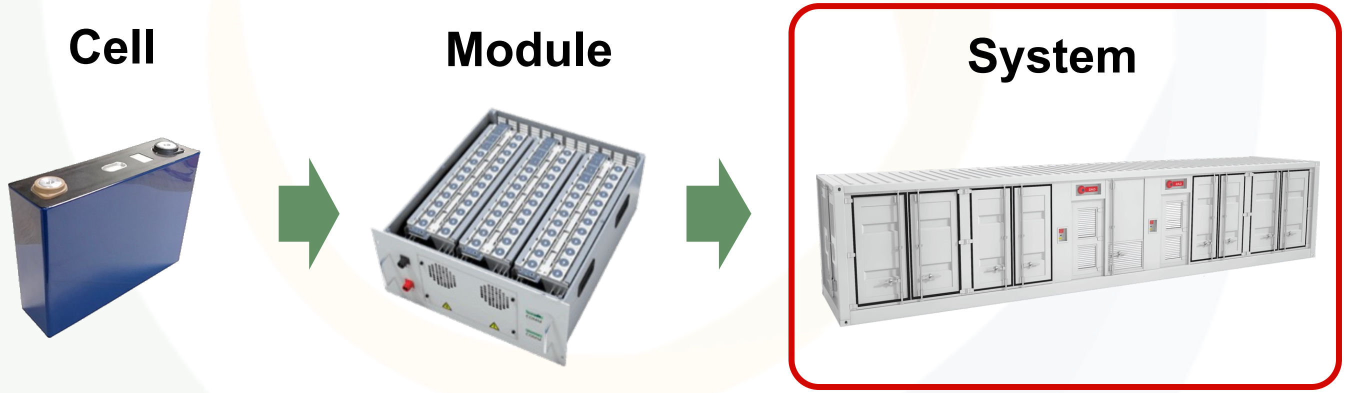
Finding Severity	Definition
Critical	Findings that may result in severe safety risks and hazardous conditions. Critical findings are likely to cause damage to other products or property, trigger non-compliance regulatory issues, and generally constitute a breach of mandatory regulations.
Major	Findings that may reduce the battery's functionality or impact safety in either short or long term.
Minor	Findings which do not pose a clear risk of production failure, but rather fall outside the quality requirements.

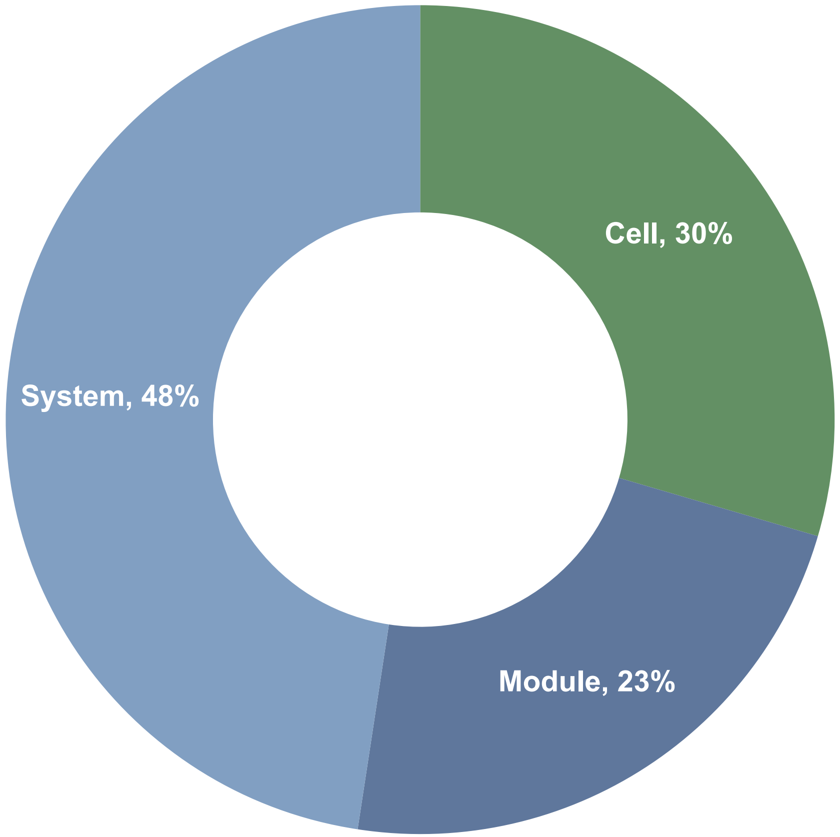
Distribution of Total Findings

With so much industry attention focused on cell selection, system integration should not be overlooked as a potential source of problems. **System-level defects accounted for nearly 50% of our QA findings.**

The large number of system-level issues is mainly caused by the following two contributors:

- The BESS integration process is highly manual and labor-intensive, with less stringent quality control procedures.
- Systems are very complex and are vulnerable to underlying problems originating from defects in upstream components that were not caught during earlier quality checks.





Distribution of all BESS Findings

Breakdown of System-level Findings

The majority of system-level findings occurred in the **Balance of System** and **enclosure**. **Performance test** findings usually indicate larger or more complex problems.

58% of system-level findings are Balance of System related

Why/How Does It Happen
Component defects and improper system integration procedures.

Example

- Liquid coolant leakage due to deformed flange plates, defective valves, loose pipe connections within the coolant circulation system
- Malfunctioning temperature, smoke, gas sensors, audible and visual alarms due to internal mis-wiring
- Live conductor exposed within the AC/DC distribution

34% of system-level findings are enclosure related

Why/How Does It Happen
Defects from enclosure manufacturing process and mishandling during transportation.

Example

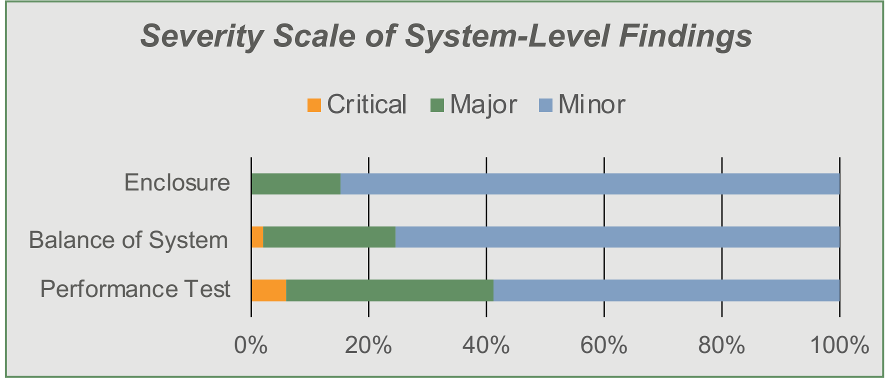
- Poor strength and rigidity: lifting provision test, structural deformation, etc.
- Poor wiring and cabling arrangement
- Grounding mechanism defects
- Water ingress issue
- Appearance defects: painting specifications, markings, nameplate, openings, etc.

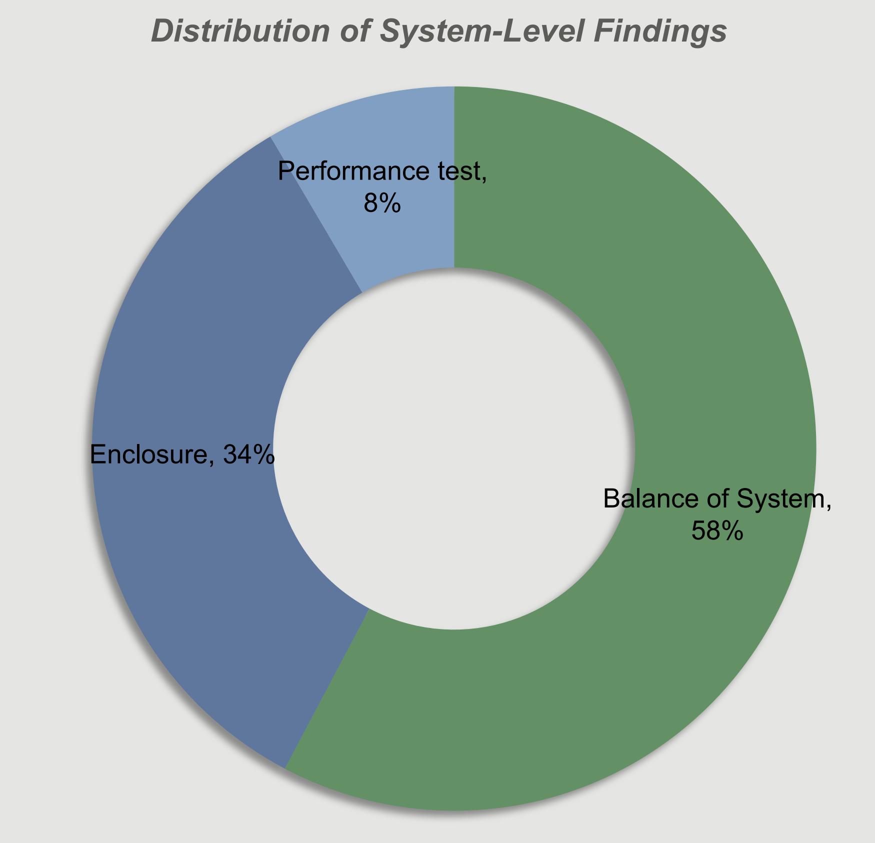
8% of system-level findings are performance test related

Why/How Does It Happen
A wide variety of manufacturing defects and/or improper system integration.

Example

- Underachieving capacity and Round Trip Efficiency results from abnormally large temperature and voltage variations among battery cells within a module, due to high impedance from poorly welded wiring connections
- Charging/discharging failure due to wiring issues in battery rack's high voltage boxes

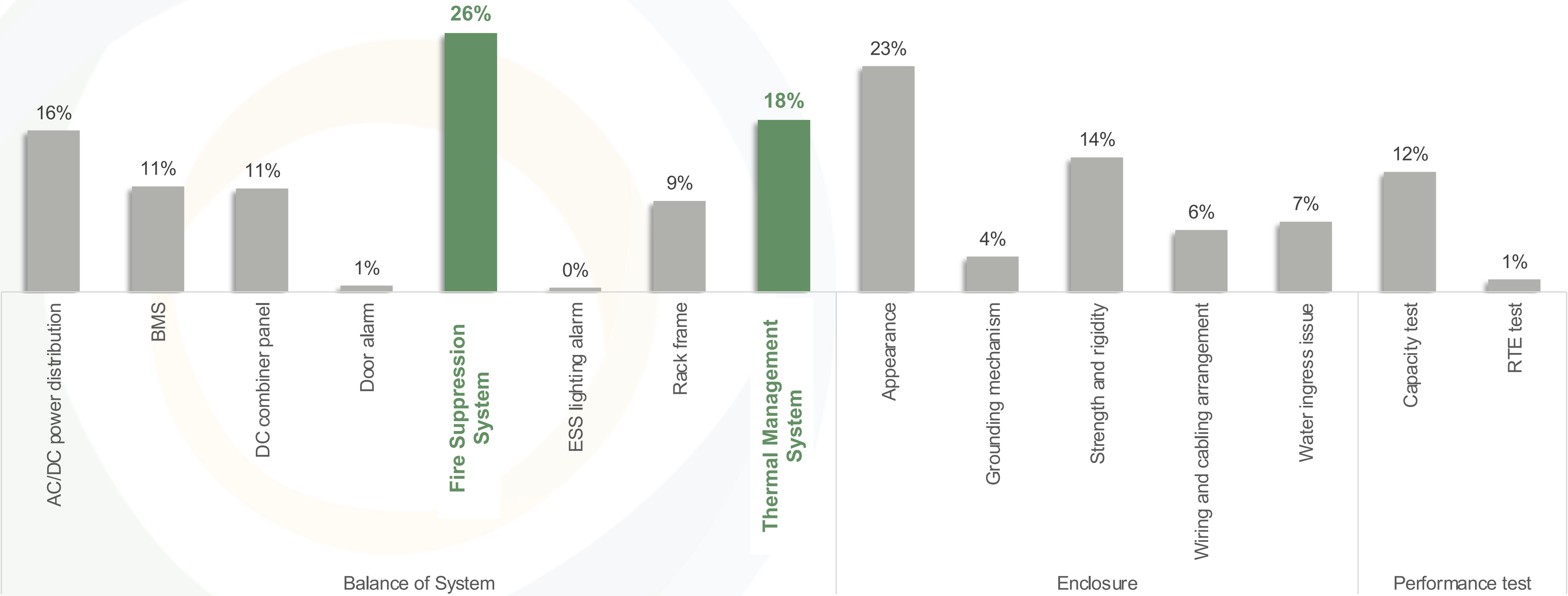




26% of BESS units that CEA inspected had defects in the **Fire Suppression System**, while **18% of units** had **Thermal Management System** defects.

*Fire suppression and thermal management systems are critical for functional safety, and defects in these systems can lead to **increased risk of fire**.*

Frequency of system-level BESS defects over total inspected units



Case Study – Common Fire Suppression System Findings

26% of inspected BESS units had <u>fire suppression system</u> defects

Non-responding release actuator for the fire extinguishing agent

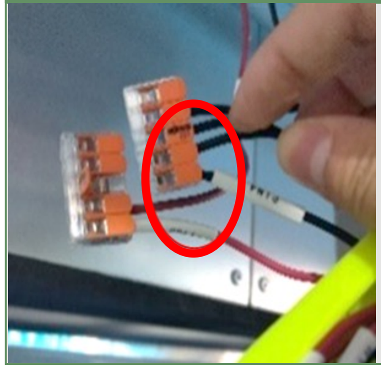
Why/How Does It Happen
A diode within the actuator was faulty.
Risk
A malfunctioning actuator will not respond to the command of releasing a fire extinguishing agent, potentially allowing the fire to further propagate.
Example

Fire alarm abort button was not functional

Why/How Does It Happen
The fire alarm abort button was not responding to the user commands due to incorrect wiring.
Risk
The abort button allows user to deactivate an improperly triggered fire alarm; failure to deactivate can lead to unwanted fire extinguishing agent or sprinkler system activation which can cause serious damage to equipment.
Example

Non-responding smoke & temperature sensors

Why/How Does It Happen
The smoke sensor was incorrectly wired, and a temperature sensor was reversely connected to power source.
Risk
An incorrectly wired smoke sensor cannot detect the presence of smoke within the system. A reversely connected temperature sensor can have a false reading. Malfunctioning of these sensors can pose a high fire and explosion risk.
Example

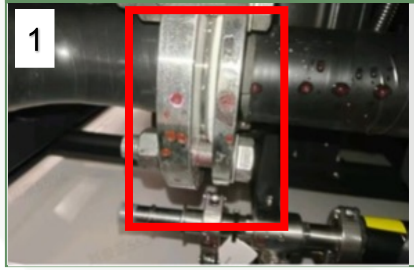


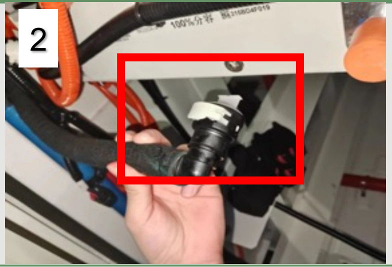
Case Study – Common Thermal Management System Findings

18% of inspected BESS units had thermal management system defects

Circulation System Components Failure

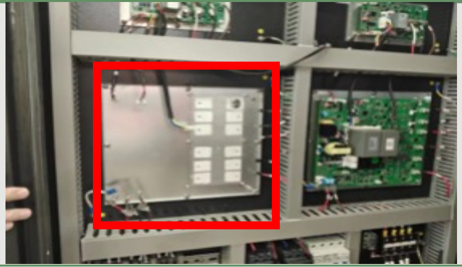
Why/How Does It Happen		
1. Flange plates are deformed from overtightening due to a loosely defined screw mounting Standard Operating Procedure (SOP).	2. Loose pipe connection: the fastener was not fastened from operator's mis-installation and not following SOP.	3. Defective incoming material: the valve comes with a loose stem.
Risk		
1. Internal short circuiting and thermal runaway initiation from continuous coolant leakage.	2. Severe short-circuiting events and thermal runaway initiation from potential massive coolant leakage.	3. Faster battery degradation from insufficient coolant flow control and internal short circuiting and thermal runaway initiation from continuous coolant leakage.
Example		

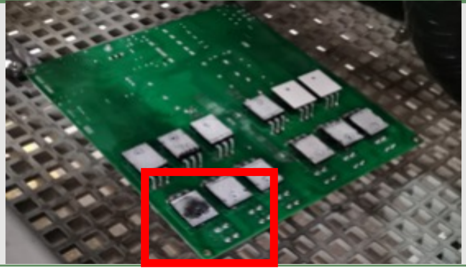




Compressor mainboard short circuiting

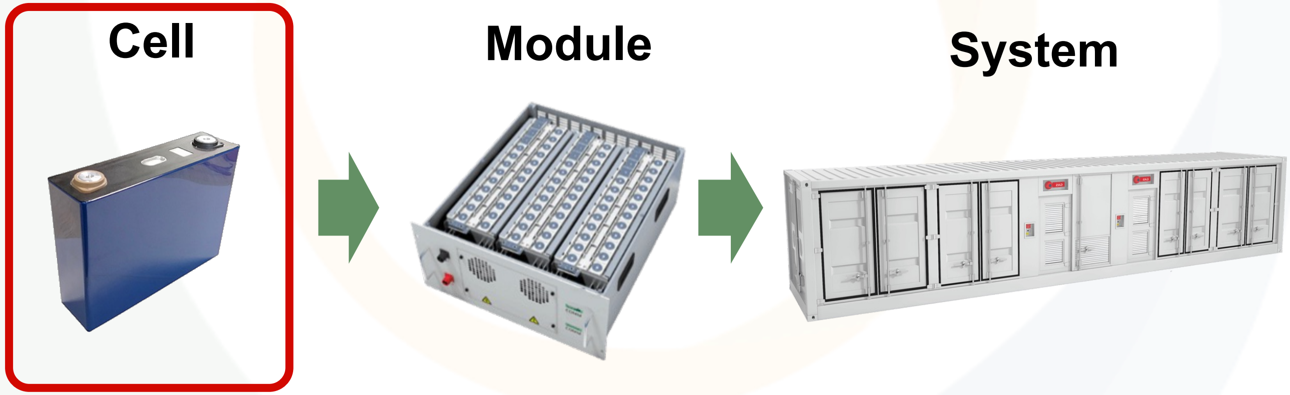
Why/How Does It Happen
Defective mainboard with a burned MOS (Metal Oxide Semiconductor) tube for compressor control.
Risk
1. Faster battery degradation from dysfunctional liquid cooling system. 2. Initiating thermal runaway or explosion with sparking from burned components.
Example

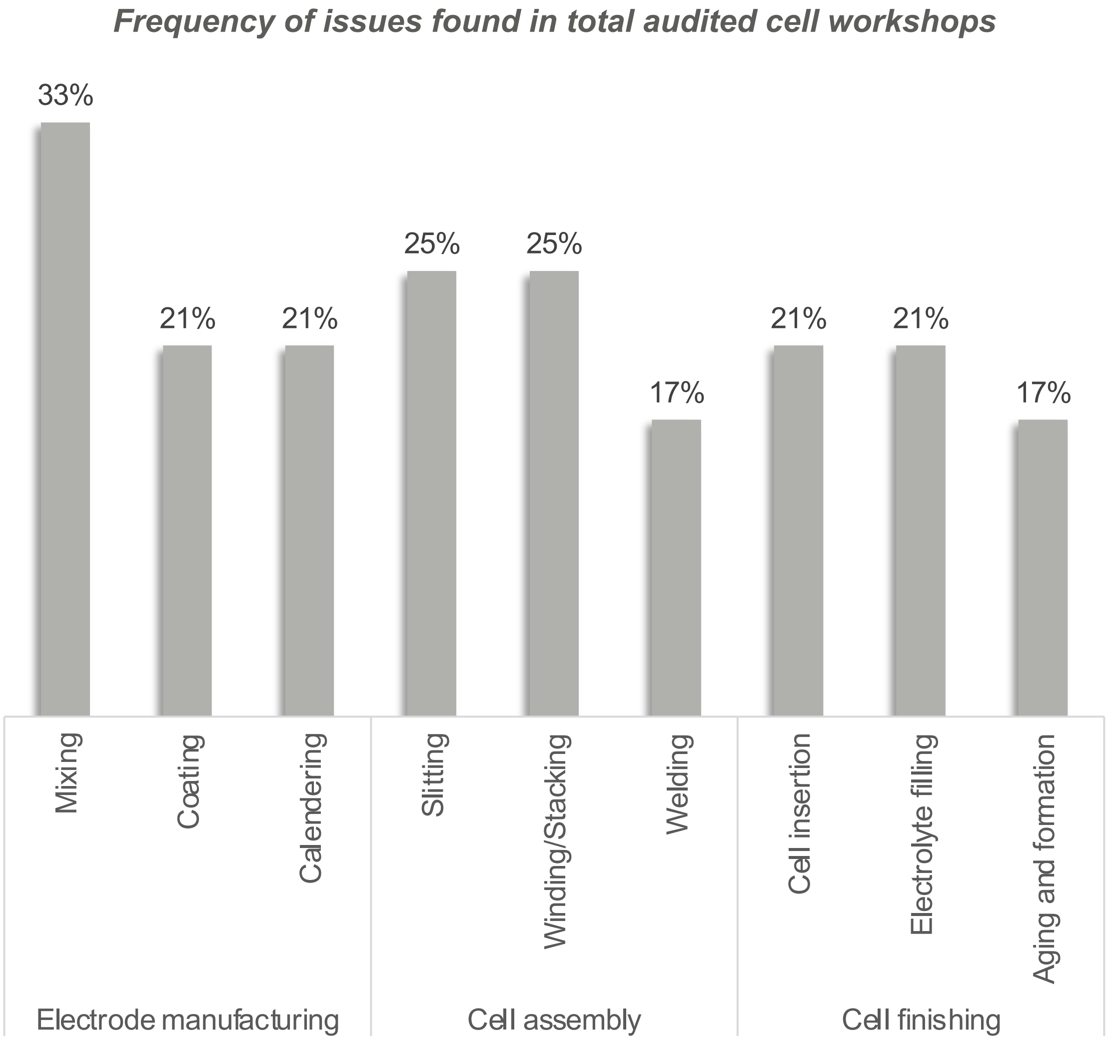




30% of the Total Findings Occurred During Battery Cell Manufacturing

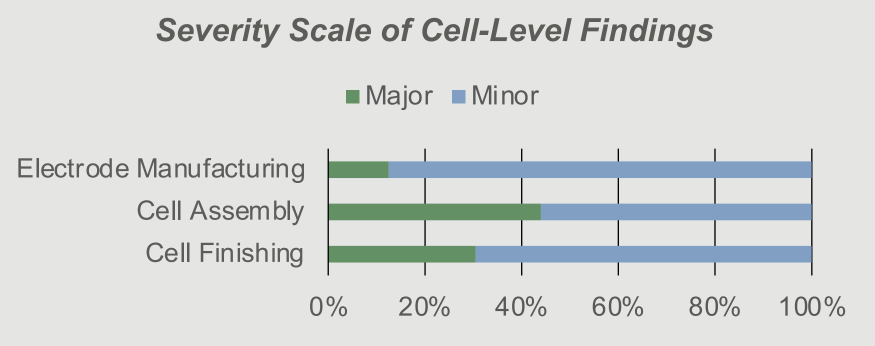
- Although battery cell factories have the highest level of automation, they make up a larger number of findings (compared to battery modules) due to their lengthy production processes and higher precision requirements, leading to more room for error.
- Audit findings on cells typically have a higher severity rating as cells are the building blocks of the energy storage system, and defects can be detrimental to system performance and safety.





Breakdown of Battery Cell Findings

Findings are evenly distributed due to strict precision and safety requirements throughout the entire cell manufacturing process.



32% of cell findings occur during **electrode manufacturing**

Why/How Does It Happen

Improper measurement system analysis and process control

Example

- Mixing: out-of-calibration viscosity meter, lack of expiration control record over the mixed active material
- Coating: missing key coating quality measurements such as surface density, coating thickness, and moisture content.
- Calendaring: deformed electrode sheets due to roller misalignment

38% of cell findings occur during **cell assembly**

Why/How Does It Happen

Improper process and quality control execution

Example

- Slitting: lack of burr size control, lack of monitoring on the cutter status and remaining life
- Stacking/winding: lack of inline electrode alignment inspection
- Welding: uncalibrated welding strength test that are conducted manually without well-defined pass/fail criteria

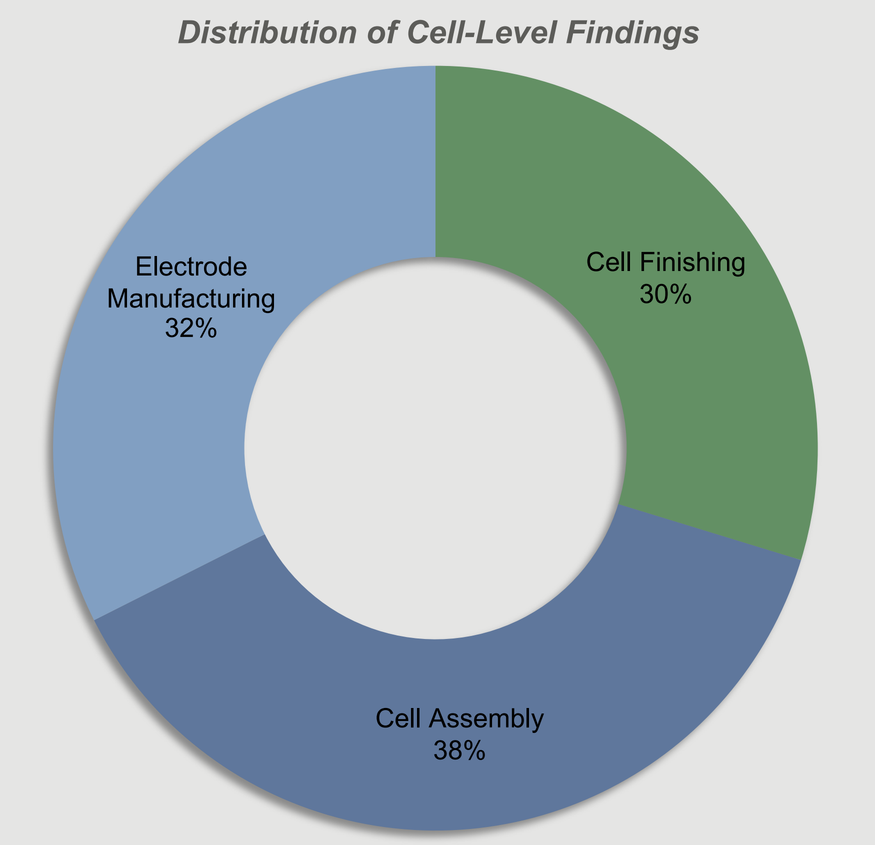
30% of cell findings occur during **cell finishing**

Why/How Does It Happen

Improper process and quality control execution

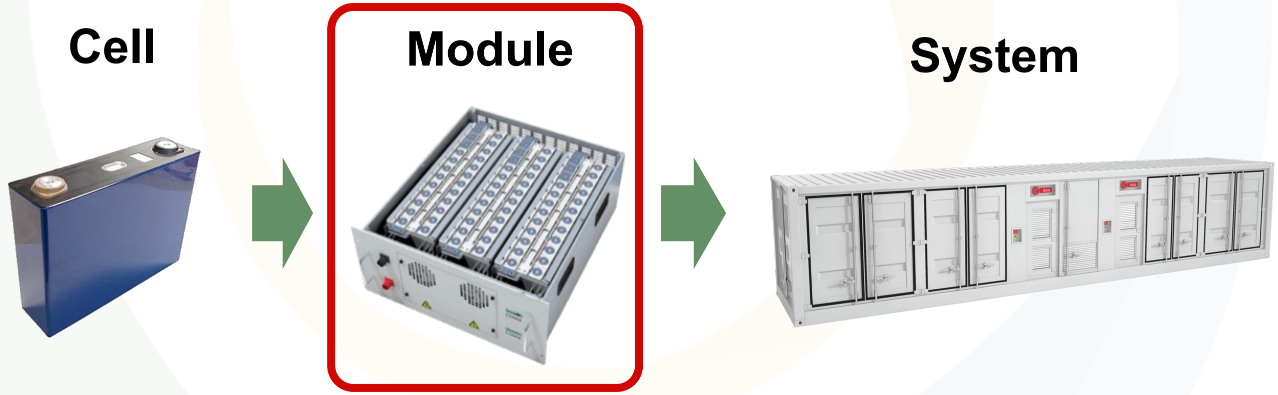
Example

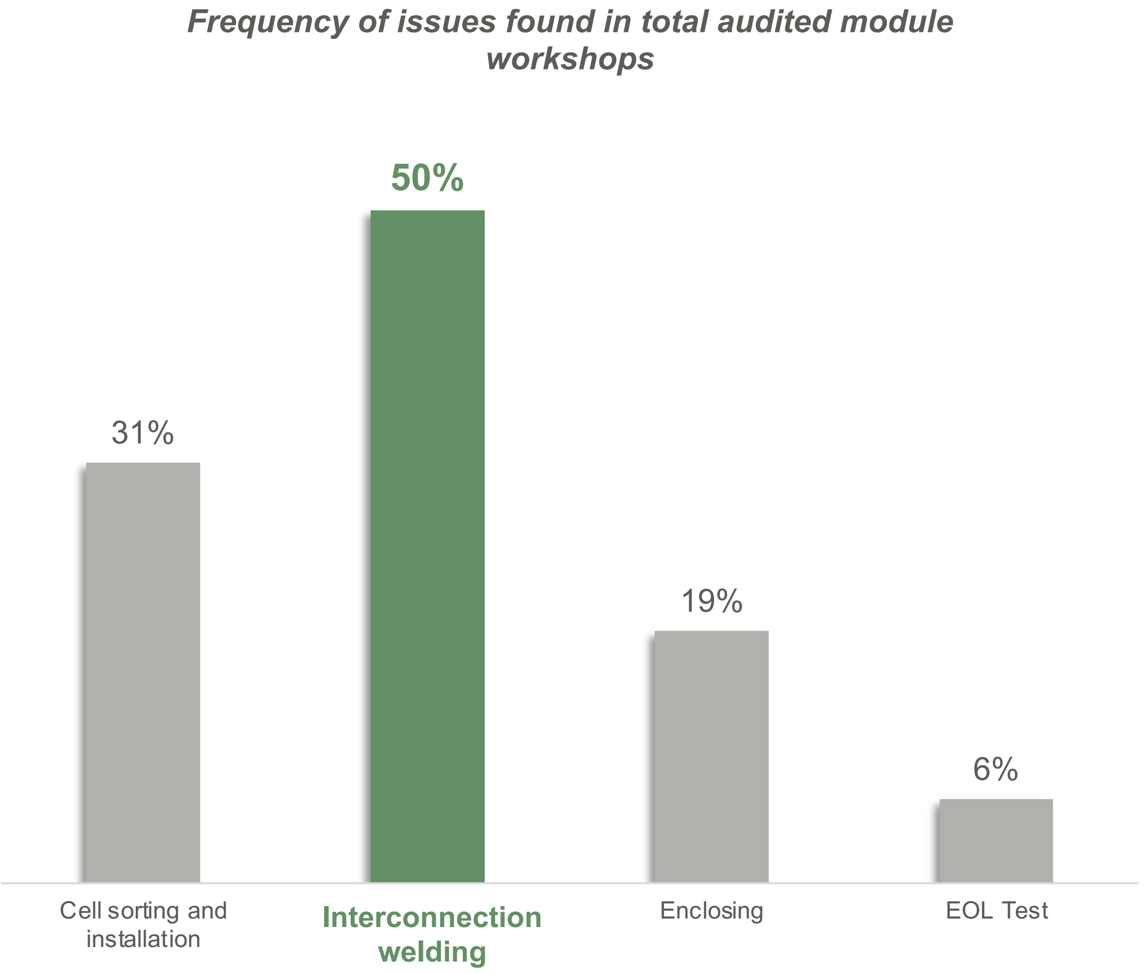
- Cell (jelly-roll/stack) insertion: lack of laser welding parameter verification, lack of inline alignment and clearance inspection after the aluminum cap is welded on
- Electrolyte filling: Loose control of environmental conditions (temperature and humidity), lack of sealing quality inspection which can lead to electrolyte leakage



23% of the Findings Occurred During Module Manufacturing, Largely Due to More Manual Production Lines

Module manufacturing issues often occur because lines are less automated, which creates room for imprecision in material handling and inferior welding quality.

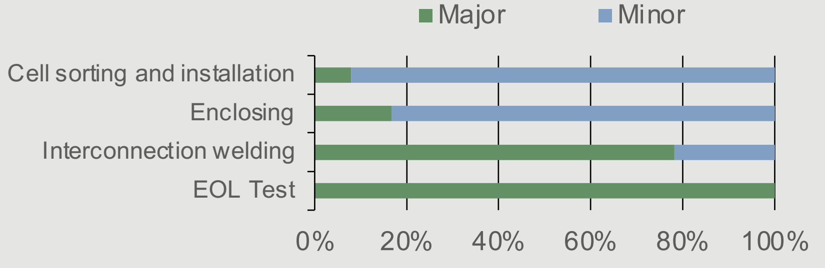




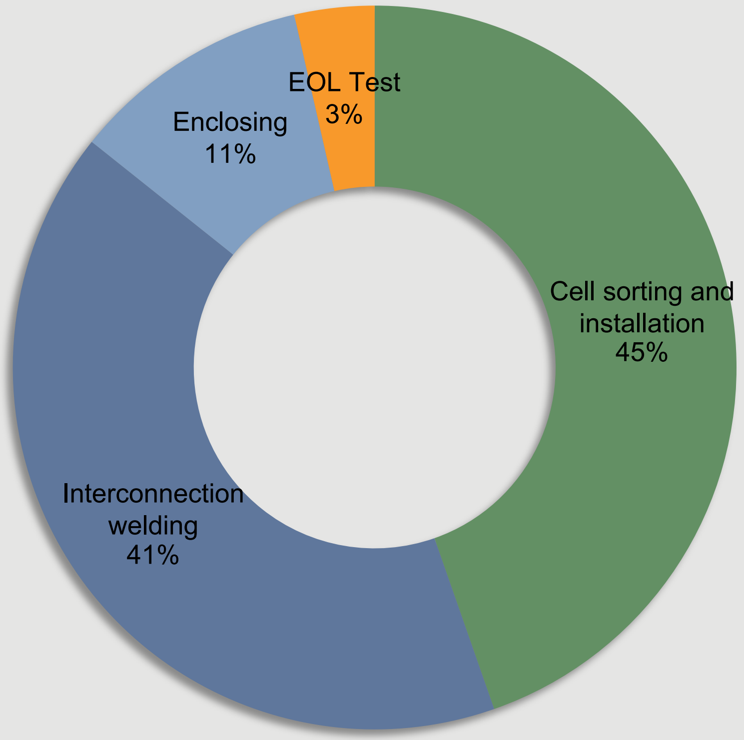
Breakdown of Module-Level Findings

The automation level of module production varies among manufacturers. Welding quality issues and environmental control pitfalls can lead to end-of-line (EOL) test failures.

Severity Scale of Module-Level Findings



Distribution of Module-Level Findings



45% of module findings occur at cell sorting and installation	41% of module findings occur during interconnection welding	11% of module findings occur during enclosing	3% of module findings occur during EOL testing
Why/How Does It Happen	**Why/How Does It Happen**	**Why/How Does It Happen**	**Why/How Does It Happen**
Manufacturing inconsistency due to manual operation and improper quality control protocols	Lack of efficient quality control procedures and mis-operation risks due to a highly manual process	Lack of efficient quality control procedures and mis-operation risks due to a highly manual process	Cell manufacturing inconsistency and mis-wiring from highly manual processes
Example	**Example**	**Example**	**Example**
• Lack of error-proofing measures to ensure cells are assembled with the right orientation • Inconsistent glue usage and position • Unqualified BOM (Bill of Materials) change on insulation layers within the module.	• Mislocated welding position • Non-calibrated welding strength test • Lack of procedure of cleaning up welding slags.	• Inconsistent cell group placement • Mechanical damages to fixtures and cooling plates.	• Failed dielectric withstand voltage test due to poor internal wiring insulation and wiring arrangement • Abnormal cell voltage difference due to defective cells.

What Can You Do To Ensure the Long-term Financial Health of Your BESS Assets?

Golden FAT

- **Closing the Gaps**: We review your procurement contract, project requirements, and FAT checklist to ensure your energy system is safe and performs well, preventing any surprises.
- **Early Detection**: We identify risks in the supplier's checklists early to save costs and extend your system's operational life.
- **Expert Check-Up**: Our experts verify adherence to key safety and performance standards for a reliable energy system.
- **Negotiation Support**: We support you in negotiating and adjusting the FAT checklist deviations.

Factory QA

- **Factory Audit (FA):** Engineers check factories with a 300+ point checklist, assess risks, and recommend fixes.
- **Inline Production Monitoring (IPM)**: Engineers monitor production in real-time, ensure quality, spot issues, and suggest corrections.
- **Pre-Shipment Inspection (PSI):** Engineers inspect and test a random sample of finished products, record findings, and advise on improvements.
- **Factory Acceptance Test (FAT):** Engineers inspect and test finished products for performance and suggest corrective actions.

INSIGHTS

For more information

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