Global Electronics Association™

The Importance of Reliable Charging Station Electronics for Building a Sustainable EV Ecosystem:

"R" YOU READY?

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ABSTRACT

The rapid transition to electric vehicles (EVs) demands a robust and reliable charging infrastructure to support user confidence and safety. This paper explores how the reliability of EV charging station electronics is foundational to the broader sustainability of the EV ecosystem. Drawing parallels from high-reliability industries such as automotive and aerospace, the paper introduces the "Connect – Clean – Coat" methodology as a practical framework for ensuring durable and high-performing electronics in harsh outdoor environments. It outlines challenges facing Level 3 chargers—including high-voltage operation, thermal extremes, humidity, and contamination—and emphasizes how failure in these systems leads to high maintenance costs, lost revenue, and negative user experiences.

The paper also highlights industry collaboration efforts led by the Global Electronics Association e-Mobility Quality and Reliability Advisory Group, and introduces proven reliability testing methods such as HALT and HASS to uncover design and process vulnerabilities. By adopting best practices and harmonized standards, manufacturers can reduce total cost of ownership (TCO), minimize environmental impact, and build consumer trust on the path to achieving zero-failure charging infrastructure. Reliability, the new "R" in sustainability, is essential for the successful scaling of electric mobility infrastructure.

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INTRODUCTION

The transition to electric vehicles is in full swing. A big question that consumers have is, "Will I be able to find an EV charger that works when I need it?" Can you imagine being low on a charge in the dead of winter, and finding a charging station, only to be let down when the charger doesn't work? This is not only a huge safety issue; it is also a story that can really hinder consumers from wanting to transition to an EV. Consumers rarely, if ever, have a fear of pulling up to a gas station and not getting fuel. This white paper reinforces why the reliability of EV charger electronics is so important, provides a description of the environmental and operational challenges that charging systems face, highlights role of reliability in ensuring sustainable charging systems, and introduces the "connect-clean-coat" approach as a means of achieving reliable charging system electronics. Together, these lessons can lead to bottom-line benefits in total cost of ownership (TCO) as well as set the course towards zero failures. Do you have the proper resources and knowledge to enable a successful transition?

WHY IS THE RELIABILITY OF EV CHARGERS SO IMPORTANT?

The reliability and sustainability of EV charging systems are critical factors in the widespread adoption of EVs.[1] The need for a robust and dependable charging infrastructure becomes increasingly important as the demand for EVs continues to grow. However, the current EV charging systems face several challenges that impact their reliability. These challenges stem from the rapid development of EV technologies and significant differences from traditional internal combustion engine (ICE) technologies.

EV charging is generally categorized into three levels based on charging speed, power delivery, and infrastructure requirements. The Level 1 charger typically delivers 1.2 – 1.8 kW of power and uses a standard home outlet. It uses standard equipment but has the slowest charging rate, typically taking overnight. Level 2 charging uses a 240-volt outlet and delivers 3.3 to 19.2 kW, depending on the charger and vehicle capacity. It is commonly installed in homes, workplaces, and public locations and requires several hours of charging. Level 2 chargers often require a dedicated circuit and a professionally installed charging station. Level 3 charging, also known as DC Fast Charging (DCFC), bypasses the vehicle's onboard charger to deliver high-voltage direct current at power levels ranging from 50 kW to over 350 kW. Charging takes approximately 20 – 30 minutes for a passenger EV, making them ideal for highway corridors and commercial use. Level 3 chargers are significantly more expensive and require specialized infrastructure and utility coordination. Level 3 chargers, which are essential for the public charging network, generate significant heat and must withstand the harsh outdoor environment. Thus, Level 3 charging and reliability is the focus area of this paper.

Unreliable electronics in EV charging stations can have significant cost implications for charging station operators and automotive manufacturers, along with their customers. The TCO has a direct impact on the return on investment. For charging station operators, frequent malfunctions necessitate increased spending on repairs and maintenance. For instance, Electrify America announced a $172 million investment to replace or upgrade 600 charging stalls in California to address performance issues.[2] Inoperable chargers also lead to lost revenue opportunities, as potential customers are unable to charge their vehicles. A study analyzing over 19 million data points highlighted that reliability issues in EV charging infrastructure negatively impact the user experience, potentially deterring usage.[3] Unreliable chargers can damage the operator's reputation, leading to decreased customer loyalty and potential loss of market share. Drivers have expressed frustration with broken equipment, making charging unreliable and inconvenient.[4] Dissatisfied users post their negative experiences with broken stations on social media, affecting public perception. Additionally, charging network operators may face regulatory or legal penalties and be required to refund customers if the stations fail to meet uptime requirements mandated by regulators. California has begun implementing uptime requirement regulations to enhance the reliability of public EV charging stations. Assembly Bill 2061 mandates the California Energy Commission (CEC) to develop uptime recordkeeping and reporting standards for EV chargers and charging stations that receive state or ratepayer incentives.[5]

For automotive manufacturers, consumers may be hesitant to purchase EVs if the charging infrastructure is perceived as unreliable, directly affecting vehicle sales. Ford, for example, scrapped plans for an electric SUV, citing concerns over EV adoption rates influenced by charging infrastructure issues.[6] Manufacturers may face higher customer support expenses addressing concerns related to charging difficulties, even if the issues stem from third-party charging stations. The anxiety around EV charging is noted as an inhibitor to EV adoption, which can lead to increased inquiries and support needs from potential and current EV owners. Association with unreliable charging experiences can tarnish a manufacturer's brand, especially if consumers perceive the EV ecosystem as inadequate. Public dissatisfaction with charging infrastructure can reflect poorly on automotive brands that promote them. Addressing these reliability challenges is crucial for the sustained growth of the EV market and requires coordinated efforts between charging infrastructure providers and automotive manufacturers.

A report by the National Renewable Energy Laboratory highlights the impact of charging station reliability, resilience, and location on EV adoption.[7] This same report notes that the majority of charging events currently occur at home. This means that EVs are primarily being used as a daily commuter vehicle and not as a direct replacement for the overall function of ICE vehicles. What is necessary to get this to the next level?

THE NEW R? RELIABILITY IS SUSTAINABILITY.

In the evolving landscape of EV infrastructure, a new paradigm emerges: reliability as a cornerstone of sustainability. While traditional sustainability emphasizes Reduce, Reuse, Recycle, and Repurpose, the reliability and longevity of EV charging stations directly influence their environmental impact. Reliable chargers minimize unplanned downtime, reduce maintenance needs, and limit the environmental and economic costs associated with repeated repairs or replacements.

The automotive electronics industry, led by OEMs, Tier 1’s, electronic manufacturing services (EMS), and suppliers, has a long history of packaging electronics for harsh environments, albeit high voltage has become a more relevant consideration for EV electronics. It is apparent to the authors of this paper that the charging station industry stands to benefit from existing best practices used in the automotive industry. Product and program managers responsible for the design of charging stations may not have direct automotive electronic packaging experience. It’s important to be aware of the “3 pillars” of high voltage design and manufacturing, which are humidity robustness, isolation coordination, and technical cleanliness. IPC Standards published by the Global Electronics Association address the 3 pillars through the development of test methods, design guidelines, and standards to improve quality and reliability, reduce scrap and costs, and advance the electronics manufacturing industry in general.

The outdoor environment can have a significant impact on the reliability of charging station electronics and automotive electronics in general. Most EV charging station electronics operate between -30°C and 50°C, with power modules reaching 100°C and power die applications exceeding 225°C. In addition to temperature extremes, charging stations and their electronic assemblies are exposed to humidity, rain, snow, ice, salt spray, dust, corrosive gases,[8,9,10] and even insects![11,12] Compounding the environmental challenges is the fact that Level 3 chargers typically operate at high voltages within the 400 – 800V range, aligning with the battery architectures of EVs. Newer EV models are trending towards 800V battery systems to facilitate faster charging times. Higher voltages accelerate wear-out mechanisms on PCB assemblies (PCBAs), especially in combination with harsh outdoor environments. Several high-voltage failure mechanisms have recently been described in technical papers presented at the IPC APEX EXPO Technical Conferences.[13,14,15] These advancements were made possible with the use of a recently released industry test method for high voltage, *“High Voltage Moisture and Insulation Resistance Test of Fabricated Printed Board Test Patterns.”*[16]

Reliability and sustainability are intrinsically linked when it comes to EV charging systems. A reliable EV charging infrastructure ensures that Charging stations are consistently operational and accessible, which in turn promotes the widespread adoption of EVs.A reliable charger is one that does not require unnecessary repairs or replacement, thereby eliminating the environmental impacts caused by unplanned maintenance or equipment failures. Charging equipment can be powered by renewable energy sources and utilize efficient charging infrastructure. Incorporating solar panels into Charging stations allows them to generate clean energy on-site, decreasing reliance on fossil fuels.[17] By focusing on both reliability and sustainability, a robust EV charging network can be created that supports the transition to electric mobility.

What does reliability mean? From a relationship standpoint, reliability is the trustworthiness and dependability of an individual in keeping commitments. When it comes to engineering and technology, Reliability can be defined as the probability that a system or component will perform its required functions under specified conditions for a designated period of time. Now, if you combine those two definitions, consumers are trusting a person stating a reliability goal for system performance, like an EV Charging station. Currently, there are many consumers who don't trust the reliability of public EV Charging stations. How can EV charging station manufacturers increase reliability and strengthen trust with consumers? One industry group focused on helping improve the reliability of EV charging station electronics is the Global Electronics Association Mobility Quality and Reliability Group.[18]

Ensuring reliable EV charging station electronics is necessary for achieving sustainability goals. Poor solder connections, contamination, and inadequate PCBA protection can lead to frequent failures, increased maintenance, and negative user experiences, thus hindering EV adoption. By prioritizing robust design, quality control, and environmental resilience in Charging stations, sustainability leaders can support seamless EV integration and foster a cleaner, more sustainable transportation future. Reliable Charging stations are key to reducing TCO for EV users, stabilizing fleet operations, and promoting wider EV adoption. Addressing reliability ensures that financial investments in clean transportation achieve their intended environmental and economic goals.

"CONNECT – CLEAN – COAT" METHODOLOGY

A challenge facing the industry is that the standards for designing high-reliability charging stations are not fully developed. Thus, the members the Global Electronics Association e-Mobility Quality and Reliability Group have developed and promoted a methodology for the design and manufacturing of high-reliability electronics called "Connect – Clean – Coat."[19] These important steps of the manufacturing process have proven beneficial to industries like aerospace, military, and automotive, as well as other industries whose products require high reliability. The following sections provide further insights.

Connect

Solder joints are critical for providing mechanical support, electrical connectivity, and thermal pathways in electronic assemblies. Any defects, such as cold solder joints, voids, or cracks, can compromise these functions, leading to failures. Making proper electrical connections or soldering for EV chargers is crucial for ensuring both safety and efficiency in the charging process. Proper electrical connections prevent issues such as overheating, electrical arcing, and potential fire hazards, which can arise from loose or faulty connections. In the context of high-power applications like EV charging, even minor imperfections in soldering can lead to significant performance degradation and reliability issues.

For instance, a poorly formed solder joint, as the example displayed in Figure 1, can cause increased resistance, leading to inefficient power transfer and potential damage to the charging equipment. The defective solder joint is due to improper board design parameters. Figure 2 shows an example of a poorly formed solder joint and solder ball formation due to improper stencil design or inadequate screen-printing process parameters. The uncontained solder ball may cause latent reliability issues due to movement and electrical shorting of fine pitch components.

A study highlighted that reinforced solder preforms can improve reliability by providing consistent solder joint bond-lines, thereby reducing voiding and enhancing thermal performance of power components.[20] Additionally, proper grounding and secure connections are essential to protect both the vehicle and the charging infrastructure from electrical faults and surges. Ensuring high-quality electrical connections and soldering practices is vital for the long-term reliability and safety of EV charging.

Process characterization is a very important factor in solder joint formation and reliability. An improper reflow thermal profile can lead to secondary issues. Specifically, if the thermal profile fails to properly deactivate flux residues, it creates a significant risk of long-term field failures due to electrochemical migration.

Fractures in solder joints may result from stress conditions arising during soldering processes or from temperature cycling effects due to the environment. Proper design, material selection, and process characterization are important factors to minimize thermal coefficient of expansion mismatches and the induced stress that can lead to solder joint fractures. Figure 3 shows a fractured solder joint of a corner ball on a ball grid array (BGA) component. The crack was generated due to stress arising from the reflow process. The ball interconnects located on the corners of the BGA package experience the highest stress levels during thermal excursions. Such partial fractures, or cracks, are especially concerning because they can go undetected at end-of-line testing. Figure 4 displays a crack in the solder joint of a surface mount technology (SMT) connector lead that resulted due to temperature cycling stresses in the automotive environment after only 3 months.

Therefore, as illustrated in these examples, ensuring high-quality soldering processes and conducting rigorous inspections are essential to maintain the reliability and performance of solder joints in high-power applications like EV charging.

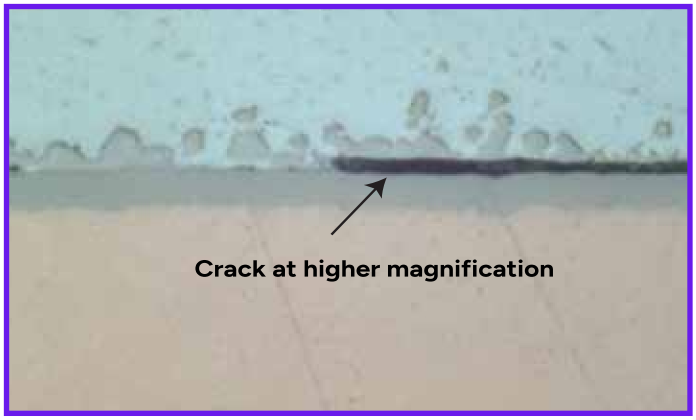


Figure 1. Lifted component lead (open solder joint connection)

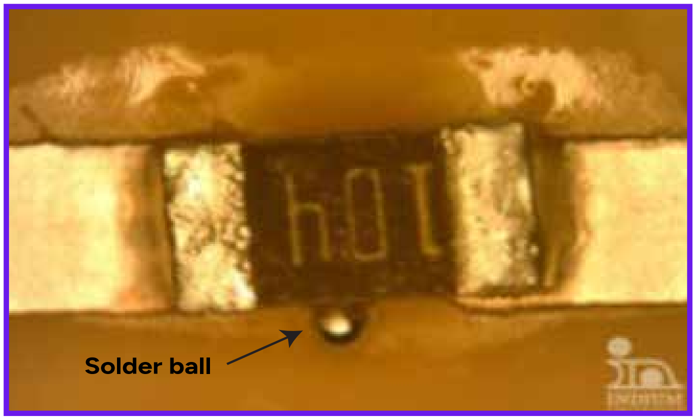


Figure 2. Poor component soldering quality including solder ball formation

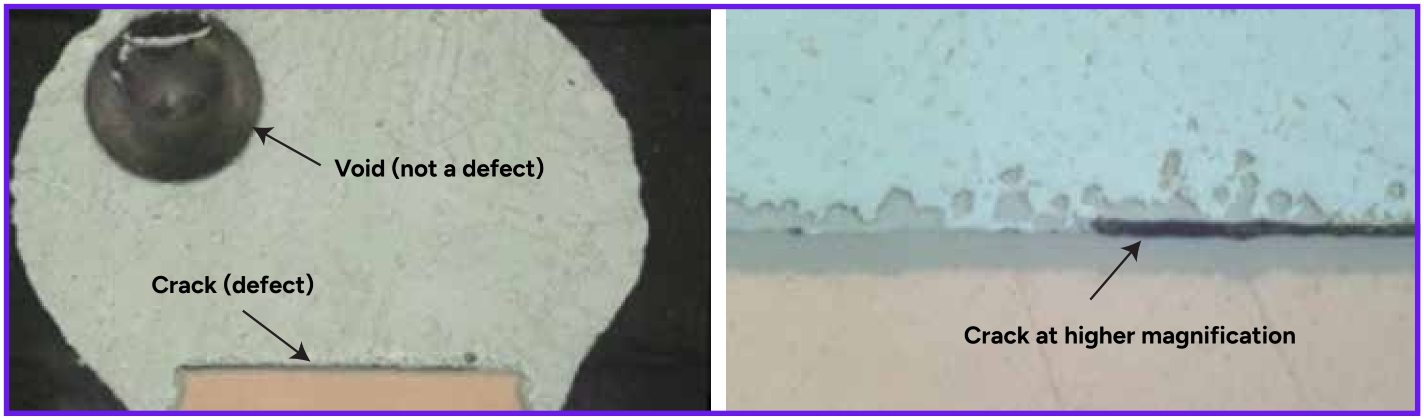


Figure 3. Stress induced crack in BGA corner ball solder joint following the soldering process

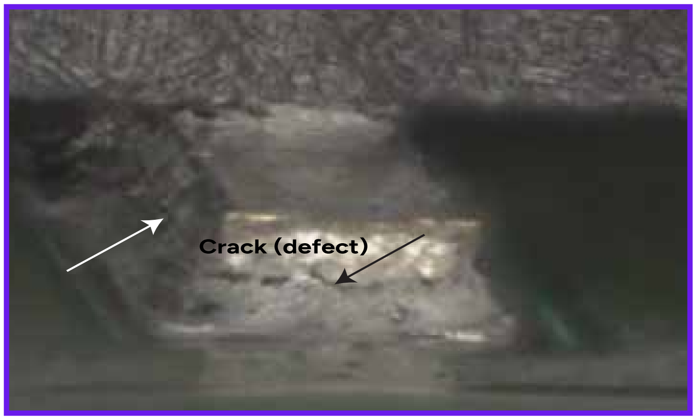


Figure 4. Stress induced crack in SMT connector solder joint due to thermal cycling

Clean

Failures associated with contaminants left on electronic assemblies can have significant impacts on the reliability and performance of the devices. Contaminants such as processing residues can lead to various issues, including corrosion, electrochemical migration, and short circuits. These contaminants can create conductive paths that cause electrical shorts or degrade the insulation properties of the assembly, leading to intermittent or permanent failures. Figure 5 shows a soldered assembly before and after removal of flux residues using a cleaning process. Additionally, contaminants can interfere with the adhesion of protective coatings or potting materials, reducing their effectiveness and leaving the assembly vulnerable to environmental factors such as moisture and dust. Ensuring proper cleaning and handling procedures during the manufacturing process is crucial to prevent these failures and maintain the long-term reliability of electronic assemblies. A recent technical conference session highlighted the role of different ionic contaminants resulting from solder flux residues under humidity and bias voltage conditions, leading to electrochemical migration failures.[21,22,23,24] Figure 6 shows the formation of a dendrite between electrical conductors. Dendrites form under humid conditions, with a bias voltage, in the presence of ionic contamination. Dendrites reduce the electrical resistance between the conductors and can even lead to hard shorts and failures. Parasitic current leakage, the precursor to dendrite shorting, can lead to unidentified electrical events and failures in the field. Parasitic leakage may occur if ionic contamination is present on sensitive circuits, when operational in humid conditions. Parasitic leakage induced electrical events are difficult to identify because they may not leave a "fingerprint." They can fully recover and are often categorized as "no trouble found" (NTF) warranty returns.

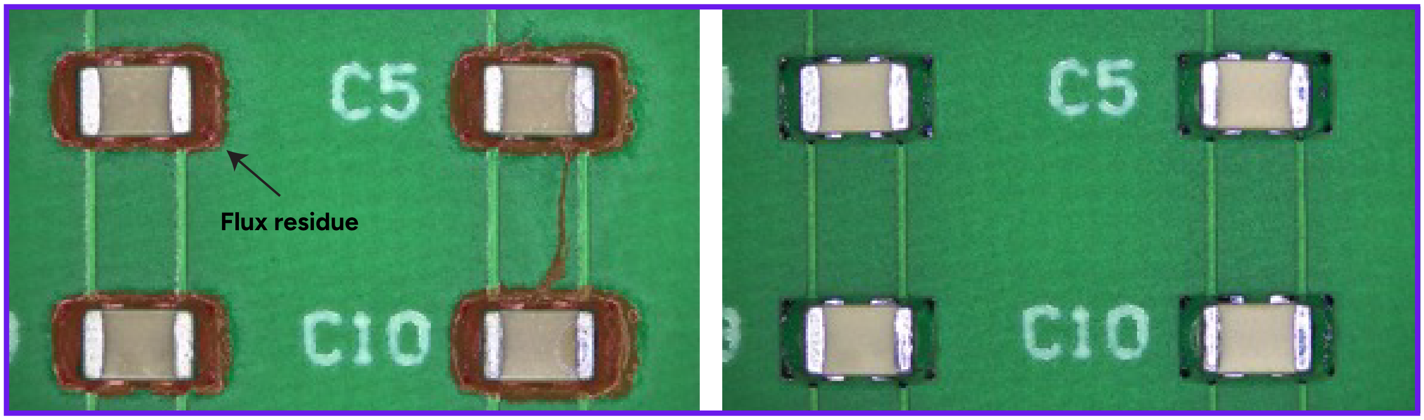


Figure 5. Soldered components before and after removal of flux residues

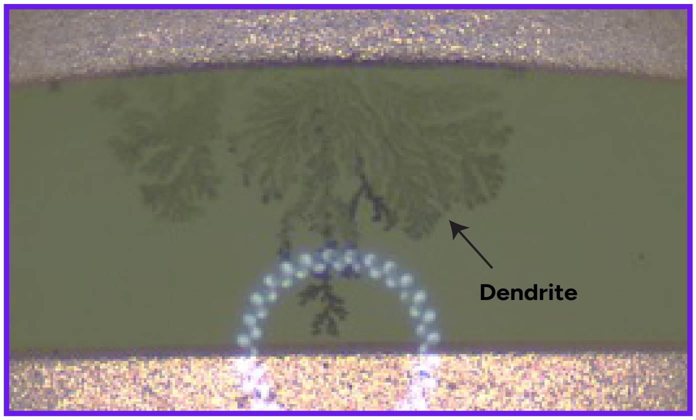


Figure 6. Dendrite formed between electrical conductors, reducing the insulation resistance

Cleanliness relates to reliability. Residues of the assembly process are the cumulative effect of PCB fabrication residues, the porosity of solder masks, assembly materials including fluxes, cleaning and rinsing effectiveness, components themselves, as well as rework and repair introduced residues. It is the cumulative effect of these conditions that results in residues trapped from pad-to-pad, via-to-pad, under low-standoff components, as well as under protective coatings. Some components and circuits of the PCBA may be more sensitive than others and it is important to understand contamination limits and establish processes and controls to achieve them.

To be accurate, not all process residues are necessarily harmful to reliability and certain limits are tolerable. The automotive industry has had success with no-clean solder technologies where the flux residues are intended to remain on the PCBA throughout the life of the product. However, ICE applications commonly operate at low voltage (12V) and EV and Charging stations operate much higher (400 to >800V). The full effects of high-voltage and residue contamination are still under investigation. Significant material and process qualification, as well as process controls, are required to ensure reliability and that an allowed amount of contamination is permitted to remain on the PCBA. Unfortunately, a lack of proper material characterization and process control can result in elevated levels of contaminants impacting electrical performance. High-level contaminants leading to issues include ionic residues such as weak organic acids (WOA) used in solder fluxes. Understanding contamination limits and controlling them via effective materials management, process control, and cleaning when required, are instrumental to producing reliable products.

A final point is that any cleaning strategy should be aligned with proper design-for-reliability (DFR) practices. It is important to establish a sufficient creepage distance between conductors and components at the design level. This proactive approach reduces the dependency on manufacturing processes alone to mitigate contamination risks.

Coat

Adding a conformal coating or protective material to electronic assemblies offers several significant benefits. Figures 7 and 8 show examples of PCB assemblies covered with conformal coatings. These coatings act as a barrier against environmental contaminants such as dust, moisture, and chemicals, which can cause corrosion, electrical shorts, and other types of damage. By providing a protective layer, conformal coatings extend the lifespan of the electronic assemblies that EV chargers are comprised of and improve their reliability, reducing the likelihood of failures and the need for costly repairs. Overall, the use of conformal coatings is a cost-effective strategy to ensure the durability and performance of electronic devices in various challenging environments. The coating material type selection and performance are dependent on both the environmental requirements and the material and process compatibility requirements of the PCB assembly "system." For example, to ensure the conformal coating provides protection as expected, it is important that the conformal coating is compatible with the PCB solder mask, providing sufficient wetting and coverage of the PCB surface. Additionally, it is important that any tolerable process residues are compatible with the conformal coating, e.g., that they do not cause delamination and or chemically react leading to degradation or the formation of byproducts that could lead to electrochemical migration.

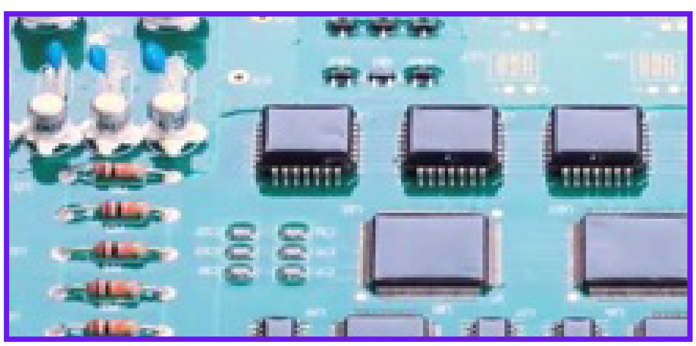


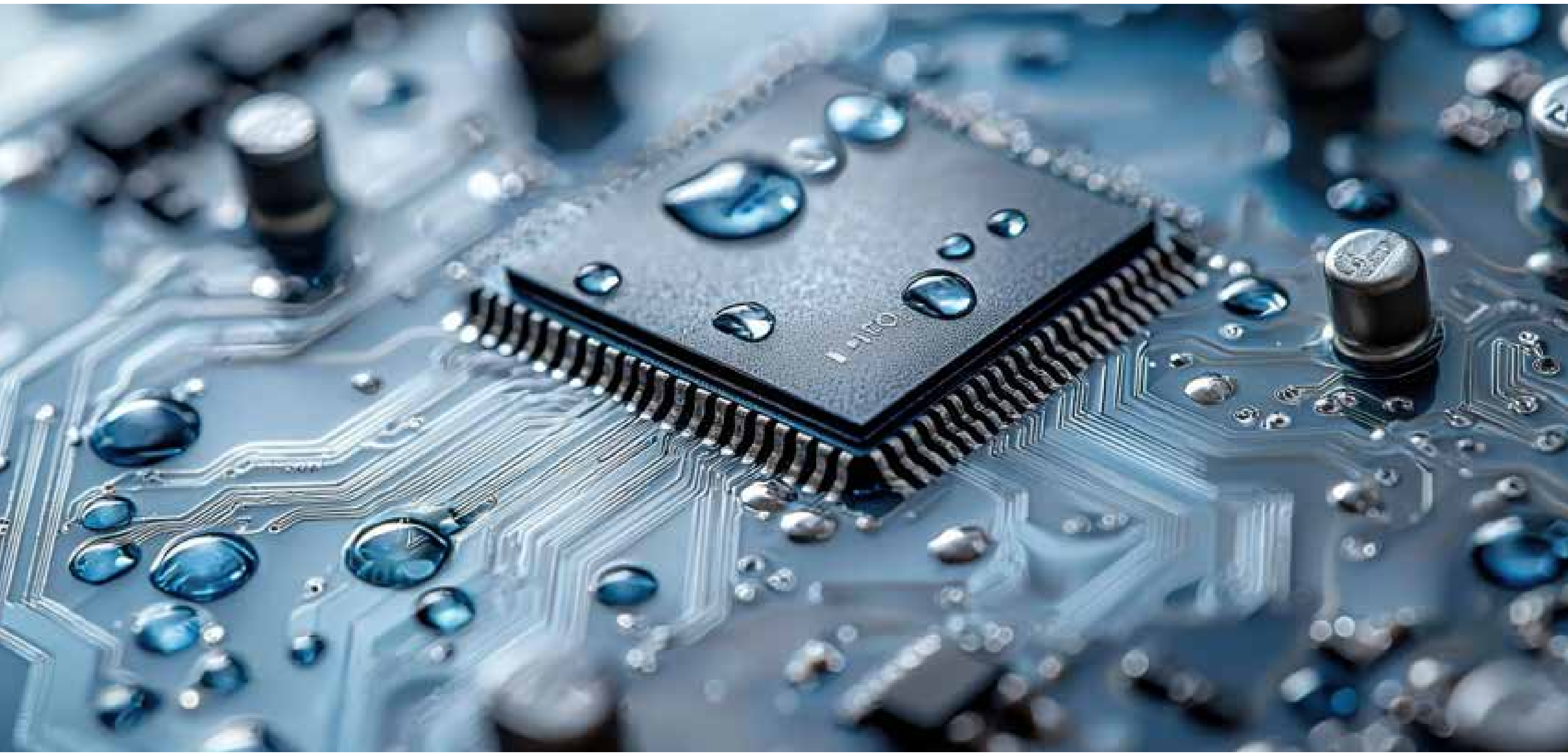
Figure 7. Example of a conformal coating on a PCB assembly

Figure 8. Conformal coated PCB assembly under UV detection light

A pioneering investigation by Elsinger et. al., of Robert Bosch GmbH, examined the surface insulation resistance (SIR) of PCBAs, protected with conformal coatings, under high-voltage stress up to 1000V.[25] Test boards were prepared per the IPC-9202 standard, featuring comb-structured pads to assess different creepage distances in line with IEC 60664-3 and IPC-2221B guidelines. SIR tests at 500V to 1000V were conducted under static humidity conditions of 65°C/93%RH for 1000 hours, followed by damp heat tests per IEC 60068-2-38. The results showed that conformal coatings enhanced electrochemical reliability, allowing for reduced creepage distances if PCB materials, soldering, and coatings were compatible. The method offered a basis for testing PCB assemblies for elevated voltage requirements.

The addition of protective measures to many of these assemblies, at a nominal cost, can significantly increase the long-term reliability of the overall systems. This, in turn, reduces the need for frequent replacements and repairs, thereby minimizing the environmental footprint associated with the production and disposal of charging equipment.

Another consideration is creep corrosion, or copper sulfide crystal growth, on exposed copper or silver surfaces through the conformal coating or on poorly covered surfaces. Sulfur corrosion on resistors can be caused by sulfur gases passing through the coating. This corrosion can reduce the electrical insulation properties of a coating or worse create a complete breakage in the coating allowing for an unwanted electrical path. Sulfur gases can originate from the environment but also from packaging, rubber, and foam materials used for various reasons in electronic packaging like vibration dampening. Other components are at risk including LEDs. Certain coating materials like Parylene have been proven in some studies to be effective at preventing sulfur gas attack of sensitive components.[10] In summary, the Connect – Clean – Coat methodology can help to ensure proper electrical connections and soldering practices help prevent overheating, arcing, and potential hazards that could compromise both the charging equipment and the vehicle. Maintaining cleanliness during the manufacturing process minimizes the risk of corrosion, electrochemical migration, and short circuits, which can significantly impact the performance and lifespan of the system. Furthermore, applying conformal coatings or protective materials adds an essential layer of defense against dust, moisture, and other external factors that could lead to component degradation or failure.



ADDITIONAL "Rs" RELEVANT TO CHARGER RELIABILITY

Manufacturing Rework

The reworking of PCB assemblies (PCBAs) is used in the electronics industry to restore functionality to flawed or damaged products. Rework can be done within the production process, and all assemblies verified to meet the end-of-line criteria. Rework involves several strategies, such as proper storage and handling to prevent contamination and damage, knowing the specific details of the PCBA, and using appropriate rework techniques. The process can be compared to surgery, requiring careful attention to detail and expertise. While it can be daunting, it is often more economical than scrapping the board and starting over.

Due to the high throughput of today's PCBA manufacturing processes, in many cases, PCBAs are completed and even conformal coated prior to final functional testing. This means a large number of units are complete or work in process prior to a problem being identified. If the root cause can be identified and it is feasible to rework, the source of error will be resolved. In some cases, it is more economical to scrap the assemblies than to rework. This unplanned waste attributes negatively to the sustainability of end products produced, as all of that raw material needs to be recycled or disposed of. Alternatively, it consumes additional energy and resource to make the units functional for the field.

Field Repair and Replacement

Repairing commercial EV charging stations in the field has become parallel to repairing any industrial-grade piece of electrical equipment. Repairing should be aligned with normal wear and tear and not due to poor build quality. Level 3 chargers are becoming more modular, similar to how vehicles are separated into replaceable units. This addresses a degree of efficiency to the repairing aspect of the level three units. Level 1 and Level 2 units are becoming more commoditized and more cost-effective for personal use. Just like any other electrical device, these chargers may encounter issues that can be fixed. Common problems include blown fuses, faulty connectors, power supply issues, or software glitches. While it is necessary to consider repair options, if devices are designed to be more reliable, repairing becomes less frequent.

Designing units for proper maintenance maximizes uptime and availability, ensuring that EV drivers can consistently find operational charging stations when needed. This is vital for attracting and retaining EV drivers, as frequent downtime can lead to frustrated customers and a loss of revenue opportunities. This is also critical to ensuring the safety of users, as degraded electrical components can increase the risk of malfunctions or hazardous conditions. Finally, maintaining customer satisfaction is essential, as reliable charging stations provide a smooth charging experience, fostering customer loyalty and positive reviews. Regular maintenance and reliability prevent expensive repairs by identifying minor issues early, which can prevent them from escalating into significant, costly problems or the need to replace entire units.

Acquiring the hardware components needed to repair charging stations is also a challenge because power electronic components are specific to each OEM, and their level of support may vary in the event of equipment failure.[26] Maintenance, repair, and replacement of charging station components and charging stations themselves can be a sizable life cycle cost contributor even without specific reliability events.[27] Thus, poor reliability will quickly translate into high TCO and a lower return on investment.

Replacing EV charging stations can have several negative implications. The process of manufacturing and installing new charging stations involves significant resource consumption and energy use, which can contribute to environmental degradation. Additionally, disposing of old charging stations can lead to electronic waste, which poses a challenge for waste management and recycling systems. Frequent replacements can also be costly for both manufacturers and consumers, potentially leading to higher prices for charging services.

Robustness vs. Reliability

charging station durability is governed by multiple international standards and regional certifications that ensure both functionality and resilience under various conditions. The International Electrotechnical Commission (IEC) establishes the primary requirements in IEC 61851-1. These standards mandate that charging components meet specific durability benchmarks such as impact protection and ingress protection. Impact protection is quantified through IK ratings, which indicate the amount of impact energy an enclosure can endure, with testing procedures outlined in IEC 62262. Ingress protection is expressed through IP ratings, consisting of two numbers that define the level of resistance against solid objects (like dust) and water, with guidelines provided in IEC 60529.

Additionally, IEC 61851-1 specifies that charging components must operate reliably under extreme environmental conditions, such as severe heat and cold, with the relevant testing protocols detailed in IEC 60068. While these IEC standards are international, regional adaptations occur; for example, in North America, Underwriters Laboratories (UL) certifies products. Various UL designations—such as UL Certified, Listed, or Recognized—reflect different levels of testing, often incorporating IEC 61851 requirements. Major manufacturers, including ChargePoint and Tesla, typically obtain UL certification to demonstrate that their charging stations meet these stringent durability standards.

There are well established manufacturing acceptance requirements for electronic assemblies that are defined by standards organizations like the Global Electronics Association. However, EVs have introduced new requirements to the automotive and charger space, like "always on," high voltage, and new thermal challenges. Developing and performing accelerated aging tests for electronic products can be expensive. This is why industry groups are formed, share critical learnings, and try to harmonize test methods to be as efficient and thorough as possible. Industry recognized tests are developed over decades, incorporating lessons learned from field data. This tribal knowledge is often missing for developing technologies. They can reference the most relevant industry knowledge to achieve a reasonable facsimile. Critical to any emerging industry is creating an understanding of the contributing factors that impact the longevity of the product. Commonly there are two types of testing; HALT (highly accelerated life test) and HASS (highly accelerated stress screening). This can be viewed as robustness vs. reliability.

Highly Accelerated Life Testing (HALT) and Highly Accelerated Stress Screening (HASS) are methodologies that can be employed to enhance the reliability of electronic assemblies, particularly in demanding applications like EV charging stations. As described above, EV charging stations operate in diverse and often harsh environments, making reliability paramount. ChargerHelp's 2024 report on EV charging reliability showed that older EV charging stations experience higher downtime, with a notable increase in failure rates around the 4-year mark. [28,29] This was due to both equipment degradation and the superior quality of newer technology. Failures can stem from design flaws or manufacturing defects, both of which can be mitigated through HALT and HASS. HALT is integrated during the design phase to build robust products, while HASS is applied during production to maintain quality. HALT is exploratory in nature, aiming to "test-to-fail" to improve design robustness by pushing components beyond their operational limits to induce failures and uncover potential design flaws for improvement. HALT can expose vulnerabilities in components such as power converters, control systems, and communication modules by subjecting them to extreme temperatures and other environmental conditions during the design phase. Identifying these weaknesses early allows engineers to reinforce designs, ensuring components can withstand real-world stresses. Once the design is finalized, HASS is employed during production to screen for manufacturing defects like poor solder joints or component misplacements. By applying controlled stress levels, HASS ensures that only units meeting quality standards proceed to deployment. Early detection of design flaws through HALT reduces costly redesigns and recalls. HASS ensures manufacturing consistency, reducing warranty claims.

In summary, HALT and HASS are complementary processes that, when applied appropriately, significantly enhance the reliability and longevity of electronic assemblies like those used in EV charging stations. Their implementation is a proactive approach to quality assurance, ensuring that both design and manufacturing processes contribute to the delivery of dependable products.

HOW THE GLOBAL ELECTRONICS ASSOCIATION CAN HELP

As a global non-profit organization, the Global Electronics Association brings together industry partners to help develop and maintain best practice standards for the design of reliable electronics going into the various end-use environments. A group of industry experts has joined together to form the e-Mobility Quality and Reliability Advisory Group (EVQR). This Group was formed to help connect industry-developed and proven standards to the growing world of E-mobility, which includes EV chargers. With their decades of combined experience, the Global Electronics Association has developed an IPC class system to help determine the best level of reliability for a particular system based on the end-use environment in which the electronics will be used.

IPC Reliability Focus – J-STD-001 and IPC-A-610

Class 1: General electronic products, consumer products
Lowest requirements

Class 2: Dedicated service electronic products
Extended lifespan; more reliable than Class 1

Class 3: Critical high performance, downtime cannot be tolerated
Highest level of requirements

Using the class system, the Advisory Group (EVQR) has talked with EV charging manufacturers and developed Table 1 to help guide the EV Charger market with the right IPC class for electronics going into EV Chargers.

Table 1. Charging level type and corresponding IPC Class distinction recommendation

	Level 1	Level 2	Level 3
Personal Charger -Indoor	Class 2 min.	Class 2 min.	NA
Personal - Charger Outdoor	Class 2 min.	Class 2 min.	NA
Public Charger – Covered parking garage	Class 2 min.	Class 2 min.	Class 3
Public Charger – Covered parking garage coastline	Class 2 min.	Class 2/3	Class 3
Public Charger – Outdoor	Class 2 min.	Class 2/3	Class 3
Public Charger – Outdoor Coastline	Class 2/3	Class 3	Class 3

Additionally, it is possible to view EV as a combination of high-voltage power distribution combined with high-reliability electronics. These sub-segments are not new and in fact the Global Electronics Association has IPC handbooks that provide guidance on defining how to make these devices robust against the harsh day-to-day activities and reliable against the long-term environments these devices must withstand.

SUMMARY

This paper emphasizes that the long-term success of EV adoption hinges on the reliability of EV charging infrastructure. Reliability not only influences consumer confidence and satisfaction but also directly affects sustainability by reducing waste, repair frequency, and total cost of ownership. Public fast chargers (Level 3), operating at high voltages in harsh outdoor environments, face unique challenges—such as extreme temperatures, moisture, salt, and corrosion—that accelerate component degradation and failures.

Unreliable chargers lead to downtime, lost revenue, negative user experiences, and reduced EV adoption rates. For instance, Electrify America's $172M overhaul of unreliable units in California underscores the cost implications. To address these issues, the paper introduces the "Connect – Clean – Coat" methodology, adapted from high-reliability sectors like aerospace and automotive. This approach emphasizes robust soldering ("Connect"), removal of ionic and particulate contaminants ("Clean"), and protection from environmental exposure via conformal coatings ("Coat").

Also highlighted in this paper is the critical role of standards bodies like the Global Electronics Association (producer of IPC standards) and introduces design-for-reliability concepts such as HALT (Highly Accelerated Life Testing) and HASS (Highly Accelerated Stress Screening). These methodologies help uncover design and manufacturing weaknesses early. Global Electronics Association's e-Mobility Quality and Reliability Advisory Group is leading efforts to apply proven electronics manufacturing standards to EV charger development. Addressing quality and reliability issues requires industry-wide collaboration and the sharing of field data. By aligning reliability with sustainability, the industry can ensure robust, trusted, and environmentally responsible EV infrastructure. Reliability is the new "R" in sustainability.

REFERENCES

1 Sustainability in EV Charging: Powering a Greener Future for Electric Vehicles, November 9, 2024, www.carstrucksroads.com [https://carstrucksroads.com/Sustainability-in-ev-charging/]

2 "Electrify America to Replace 600 Chargers in California, Invest $172 Million," InsideEVs, October 24, 2023. [https://insideevs.com/news/692999/electrify-america-to-replace-600-chargers-california/]

3 "Understanding EV Charging Reliability: A Deep Dive into the ChargerHelp Report," ChargerHelp, Sep 12, 2024 (Updated: Oct 17, 2024). [https://www.chargerhelp.com/post/understanding-ev-charging- Reliability-a-deep-dive-into-the-chargerhelp-report]

4 "The state of EV charging in America: Harvard research shows chargers 78% reliable and pricing like the 'Wild West,'" Harvard Business School, Institute for the Study of Business in Global Society, June 26, 2024. [https://www.hbs.edu/bigs/the-state-of-ev-charging-in-america]

5 California Bill - AB-2061 Transportation electrification: electric vehicle charging infrastructure. [https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=202120220AB2061]

6 "Ford Scraps Plans for Electric SUV at Potential Cost of $1.9bn," The Times, Aug. 22, 2024. [https://www.thetimes.com/business-money/technology/article/ford-scraps-plans-for-electric-suv-at-potential-cost-of-19bn-gknght55t]

7 Powell, B.; Johnson, C. 2024. Impact of Electric Vehicle Charging station Reliability, Resilience, and Location on Electric Vehicle Adoption. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5R00-89896

8 Singh, P.; Palmer, L.; Fu, H. DATA CENTER AIR QUALITY AND HARDWARE CORROSION

9 Clancy, S.; Schueller, R.; Genthe, C.; Leone, P. Creep Corrosion in Electronics A Panel Discussion, IPC Engineering Webinar, May 01, 2024

10 Chen, C.; Lee, J.C.B.; Chang, G.; Lin, J.; Hsieh, C.; Liao, J.; Huang, J. The Surface Finish Effect on the Creep Corrosion in PCB, APEX 2012

11 https://www.whichcar.com.au/advice/why-are-ev-chargers-unreliable

12 Sünetci, Ö. ENSURING HIGH QUALITY BY ACCELERATING THE RELIABILITY TESTING OF HOME APPLIANCE BOARDS FOR SIMULATING HARSH ENVIRONMENTS, Proceedings of the SMTA Electronics in Harsh Environments Conference 2023, pp. 99 – 102.

13 Elsinger, H.; Hahn, A.; You, Z.; Henneken, L. (2023, January). Investigation of the Electrochemical Reliability of Conformal Coatings Under High Voltage. Proceedings of the IPC APEX EXPO Technical Conference 2023, San Diego, CA, United States, pp. 1281 – 1304.

14 Henneken, L. (2025, March). High Voltage Temperature-Humidity-Bias Testing of Electronic Materials on the Outer Layer of a PCB – A Round Robin Study and Beyond. Proceedings of the IPC APEX EXPO Technical Conference 2025, Anaheim, CA, United States, pp. 10 – 25.

15 Olbrich, W. (2025, March). An Industry Survey to Report and Compare the Understanding of Failure Mechanisms of and Protection Measures against High Voltage Induced Damages to PCB. Proceedings of the IPC APEX EXPO Technical Conference 2025, Anaheim, CA, United States, pp. 26 – 34.

16 IPC-TM-650, #2.5.7.4, (2023, May) High Voltage Moisture and Insulation Resistance Test of Fabricated Printed Board Test Patterns

17 Armenta-Déu, C.; Sancho, L. Sustainable Charging stations for Electric Vehicles. Eng 2024, 5, 3115–3136. https://doi.org/10.3390/eng5040163

18 IPC e-Mobility Quality and Reliability Group https://www.ipc.org/automotive-and-e-mobility-solutions

19 O'Leary, B.; Frizzell, B.; Schwartz, J.; Rak, S. F. Connecting EV Charging station's Reliability with IPC Electronics Industry Standards, Panel Discussion, The Battery Show, North America 2024, Detroit, MI, Oct. 9, 2024

20 Oct 22, 2018, Tim Jensen, Achieving Increased Solder Joint Reliability and Low Voiding in High Power Applications. EE Power

21 Bixenman, M. (2025, March). Methods Used to Qualify Soldering and Cleaning Materials and Processes. Proceedings of the IPC APEX EXPO Technical Conference 2025, Anaheim, CA, United States, pp. 40 – 55.

22 Li, F.; Ambat, R.; Gupta, K.K. (2025, March). From the Corrosion to Short Circuiting in Electronics: Investigation of the Detrimental Dendrite Development. Proceedings of the IPC APEX EXPO Technical Conference 2025, Anaheim, CA, United States, pp. 56 – 61.

23 Lakkaraju, A. R.; Bixenman, M.; Ambat, R. (2025, March). Investigating the Interplay of Ionic Process Contamination and PCBA Component Design on Water Layer Formation and PCBA Humidity Robustness. Proceedings of the IPC APEX EXPO Technical Conference 2025, Anaheim, CA, United States, pp. 62 – 74.

24 Ambat, R.; Bahrebar, S. (2025, March). Understanding the Crucial Role of Solder Flux Chemistry in Enhancing Humidity Robustness of Electronics. Proceedings of the IPC APEX EXPO Technical Conference 2025, Anaheim, CA, United States, pp. 75 – 81.

25 Elsinger, H.; Hahn, A.; You, Z.; Henneken, L. (2023, January). Investigation of the Electrochemical Reliability of Conformal Coatings Under High Voltage. Proceedings of the IPC APEX EXPO Technical Conference 2023, San Diego, CA, United States, pp. 1281 – 1304.

26 Powell, B.; Johnson, C., (2024, August). Impact of Electric Vehicle Charging station Reliability, Resilience, and Location on Electric Vehicle Adoption, National Renewable Energy Laboratory, Technical Report NREL/TP-5R00-89896, p10.

27 Armenta-Déu, C.; Sancho, L. Sustainable Charging stations for Electric Vehicles. Eng 2024, 5, 3115–3136. https://doi.org/10.3390/eng5040163

28 Guerra, M. (2024, Aug. 6). The EV Charging Experience is Often Awful: Here's Why, www.batterytechonline.com [https://www.batterytechonline.com/charging/the-ev-charging-experience-is-often-awful-here-s-why]

29 ChargerHelp Annual Reliability Report, The State of EV Charging and the Driver Experience, June 2024

Global Electronics Association e-Mobility Quality and Reliability Advisory Group

Insights, points of view, and recommendations provided within this white paper are intended to provide awareness, education, guidance, and strategic direction to the electronics industry regarding design, manufacture, and reliability of charging equipment for e-Mobility.

Global Electronics Association's e-Mobility Quality and Reliability Advisory Group (EVQR) represents a cross-section of the automotive electronics supply chain, collaborating to identify solutions and best practices to assure design, materials, process optimization, and qualifications to achieve reliable and quality-built products while protecting innovation.

To learn more about the EVQR, visit www.electronics.org/automotive-and-e-mobility-solutions

Global Electronics Association hosts a robust library of standards that help businesses produce reliable products. For more information please visit www.electronics.org/meet-your-standards.