
JUNE 2026
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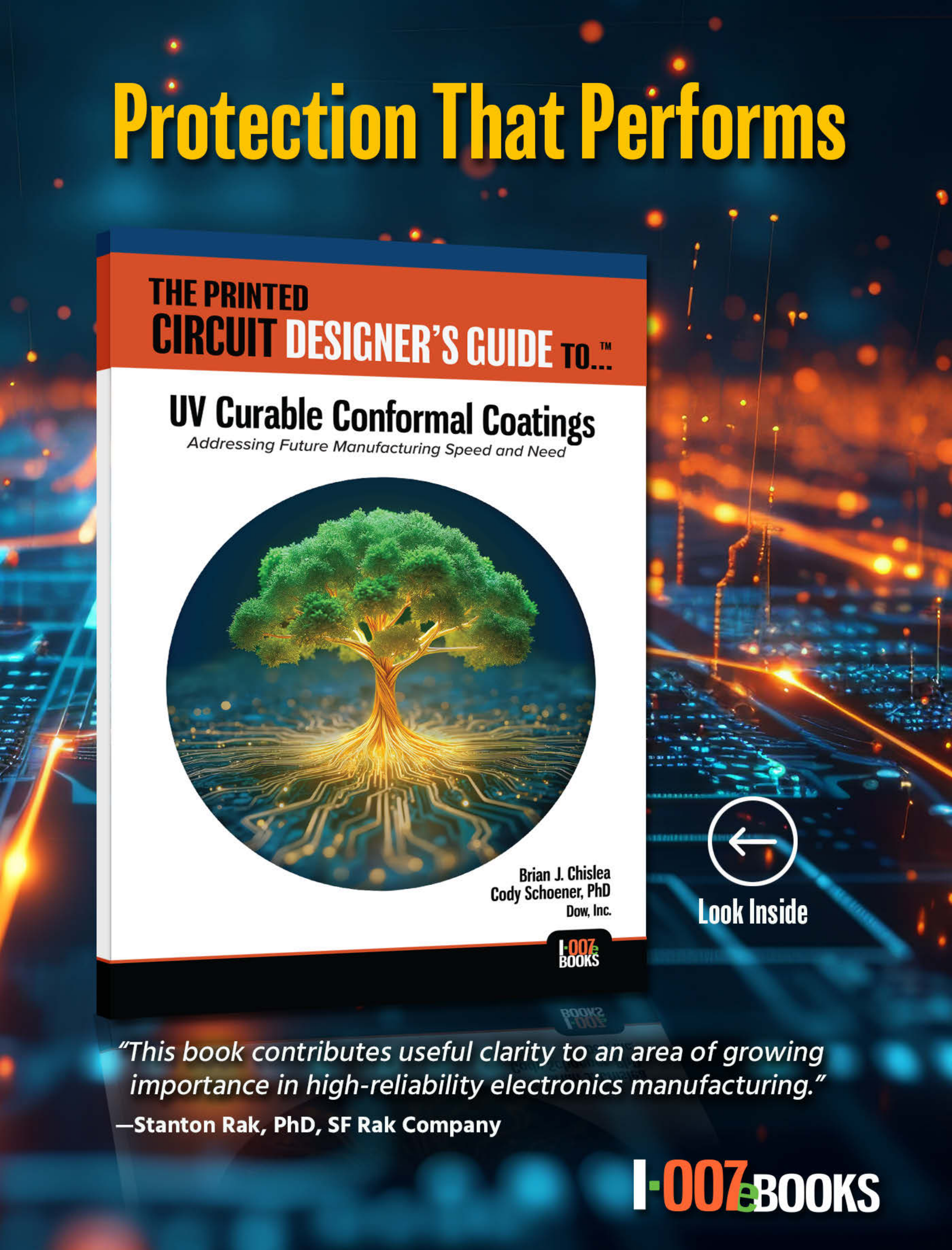
MAGAZINE
CLEANING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Cleaning for Reliability

As assemblies shrink and power densities rise, cleanliness has become the frontline for reliability. This issue explores advanced cleaning chemistries and process validation strategies for today's highly dense electronic assemblies, alongside features on materials reliability, component reclamation, and evolving manufacturing technologies.

June 2026

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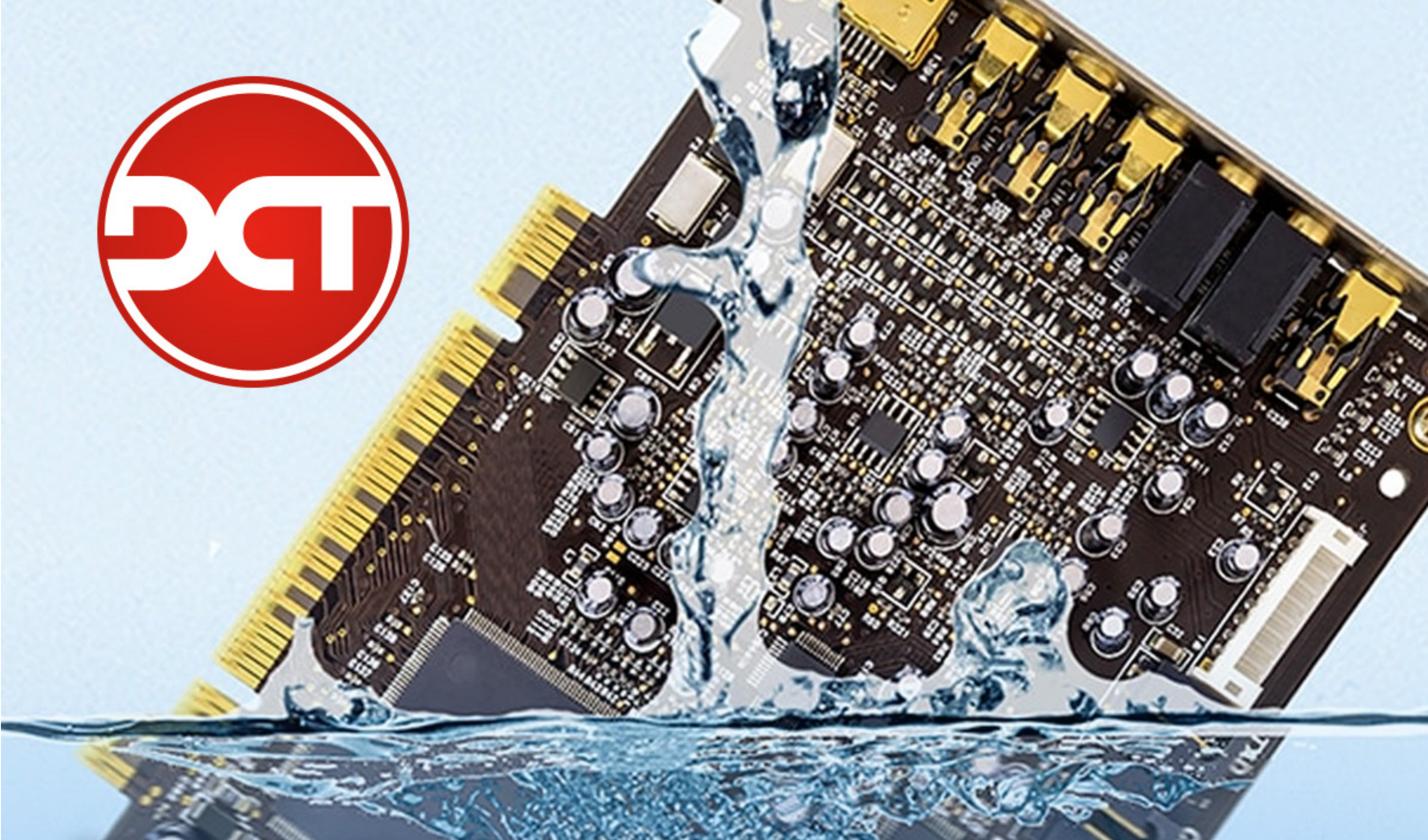
Columns

In Every Issue

SMT007 MAGAZINE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CLEANING WITH Smaller Geometries

BY NOLAN JOHNSON, I-CONNECT007

Cleaning is an under-appreciated, possibly under-considered step in the PCB assembly process. Smaller geometries, combined with increasingly larger bottom-terminated packages for complex components, using ever-smaller pitch sizes, mean that cleaning solutions must drive deeper and rinse out more easily than ever before, and must extract all flux residue and other contaminants.

This idea caught my attention during a Professional Development Course at APEX EXPO 2026, where presentations from Mike Bixenman of Magnalytix, Vladimir Sitko of PBT-works, and Adam Klett of KYZEN addressed the challenges

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of removing flux residues from highly dense electronic assemblies. The information was extremely applicable and relevant.

Changes in PCB feature sizes are affecting everything in cleaning. We're cleaning no-clean fluxes in some cases, because there's zero tolerance for residue. The formulations are changing, and legacy cleaning equipment sometimes cannot perform as required under today's standards. Bixenman, Sitko, and Klett made these challenges very clear, and I knew that the topic needed a much wider audience, so I invited them to contribute to this issue on cleaning.

In his article, Sitko reviews the main types of cleaning equipment, how they work, and what they're best suited for. Klett discusses state-of-the-art cleaning solution chemistries, and Bixenman explains how shrinking geometries and changing component dimensions are creating new challenges. Grouped together, these three articles present a solid explanation of today's cleaning processes.

But that's not all. In his article, Jon Dean of Cold Jet reveals an entirely different implementation to cleaning: dry ice pressure. This process has been perfected in other industries, and now, the company is bringing its approach to electronic assemblies.

Also in this issue, we focus on reliability. Stan Rak's EV reliability series discusses the importance of materials, and MacDermid Alpha's Ebad Rehman contributes an article titled, "Right-Sizing Silver," a deep dive into solder formulations to improve reliability.

On a more celebratory note, we join Andrea Furnari and Dustin Warren to reflect on SPEA's 50-year anniversary. I bet you didn't know that SPEA founder, Luciano Bonari, is still active in the company. We also highlight an exciting new venture for EPTAC, which opened a fabulous training facility in New Hampshire to much fanfare. Find out how this move will have a positive impact on the industry.

From our columnists, Brian Buyea discusses "When Material Choice Defines RF Performance," Nash Bell makes a case for the component reclamation, and Josh Casper ponders "When Traditional Depaneling Methods Reach Their Limits."

Of course, this is all made possible by our advertising partners, whose support has kept our work moving forward for all these years. In addition, look through our help-wanted section in each issue. We continue to live and dream electronics manufacturing (right alongside our passionate and dedicated readers), so enjoy this month's issue, and we'll see you again in July.

Nolan Johnson is managing editor of *SMT007 Magazine*. Nolan brings 30 years of career experience focused almost entirely on electronics design and manufacturing. To contact Johnson, **click here**.

BY MIKE BIXENMAN, MAGNALYTIX

Why Cleanliness Is a Critical Reliability Driver

The demand for more functionality is less space is rapidly increasing design density in electronic assemblies. Fine-pitch components, multilayer architectures, and elevated power densities are now standard across industries ranging from automotive to medical and aerospace. While these advancements result in significant performance gains, they also introduce a less visible, but highly consequential, risk: contamination.

In highly dense electronic assemblies, even microscopic flux residues can affect long-term reliability. Failure mechanisms that were once rare in larger geometries, such as electrochemical migration (ECM), dendritic growth, and leakage currents, are increasingly common. Cleanliness is no longer a secondary process consideration, but a primary factor of product performance and durability. Highly dense assemblies are uniquely vulnerable to flux residues and contamination, which directly contribute to reliability risks.

Highly dense electronic assemblies are characterized by a combination of miniaturization and complexity. Common attributes include:

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TABLE 1: RISKS ASSOCIATED WITH HIGHLY DENSE INTERCONNECTS

Risk	Severity	Likelihood	Impact
Ionic contamination → leakage current	High	High	Reliability failure
Electrochemical migration → shorts	High	Medium	Catastrophic failure
Corrosion of metals	Medium	Medium	Latent failure
Reduced SIR	High	High	Signal integrity issues
Conformal coating adhesion failure	Medium	Medium	Moisture ingress
High-frequency impedance changes	Medium	Low	Performance degradation

- Fine-pitch components (≤0.5 mm), including microBGAs, CSPs, and ultra-miniature passives (01005/008004)
- High component density per unit area
- Reduced conductor spacing across both external and internal layers
- Stacked or embedded component architectures
- Multiple reflow cycles and complex thermal profiles
- High-speed and/or high-voltage operating conditions

These design features compress the physical spacing between conductors and increase the likelihood that residues will accumulate in confined areas. As a result, contaminants have a greater opportunity to form conductive pathways, especially under environmental stress.

Reduced Spacing Amplifies Electrical Risk

As conductor spacing decreases, the voltage required to initiate electrochemical activity also declines. Ionic residues that originate from flux activators, handling, or environmental exposure can dissolve in the presence of moisture and create unintended conductive paths. In dense assemblies, these conductive paths may span only microns, yet still be sufficient to trigger failure.

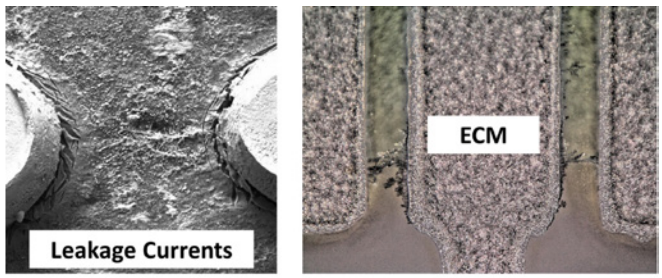

Figure 1: Leakage currents and ECM failures.

Residue Entrapment Under Bottom-terminated Components

Bottom-terminated components such as QFNs, LGAs, and microBGAs present a significant challenge for residue removal. Their low standoff heights create cavities where flux residues can become trapped during reflow. Furthermore, as pad sizes increase and pitch decreases, flux volume tends to rise, increasing the likelihood of residue accumulation. These residues can effectively bridge adjacent conductors beneath the component, often undetectable through conventional inspection methods, creating latent reliability risks.

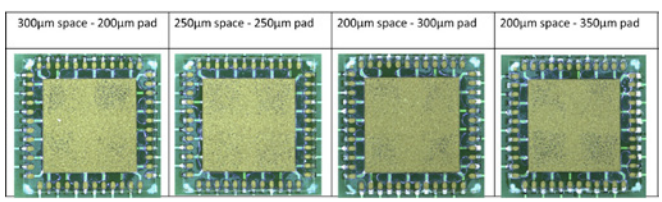

Figure 2: Flux residues under BTC as a function of pad size and pitch.

Thermal and Power Density Effects

Modern assemblies frequently operate at higher power densities, generating more heat during operation. Elevated temperatures accelerate chemical reactions and enhance moisture diffusion, increasing the reactivity of otherwise benign residues. Under these conditions, contaminants that might remain stable in low-power applications can become active contributors to corrosion, leakage, and electrochemical migration.

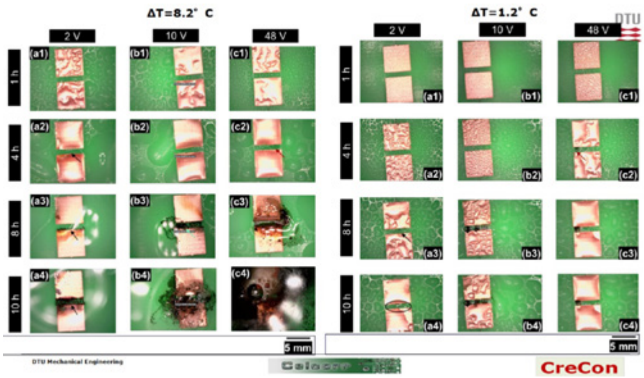

Figure 3: Corrosion potential as a function of voltage.

The Reality of No-clean Flux

No-clean fluxes are widely used in high-density assemblies to streamline processing and minimize cleaning requirements. However, the term “no-clean” can be misleading. While these materials are formulated to leave minimal and generally benign residues, their performance depends on environmental conditions and electrical bias. Under high humidity and voltage, even low levels of ionic content can promote leakage and failure between closely spaced conductors.

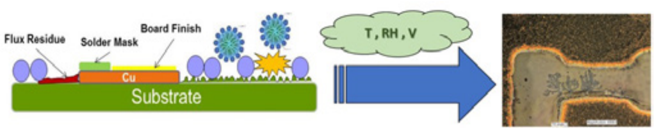

Figure 4: Flux contamination under environmental stress.

Several different failure mechanisms are driven by residues, including electrochemical migration (ECM), dendritic growth, leakage currents, and corrosion. We’ll look at each of these three causes.

Electrochemical Migration (ECM)

ECM, a critical failure mechanisms in dense assemblies, occurs when ionic residues and moisture combine under electrical bias to form conductive filaments between conductors. Key accelerators for ECM include high humidity, DC bias, tight conductor spacing, and residues containing halides or weak organic acids. Notably, ECM failures are often latent, emerging only after prolonged environmental exposure rather than during initial testing.

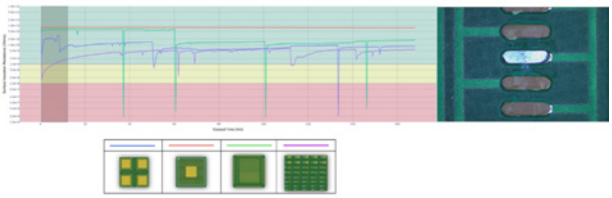

Figure 5: Leakage currents from partially cleaned flux residues.

Dendritic Growth

Closely related to ECM, dendritic growth involves the dissolution and redeposition of metal ions, forming tree-like conductive structures between conductors. This phenomenon is particularly prevalent beneath bottom-terminated components where residues are difficult to remove.

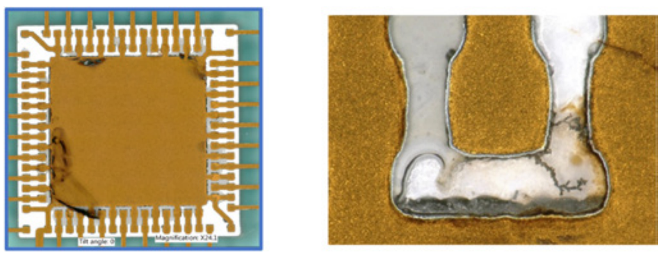

Figure 6: Dendritic growth from flux residue under a dual row QFN.

Leakage Currents and Signal Integrity Issues

Even in the absence of catastrophic failure, contamination can degrade electrical performance. Common effects include increased leakage currents, impedance instability, timing errors in high-speed circuits, and noise coupling between adjacent conductors. For advanced electronics, these subtle degradations can be just as problematic as outright failures.

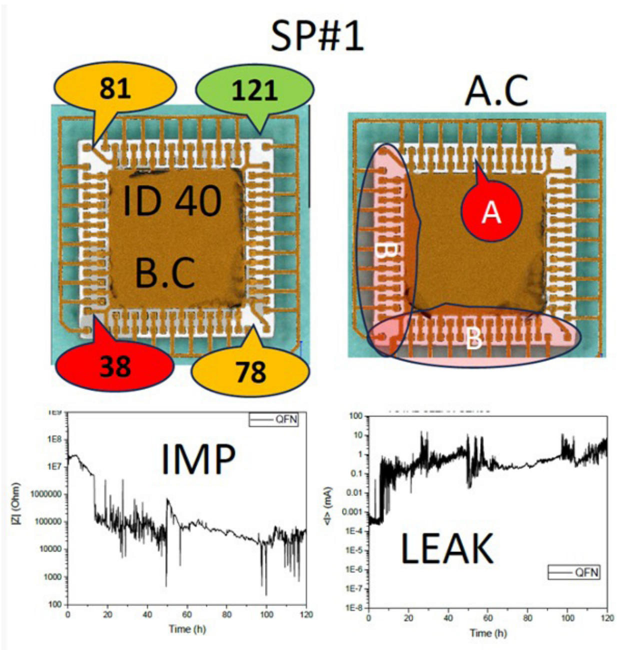

Figure 7: Flux contamination lowers impedance while increasing leakage.

Corrosion

Flux residues can also initiate localized corrosion, particularly when halides or acidic compounds are present. Over time, this can weaken conductive paths and compromise long-term reliability.

Industry standards such as J-STD-001 provide general cleanliness guidelines, but they often fall short for highly dense assemblies. In practice, manufacturers must adopt enhanced controls that may include material compatibility assessments and/or application-specific cleanliness criteria.

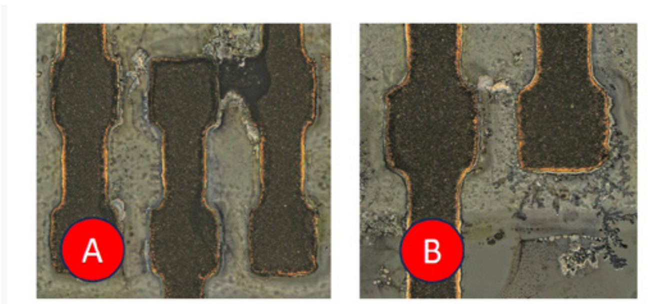

Figure 8: Conductive pathways that compromise reliability.

The Role of Surface Insulation Resistance (SIR) Testing

SIR testing is a critical tool for evaluating the electrical impact of residues under real-world stress conditions. By exposing test circuits to elevated temperature, humidity, and electrical bias, SIR testing accelerates failure mechanisms and provides insight into long-term reliability.

Typical test conditions include:

- 40°C temperature
- 90% relative humidity
- 5V electrical bias
- 168-hour duration

SIR testing is particularly valuable for flux and material qualification, process validation and change control, and high-density reliability assurance. Unlike functional testing, SIR uses dedicated test boards designed to evaluate contamination effects, providing a controlled, repeatable assessment of process chemistry and cleanliness.

Process Control Strategies for Dense Assemblies

Ensuring cleanliness in highly dense assemblies requires a holistic approach that integrates material selection, process optimization, and validation.

- **Material selection:** Use fluxes with proven SIR performance, select low-residue solder pastes, and verify compatibility of cleaning agents with component materials.

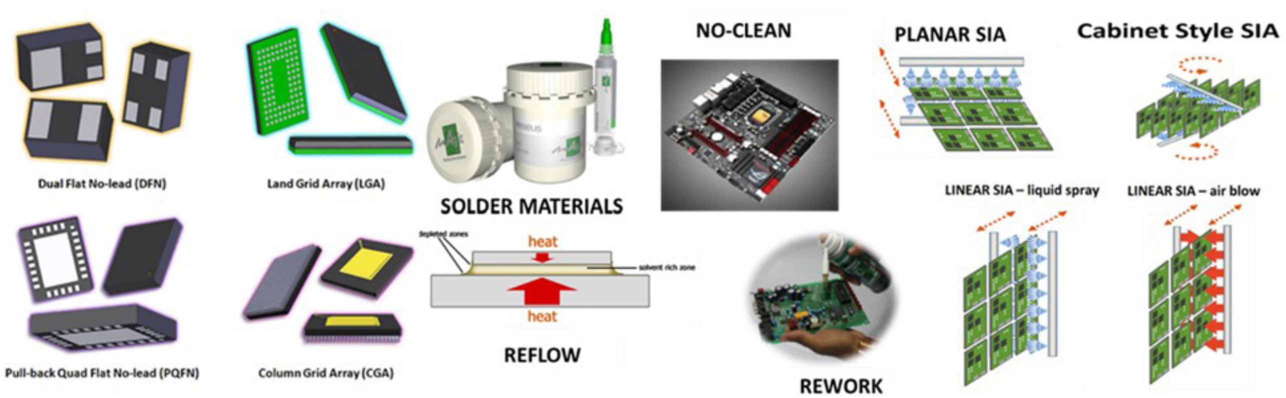

Figure 9: SIR testing the effects of flux residues.

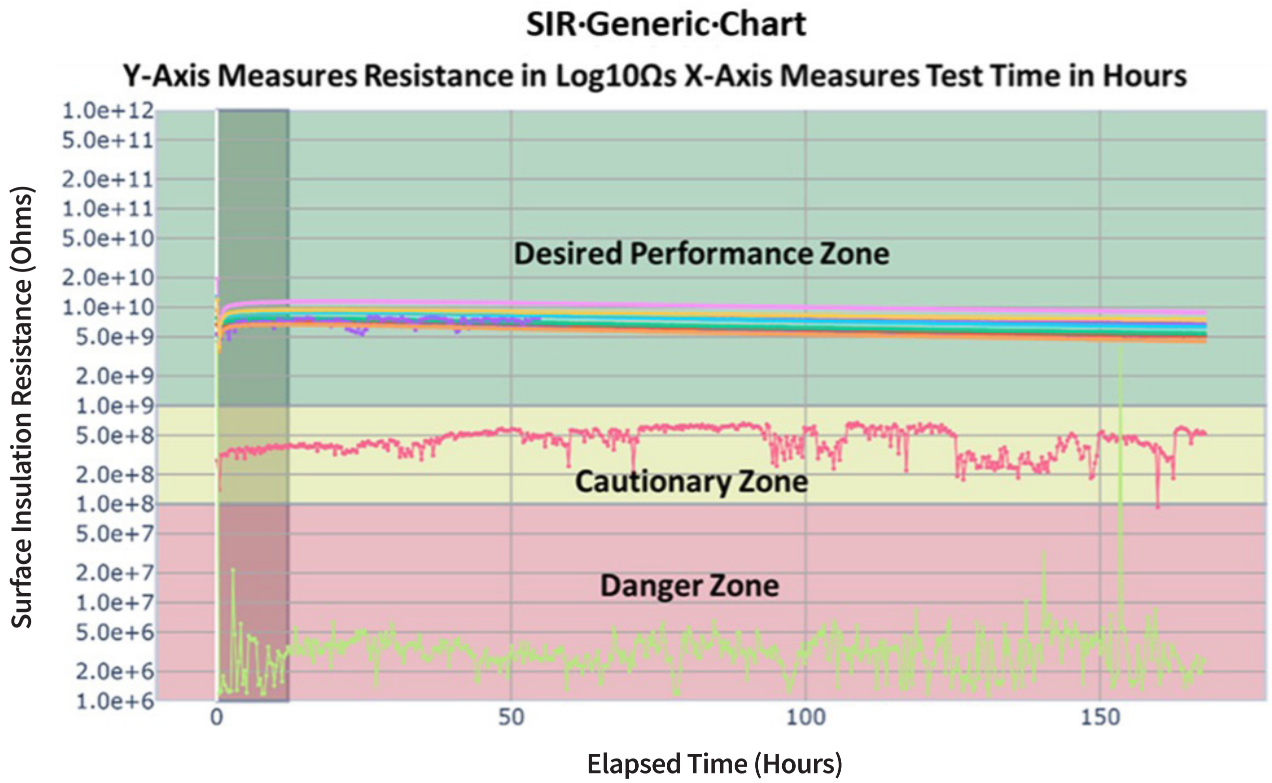

Figure 10: Insulation resistance as a function of time.

- **Assembly optimization:** Refine reflow profiles to minimize residue entrapment, optimize stencil design to control paste volume, and implement strict handling procedures to reduce contamination.
- **Cleaning validation:** Where cleaning processes are employed, SIR testing provides objective data on residue removal effectiveness, process consistency following changes, and electrical safety of any remaining residues.
- **Reliability implications:** Highly dense assemblies operate with minimal tolerance for contamination. As a result, cleanliness has a direct and measurable impact on field failure rates, warranty costs, long-term product stability, high-speed signal performance, and safety-critical system reliability.

In sectors such as aerospace, medical devices, automotive, and defense, these factors are not optional considerations; they are fundamental requirements.

Conclusion

As electronic designs push the limits of density and performance, traditional assumptions about flux residues and cleanliness are no longer sufficient. What was once considered acceptable can now pose significant reliability risks. In highly dense assemblies, cleanliness must be treated as a critical design and process parameter. Through a combination of advanced testing, disciplined process control, and a deeper understanding of contamination-driven failure mechanisms, manufacturers can better ensure the long-term reliability of their products. By mastering the principles outlined here, professionals can better design, build, and qualify assemblies that meet the demanding requirements of today's technology landscape. **SMT007**

Mike Bixenman is VP/CTO at Magnalytix.

BY VLADIMIR SITKO, PBT-WORKS

Balancing Performance, Cost, and Reliability When Selecting a Cleaning Machine

Even the most advanced cleaning chemistry requires an effective delivery system, so selecting the appropriate cleaning machine is crucial. Cleaning equipment must do far more than simply wash boards. As assemblies move toward lower standoff heights, finer pitches, and increasingly complex geometries, the equipment must deliver chemistry into confined spaces, reliably remove contamination, rinse thoroughly, and dry completely, all while balancing throughput, operating costs, and long-term reliability requirements.

This article examines the key engineering considerations for selecting cleaning equipment to clean highly dense assemblies. We will consider spray dynamics, machine configurations, process control, validation methods, and trade-offs among performance, cost, and manufacturing efficiency.

Cleaning Equipment as a Reliability System

In modern electronics manufacturing, cleaning machines are no longer viewed as simple post-soldering tools. They are engineered process systems designed to support long-term product reliability. An effective cleaning machine must be capable of:

- Delivering controlled mechanical energy
- Transporting cleaning chemistry into tight component geometries
- Maintaining optimal wash chemistry conditions
- Removing both ionic and non-ionic contamination
- Thoroughly rinsing away wash chemistry and residues
- Completely drying assemblies without trapped moisture

For high-density assemblies, successful cleaning depends on integrating all these functions. The cleaning process itself should consist of four primary phases: wash, rinse, DI rinse, and dry.

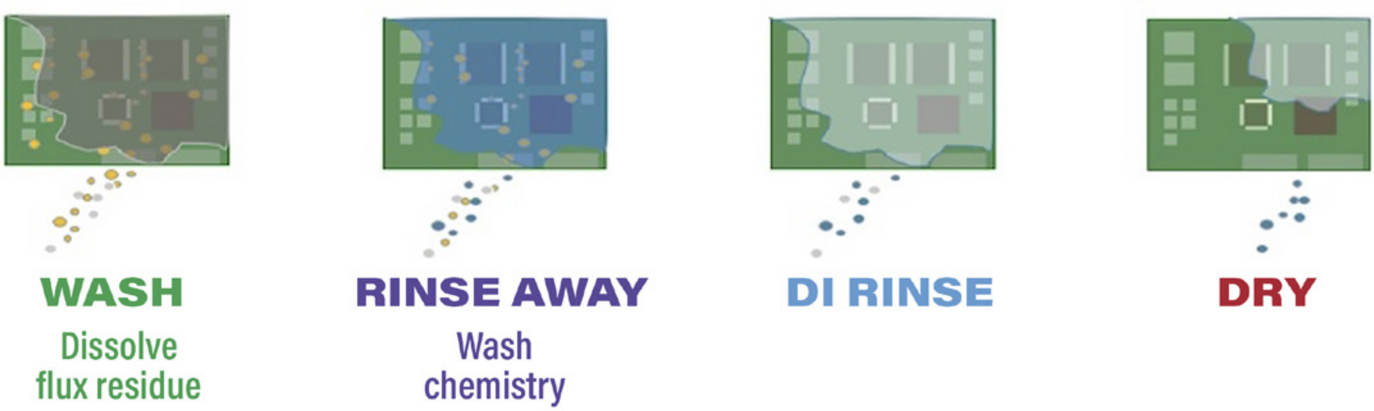

Figure 1: The four phases of the cleaning process.


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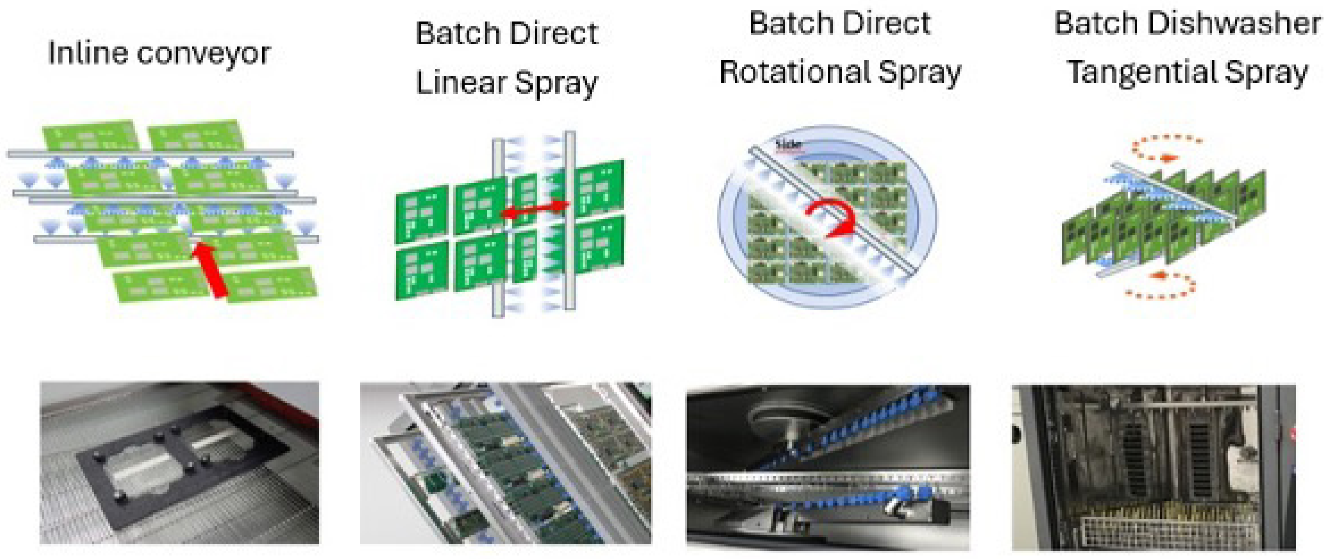


Figure 2: Different designs of spray kinematics in cleaning machines for electronic assemblies.

The Challenge of Cleaning Highly Dense Assemblies

Because of limited access beneath components, bottom-terminated components (BTCs) such as QFNs, LGAs, and microBGAs, create some of the most challenging cleaning environments in electronics manufacturing. With standoff gaps frequently below 100 µm and often less than 2 mils, flux residues can completely flood the cavities beneath these components, restricting outgassing pathways and trapping contamination beneath the termination.

The cleaning process beneath low-standoff components follows several sequential steps:

1. Wet the residue.
2. Soften residue into a gel-like state.
3. Dissolve the residue.
4. Establish flow channels beneath the component for residue removal.

Removing these residues requires significantly more than chemical solvency alone. Effective cleaning depends on high-energy spray impingement, optimized nozzle geometry, proper fluid dynamics, and sufficient chemistry exchange beneath the component.

Not all cleaning systems can deliver the required energy transfer.

Achieving this requires careful optimization of nozzle design, spray angle, flow rate, orifice geometry, and spray distance. The effectiveness of the process depends on how efficiently fresh cleaning chemistry reaches the dissolution site and removes saturated chemistry from beneath the component. This becomes particularly critical for larger bottom-terminated packages.

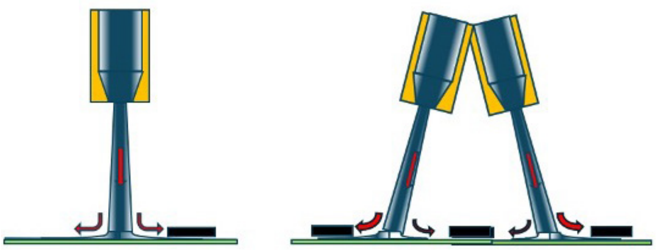


Figure 3: Direct spray against the surface.

Direct Spray vs. Tangential Spray Systems

To maximize energy transfer beneath components and minimize spray shadowing from neighboring devices, direct spray systems have demonstrated superior cleaning performance in many high-density applications.

In direct spray systems:

- Spray beams create omnidirectional flow along the board surface
- Fluid flow is optimized for penetration beneath components
- Bidirectional scanning improves cleaning uniformity across the assembly

By comparison, many batch systems use tangential spray configurations that prioritize basket-based processing and higher assembly counts per cycle. While these systems improve throughput flexibility, they often reduce kinetic energy transfer at the board surface, limiting effectiveness beneath BTCs.

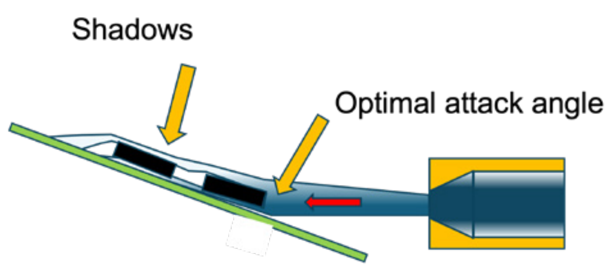


Figure 4: Tangential spray system.

Testing performed using specialized glass test boards with 60 ±5 µm gaps demonstrates the performance differences between direct and tangential spray systems. Results show that tangential spray systems typically require significantly longer wash times to remove residues beneath low-standoff components, especially during the final stages of cleaning.

Complex Flux Chemistries Increase Process Demands

Modern no-clean fluxes are specifically engineered to remain stable after reflow, but under thermal exposure, they may polymerize, harden, or become increasingly difficult to remove. Effective removal requires:

- Proper solvent systems
- Controlled wash and rinse temperatures
- Adequate agitation to maintain chemical stability
- Sufficient spray energy at the point of dissolution

Maintaining these parameters consistently over time requires ongoing process optimization and feedback. One of the greatest challenges, however, is that the most critical cleaning areas are directly beneath BTCs, making them often impossible to inspect directly.

The Value of Glass Test Vehicles

Glass test boards and transparent test components provide valuable insight into residue behavior beneath BTCs. Glass QFN chiplets, particularly when integrated into surface insulation resistance (SIR) test vehicles, allow engineers to visually evaluate flux entrapment, cleaning effectiveness, residue distribution, and process variability beneath components.

These tools provide a highly effective complement to traditional SIR testing by making contamination visible during environmental stress testing.

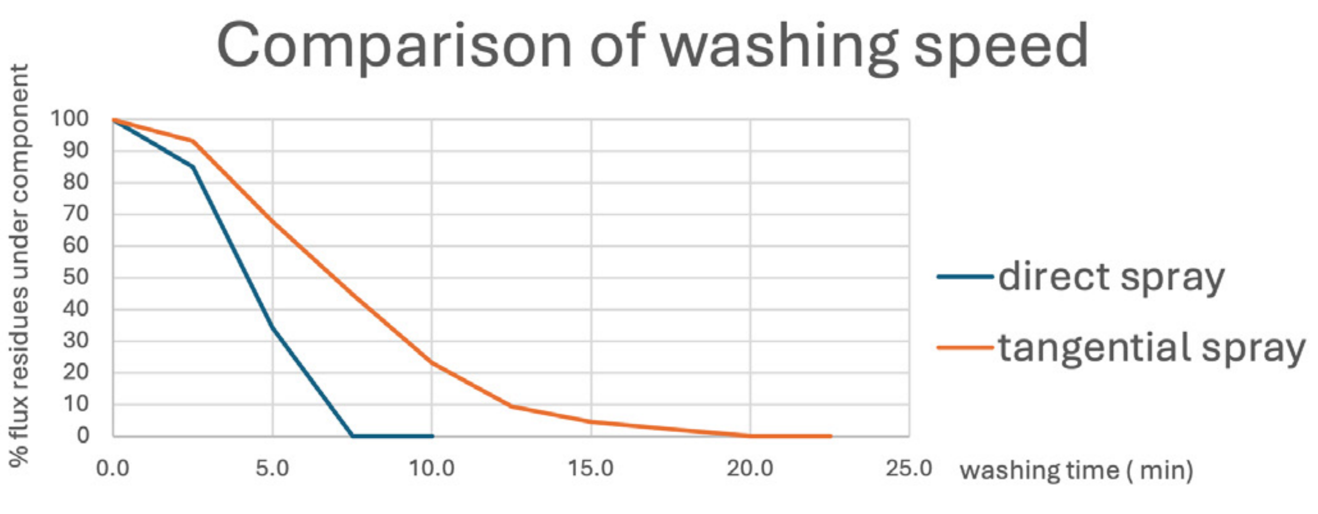
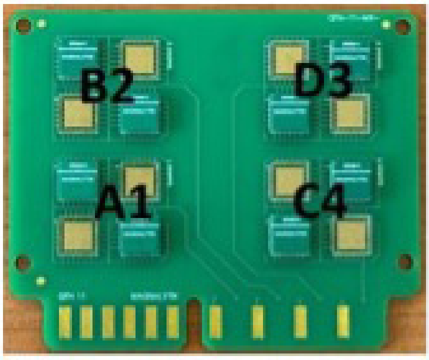


Figure 5: Comparison of washing speed of direct vs. tangential spray.



Quadrant	Component	Pitch (mm)	Pad-to-Pad Spacing (mils)	Pad Width (mils)
1	QFN 48	0.5 mm	12	8
2	QFN 48	0.5 mm	10	10
3	QFN 48	0.5 mm	8	12
4	QFN 48	0.5 mm	4	14

Figure 6: Test boards QFN11 with glass test chine QFN48_11.

The QFN11 test board, for example, incorporates multiple pad-spacing configurations that allow assemblers to examine how cleaning performance varies across different geometries and process conditions.

These transparent structures enable direct observation of the effects of cleaning machine design, chemistry selection, and process optimization

Cleaning Machine Categories

Cleaning systems for electronic assemblies generally fall into two primary categories: batch and inline systems. Both require integrated wash, rinse, and drying capability, but each offers distinct operational advantages.

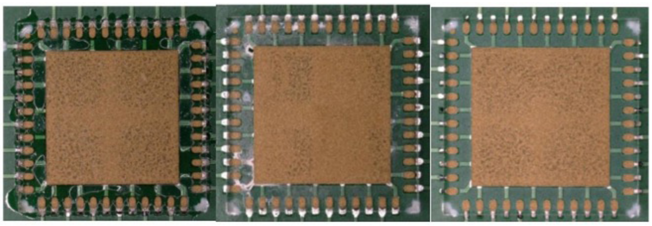


Figure 7: Glass test chip QFN 11 can be easily inspected.

Batch Cleaning Systems

Single-chamber batch systems perform washing and rinsing in a single process chamber. Two common configurations are used. The first uses rotating nozzles or nozzles with a tangential spray system. Boards are placed in baskets. Drying is accomplished with high-flow fan nozzle banks. There is no air knife system.

The second batch cleaning approach uses a linear moving nozzle system, utilizing direct spray impingement. Boards are secured in dedicated fixtures; air knives are situated between wash and rinse stages. These systems often include advanced rinse water reclamation systems and mechanical and chemical filtration systems. Modern systems may also incorporate:

- Ion exchange filtration for rinse water purification
- Activated carbon filtration to remove non-ionic contaminants
- Enhanced drying systems using air knives to reduce evaporation load

Figure 8: Diverse batch cleaning machines with a rotation nozzle system and tangential spray.

Figure 9: Batch machines with linear moving nozzles.

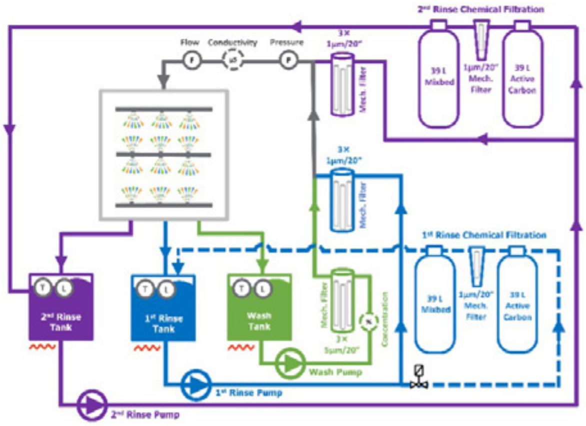


Figure 10: Piping diagram of the batch cleaning machine with closed-loop rinsing, with two cascade rinse steps.

Because air knife systems remove excess water mechanically before evaporation, they shorten drying time and reduce staining from residual droplets.

Batch systems offer greater flexibility for low- to medium-volume production, longer chemistry effectiveness, and dwell times for assemblies requiring extended soak cycles. Limitations include lower throughput, higher drag-over between wash/rinse stages, and cleaning performance that may heavily depend on nozzle design and spray dynamics.

Inline Cleaning Systems

Inline systems transport assemblies continuously through dedicated wash, rinse, and drying zones. These systems offer high throughput, repeatable cleaning profiles, reduced manual handling, and consistent multistage processing. When properly configured, inline systems are highly effective for high-density SMT applications.

Inline systems provide excellent throughput and consistent process control, making this approach strongly suitable for automotive, telecom, and industrial electronics production. Inline systems are often preferred in high-volume manufacturing environments where process consistency and throughput are critical. Limitations, on the other hand, can include a larger equipment footprint, higher capital investment, and a dependence on stable upstream production flow. Also, additional fixtures or pallets may be required for lightweight boards.

Engineering Criteria for Machine Selection

Component geometry and standoff height: Because the cleaning machine must generate sufficient mechanical energy to penetrate BTC cavities, dense-pitch structures, and dense component clusters, critical performance variables in the machinery include nozzle design, spray pressure, and fluid flow patterns.

Flux compatibility: Cleaning systems must align with flux solubility characteristics, including activa-

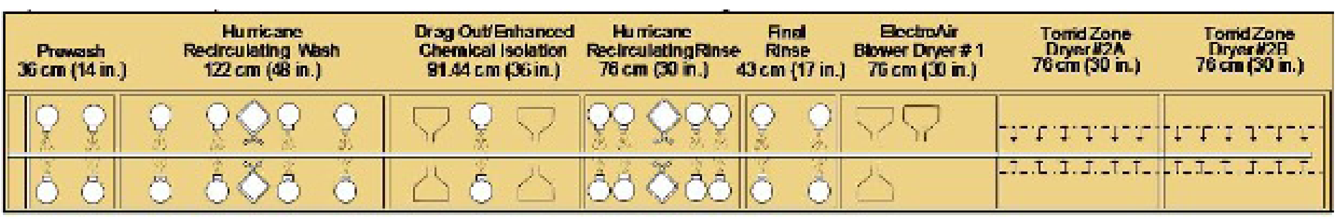


Figure 11: Schematic of a multi-stage PCB cleaning and drying system.

tion temperatures and residue hardness. Improper compatibility matching can result in incomplete cleaning or even material damage.

Throughput and production requirements: Machine selection should account for production volume, takt time, and peak capacity demands. Batch systems offer more flexibility, while inline systems prioritize speed and consistency.

Environmental and regulatory considerations: Additional environmental factors to consider include wastewater handling requirements, energy consumption, chemical handling protocols, and labor requirements associated with loading and unloading assemblies.

Process monitoring and control: Highly dense assemblies require tighter process controls. For example, tighter tolerances are often seen with wash temperature, chemistry concentration and saturation, spray pressure and flow, conveyor speed, rinse water purity, and drying efficiency. Advanced monitoring systems improve consistency and support long-term reliability assurance.

Validation and Qualification

Selecting a machine is only the beginning. Validation is essential to confirm process capability, and where test vehicles come into play. Validation should use representative assemblies containing BTCs, fine-pitch devices, known contamination loads, and glass inspection structures, where applicable.

Validation methods should include optical inspection, ion chromatography (IC), SIR testing and Under-component residue inspection.

Process window optimization should establish minimum effective wash temperatures, optimal chemistry concentrations, required spray pressures and flow rates, maximum conveyor speeds or minimum process durations.

Finally, environmental stress testing should confirm performance under elevated humidity, thermal cycling, and electrical bias conditions

Common Pitfalls in Machine Selection

Several common mistakes made during the equipment selection process can and will compromise cleaning performance and long-term reliability. These issues frequently contribute to latent field failures that may not appear during initial testing:

- Selecting equipment based solely on cost
- Assuming all no-clean fluxes can forego cleaning
- Underestimating the difficulty of cleaning BTCs
- Failing to validate using real production hardware
- Ignoring evolving package technologies
- Overlooking chemistry-machine compatibility
- Neglecting drying performance beneath components

Conclusion

Selecting a cleaning machine for highly dense electronic assemblies is a strategic engineering decision that directly impacts product reliability, process stability, and manufacturing efficiency.

The right equipment enables effective residue removal even within the most challenging geometries. The wrong choice can lead to incomplete cleaning, latent failures, increased field returns, and reduced customer confidence.

By understanding the interaction between assembly design, cleaning chemistry, spray dynamics, process control, and validation methods, manufacturers can build cleaning processes that support long-term reliability and compliance with standards such as J-STD-001 Section 8.

As electronic assemblies increase in density and complexity, cleaning equipment selection becomes far more than a capital purchase decision; it becomes a critical element of reliability engineering. **SMT007**

Vladimir Sitko is CEO of PBT-works.

BY NOLAN JOHNSON, I-CONNECT007

50 Years of Successful SPEA Testing Solutions

Luciano Bonaria, 1986

SPEA is celebrating 50 years of test innovation, building on the vision of founder Luciano Bonaria, whose zero-failure philosophy continues to shape the company today. In this interview, Andrea Furnari, vice president of sales and marketing (based in Volpiano, Italy), and Dustin Warren, vice president and regional director (based in Dallas, Texas), reflect on that legacy while pointing to what's next, from expanding global support to new developments in AI-driven test and high-performance platforms.

With a strong commitment to R&D and a growing presence close to customers worldwide, SPEA is positioning itself for the next phase of electronics manufacturing, where complexity, speed, and reliability are more critical than ever.

Andrea, there's a lot to celebrate in 50 years. How did SPEA begin?

Andrea Furnari: I would say it is a classic high-tech romantic story that starts in a garage. Luciano Bonaria, founder and president, started working in the electronics sector for General Electric in 1974. He recognized the historical moment—the birth of modern electronics—so he decided to create his own tester architecture to satisfy the huge demand for electronics at that time.

MS2
Molten Solder Surfactant
MS2 201 LF
LEAD-FREE (RoHS COMPLIANT)
PK METAL
MS2
MS2 101 PB
PK METAL
TWO WAY POWER

Back then, all the testers were very slow; they integrated instrumentation into a mainframe to create a unique instrument. Luciano had clever and innovative ideas to engineer multifunctional automatic test equipment, combining all the instrumentation: power and digital into one unique tester.

After these experiences, he began collaborating with Olivetti in 1976, where he proposed the solution to test their electronics. So, everything started from that moment, and since then, all new development at SPEA has been fully dedicated to creating electronics that do not fail in the field. That's the purpose of the fully integrated automatic test equipment that he designed at the time. Today, the logic and the purpose are still the same. But of course, the technology is completely different now.

When you look back, what core values or company culture features persist? How has Luciano's influence carried through over 50 years?

Furnari: This is a very good question because the recipe for the company is meticulous attention to detail. Precision drives everything we do at SPEA. Every feature we develop, and every task our technicians perform, is designed with the highest accuracy.

This is part of the DNA that comes from Luciano. He continues to play a vital role in the company. He is one of the main designers in our R&D team and the whole department continues to operate on the foundational concepts coming from Luciano.

It's not just Luciano who's been with SPEA a long time. With test equipment there seems to be a trend toward loyal, long-term customers, and SPEA shows it as well. What keeps companies with SPEA for so long?

Furnari: We still have customers using SPEA equipment that is at least 20 to 30 years old. The robustness of the tester, and of course, the idea of having a supplier that is very close to them, is something that they really appreciate. That's the main ingredient. We provide our customers with a comprehensive range of services that goes beyond standard market offerings.

We've opened new offices everywhere, where the customers' facilities are based. Among the others, we have new offices in Thailand and the Philippines. These are not only sales and service representative offices; these are an application development center, service center, and a sales center. Now we can provide 360-degree support to the customer. We're doubling office space in China and Singapore, and we opened the Santa Clara, California, office one month ago. Being close to our customers makes working together easier. It helps us provide faster support with expert engineers and the spare parts.

One of the keys to maximizing uptime for your customers is great local support. Dustin, it's a very competitive market, and maintaining return on investment for your customers is imperative. What's it like taking care of SPEA customers right now? What are the challenges?

Dustin Warren: Our customers in aerospace, medical, EV, and other sectors are dealing with really complex assemblies, things that aren't off the shelf. Our DNA in test excellence, which Luciano developed 50 years ago, gives us flexibility and partnership that some companies aren't able to provide their customers. We have cutting-edge, high-precision engineering from Italy, plus 50 years of test excellence. We have a local hands-on approach to problem-solving, which includes all the applications engineering, as well as support for the software and hardware, here in each office.

We don't just sell the machine here; we guarantee that their proprietary electronics will be defect-free when we're done testing. That's a bridge of trust that we built with our systems, even as we outperform many of our competitors in speed, fault coverage, and zero defects. We provide a very clear ROI that most of our American customers are looking for. That combination of test excellence, ROI, and partnership with them has really allowed us to succeed here in America.

You have possibly two customers to convince: the contract manufacturer and the OEM. When we consider current supply chain dynamics that might be affecting your parts, test service customers, and the assembly components required by the OEM, how do you keep your service local, smooth, and effective?

Warren: We look at that as a dual trust. Sometimes the CM will come to us and say, "Hey, we have this board," and we know this board because we've already been working with the OEM. That dual relationship has been critical for us, particularly in high-volume, very specific, and complex products.

But it's important that we support them. We just opened the Santa Clara office to provide local parts and service support for the West Coast, where we have a very large presence. We also have offices in Tyler, Texas, and in Phoenix. We spread our people and the parts around. We have a tight working connection with Italy as well. We're able to support customers locally, and when we can't, we're on the phone with Italy.

Andrea, we've seen the supply chain in all conditions over the years, from running very smoothly, very diverse and duplicated, to becoming overly optimized into a particular global region. What challenges does SPEA face in supporting customers on a global level? How do you manage such a network?

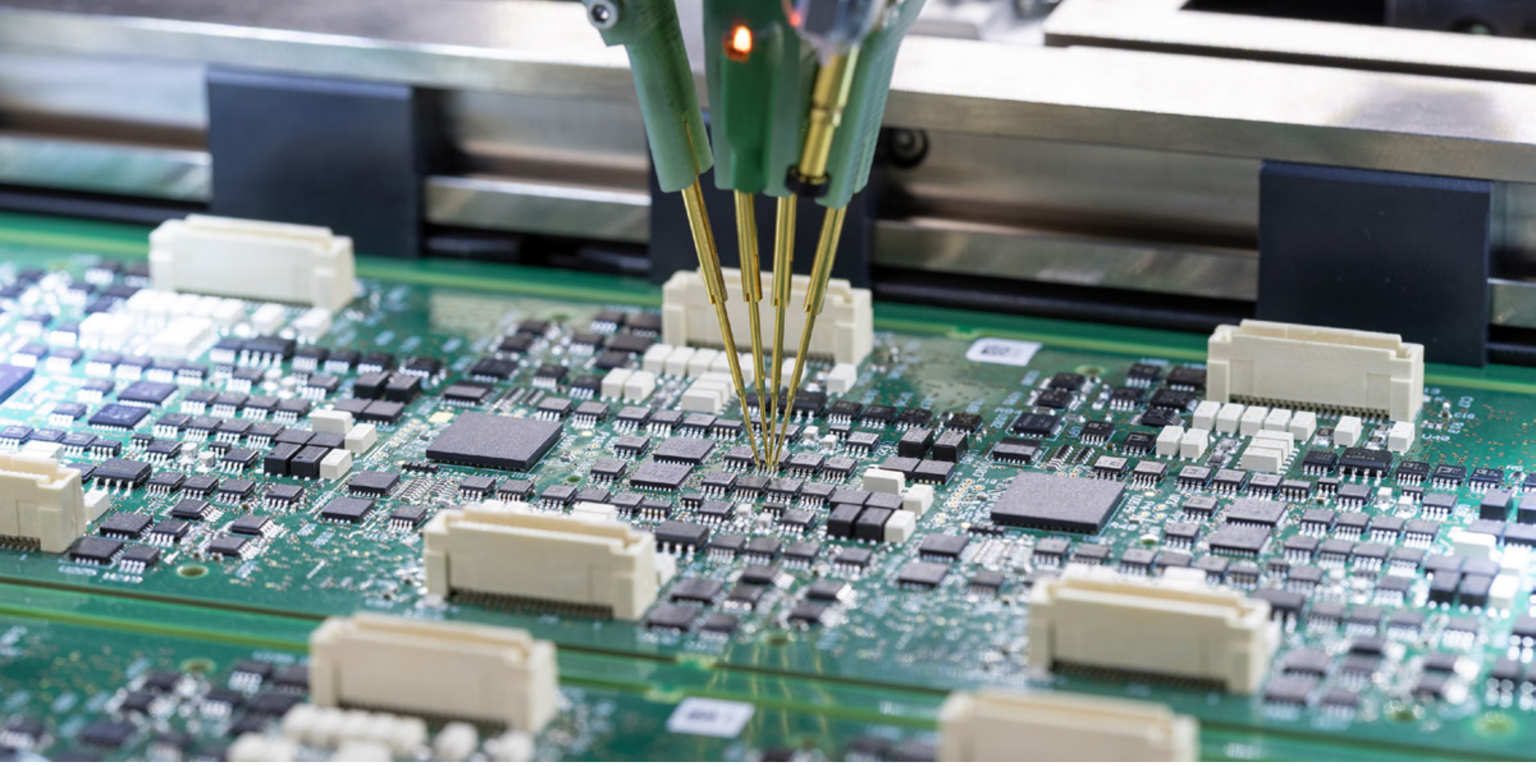
Furnari: We invest in new technology. We are a technology company, and we can design equipment that does not exist on the market. Our customers are looking for something very enhanced in terms of technology and features. For us, the priority is to lead the way in technology and shape the future of market demands. We have about 65% of the company devoted to R&D, while the remaining resources are in manufacturing. We have the power to design and continuously improve our products.

That is a significant amount of company resources devoted to research and development, for sure. Was there a lesson that SPEA learned in its 50-year history that set up that sort of R&D heavy expectation?

Furnari: That's exactly the point. In 50 years, we've seen different steps and market situations that led us to invest in new technology and expand into new markets. In 1996, we decided to invest in semiconductors by creating a new automatic tester to enter the semiconductor market.

This was very strategic; we created electronics to check the power consumption of the battery in a Swatch, and Philips Semiconductors, which manufactured those chips, became the first semiconductor customer. Thanks to this development, we established our presence in that sector.

Another lesson we learned is about new technology. Around 1995, the testing technology was limited to the classic ICT (in-circuit test) machine with a bed-of-nails. That's when we decided to invest in new automation and build the world's first flying probe machine. We created our own technology to test at very high speed. We used the linear motor technology, which was very new at the time, and had been used in several semiconductor machines. Of course, today all our equipment relies on the linear motor technology, a breakthrough that was very disruptive at that time.



I was working in a test equipment company at that time, and we were starting to use linear motors instead of worm gears. That was a pivotal moment.

Furnari: In 1996, ATE manufacturers were using brushless motors and screw drives. With the linear motor, we completely changed the paradigm of automation. After that, the speed and performance were completely different.

Dustin, all that R&D is obviously aimed toward developing what OEMs and test companies need. What are the trends in the U.S.?

Warren: We're seeing a lot of growth in several market sectors. On the semiconductor side, power electronics is absolutely taking off. Because of semiconductor packaging, electrification, aerospace, and automotive needs, there's a huge demand for power module testing with high-voltage capabilities. Beyond automotive, there's an absolute explosion in data center and high-density computing. So, a lot of our work on the semi side is geared towards that.

The boards being produced today are more complex: They're power hungry, there are more nets, and there are more discrete devices on every board. Customers are looking to test super complex boards with zero defects at a speed they need to meet the demand.

There's our zero tolerance for failures. It's in our DNA to ensure zero escapes. Andrea was talking about linear motors; that translates to speed and accuracy. In addition, our flying probes now use granite bases. Granite allows us to fully utilize the acceleration and deceleration capabilities of those linear motors, and that means we can drive them well beyond what's possible with a lead screw.

But it's more than just fast. We also deliver the precision required. We can measure the very tiny packages and hit those with the precision and accuracy needed.

Looking out three years, what do you see changing in the U.S. market?

Warren: Reshoring will be huge. What we've seen in the U.S. market for the past several years is an increased demand for flying probe. But as more manufacturing returns to North America, we'll see more high-volume work, which traditionally has been the ICT bed-of-nails. We're working a lot on our offerings there, even though it's viewed as older technology. We have by far the best electrical test capabilities in bed-of-nails, but we're also working to make it more affordable for our customers.

I want to pick up on that point. ICT bed-of-nails strongly suggests high-volume work. Do you expect more high-volume work to reshore?

Warren: I really do. With tariffs, it's very expensive for customers to import goods. The political climate and financial strain it's putting on customers means we'll see more reshoring. For example, we will see an increased use of contract manufacturers. It doesn't mean that *everything* is coming back. We won't be making refrigerators in the U.S., for example. That will still be done in Mexico. But more cutting-edge stuff will be done in the U.S., in my opinion.

Andrea, where do you see opportunities for growth on the global scale?

Furnari: In HQ, we have visibility of all the business worldwide, and I can tell you that, for electronic test products, the trend is to increase and improve the performance of the flying probes. We want the testers to be able to ramp in production to very high volume. We are increasing all the performance of the flying probe speed and overall performance with new motors, new drivers, and of course, greater accuracy.

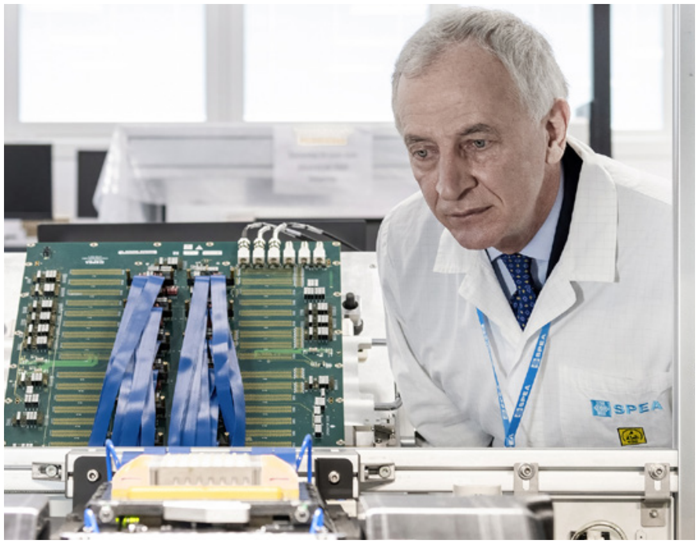
We're doing the same for the other ICT machines. We will announce a new platform for the ICT bed-of-nails machine in the coming months. We now have a solution that allows testing in parallel, up to 32 boards at a time. This is a unique value in terms of test parallelism. This is something that will be very interesting for the China and Southeast Asia markets.

In our semiconductor division, we are investing in new AI technology. AI is growing very fast; we can also feel it in the electronic test products.

Power is booming. Electric vehicle inverters and other automotive devices are moving into new high-power technology in order to have low battery consumption. Those are the main global trends and markets where we are focused.

Testing generates a lot of data, which is an ideal environment for pattern-based analysis to determine what's happening with process windows, etc. In SPEA's R&D work, how are you implementing AI into your solutions?

Furnari: We created a dedicated team inside the R&D department. We started with pattern matching and the imaging processing. We now have a team that builds our neural network to test and avoid subjective results from the operator, and to develop a specific, scientific method that we train



Luciano Bonaria continues to play a vital role in the company as one of the main designers on the R&D team.

in SPEA HQ. We are also implementing AI across our software to automate operations based on algorithms.

Soon, we will present something very disruptive. All our tests will be managed by AI software that can understand which test to run, how to design a new test product starting from the CAD file, and automatically generate the test program that you need. We are definitely moving in this direction.

That sort of research and development work is probably setting you up for the next 50 years. People can look back 20 years from now and say, "Here's the second pivotal moment."

Speaking of which, it's a great accomplishment in technology to have a half century of history. How will SPEA be marking the event?

Furnari: The idea is to split the 50-year celebration into different moments. One is for the employees who have allowed us to reach this target through 50 years of working together. Then we would like to celebrate with some of our suppliers and customers, who have worked with us a long time. We have ideas, but we won't disclose anything specific. We will be more precise in a couple of months.

That's a great teaser. Readers should stay tuned to SPEA for more information later. Dustin and Andrea, thank you very much for your time.

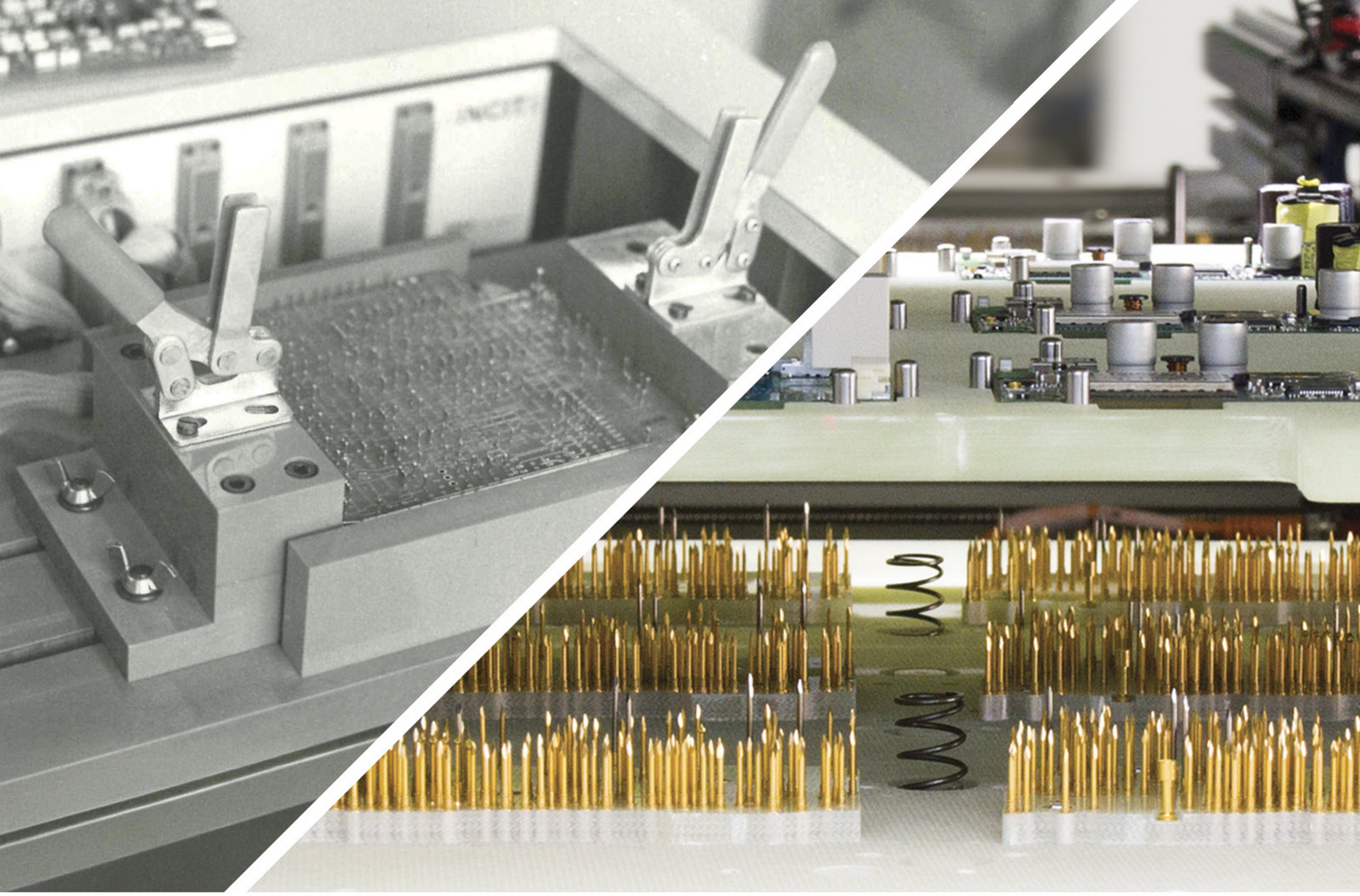
Furnari: Thank you so much. **SMT007**

BY ADAM KLETT, PH.D., KYZEN CORPORATION

Key Considerations When Selecting an Aqueous Cleaning Agent

Selecting the appropriate aqueous cleaning agent is one of the most consequential decisions in mitigating contamination risks in high-density designs. Highly dense electronic assemblies have introduced a new level of sensitivity to contamination. Reduced conductor spacing, bottom-terminated components, and elevated power densities significantly increase the risk that even minimal flux residues will lead to electrochemical migration, leakage currents, and long-term reliability failures.

I'll examine the key considerations involved in choosing an aqueous cleaning agent for removing flux residues from highly dense assemblies, and explore the interplay between flux chemistry, cleaning performance, material compatibility, environmental compliance, and process conditions, by providing a practical framework for ensuring both immediate cleanliness and long-term reliability.



Cleaning Agent Selection: A System-level Decision

Cleanliness is no longer a secondary step but a core reliability driver. In compact and complex assemblies, the margin for process variability narrows, and cleaning effectiveness becomes increasingly dependent on the interaction between chemistry and process.

Selecting an aqueous cleaning agent cannot be done in a decision vacuum. It must be evaluated within the full manufacturing context, including flux type, assembly design, cleaning equipment, and reliability requirements. The most successful selections are those that balance multiple, often competing, criteria, such as:

- Flux compatibility
- Penetration capability
- Ionic residue removal effectiveness
- Material compatibility
- Environmental and safety compliance
- Rinsing and drying performance
- Process and equipment constraints

Understanding how these factors interact is essential, as optimizing one parameter often affects another.

Flux Compatibility: Matching Chemistry to Residue

Flux residues are not uniform materials; they are complex chemical systems designed to support soldering performance. Typical formulations may include wetting agents, rheological modifiers, solvents, polymers, and activators, each contributing to the final residue's physical and chemical properties.

As a result, two fluxes classified similarly, such as "no-clean" or "water-soluble," can produce residues with dramatically different solubility, polarity, and adhesion characteristics. Additionally, application methods such as stencil printing, dispensing, or jetting can influence the distribution of residues across the assembly.

For this reason, the cleaning agent must be specifically matched to the flux in use. This is particularly critical for no-clean fluxes, which are engineered to leave minimal yet often chemically resilient residues. Supplier compatibility data can provide a useful starting point, offering insight into how specific cleaning chemistries perform with particular flux systems. However, these results should always be validated under actual production conditions.

Bath Chemistry, Flux Loading, and pH Stability

Most aqueous cleaning agents operate at a neutral to mildly alkaline pH. As cleaning progresses, acidic components from flux residues accumulate in the bath, gradually altering its chemistry.

This shift can reduce cleaning effectiveness, shorten bath life, and affect material compatibility. Therefore, a cleaning agent's buffering capability—the ability to resist these changes—is a critical performance parameter. Well-formulated aqueous chemistries typically incorporate multiple functional components, including:

- Solvent-rich phases to dissolve non-polar residues such as rosins
- Water-rich phases to address polar and ionic species
- Buffers to stabilize pH
- Surfactants to enhance wetting and penetration
- Corrosion inhibitors and defoamers to support process stability

A cleaning agent's ability to maintain consistent performance under realistic flux loading conditions is a defining characteristic of a robust solution.

Penetration Ability: Accessing Hidden Residues

In highly dense assemblies, the most problematic residues are typically located in the most inaccessible areas: beneath bottom-terminated components and within ultra-low standoff gaps. Effective cleaning in these regions depends on three sequential capabilities:

1. **Penetration:** The cleaning agent must physically reach the residue. Low surface tension is essential to enable wicking into narrow gaps.

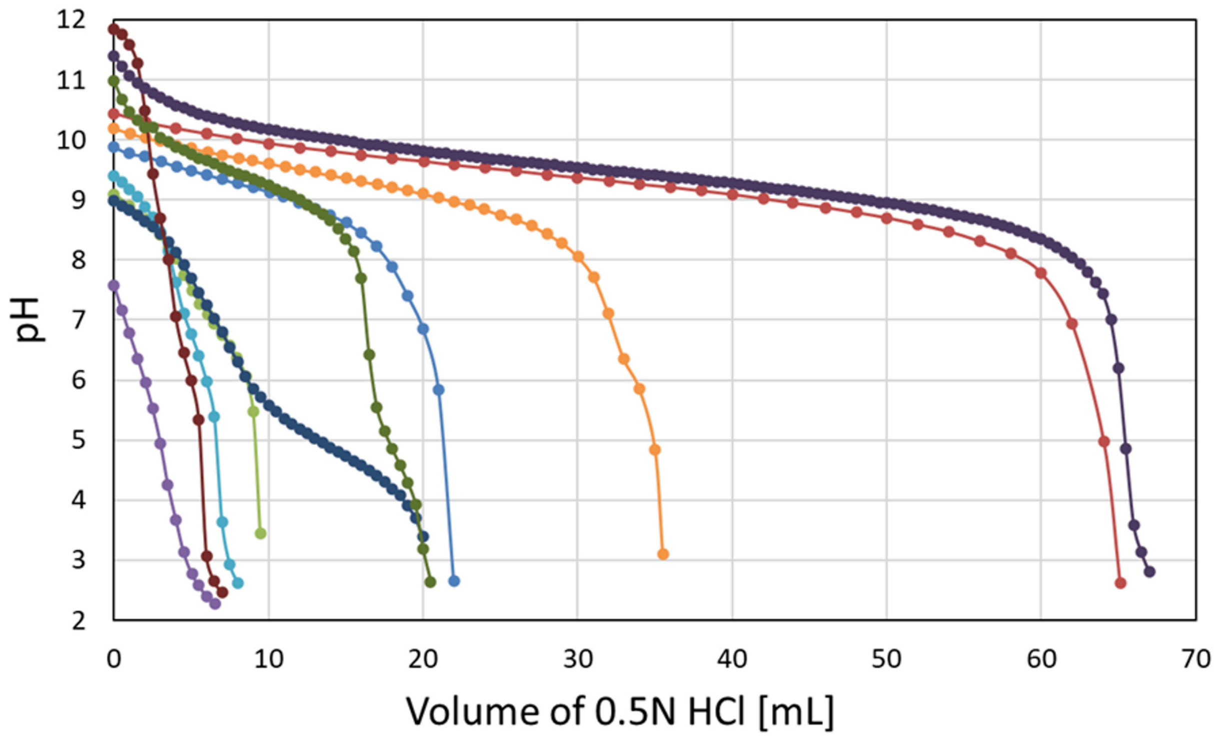


Figure 1: Titration curves illustrating differences in buffering capacity between aqueous cleaning chemistries.

2. **Dissolution:** Once contact is made, the chemistry must effectively solubilize both polar and non-polar residue components.
3. **Removal:** The dissolved residue must then be transported out from under the component through spray impingement, immersion, or agitation.

Failure at any stage compromises the entire cleaning process. Partial removal often results in residue redistribution instead of elimination, particularly in confined geometries.

Ionic Residue Removal and Reliability

While visible residues may raise cosmetic concerns, ionic contamination poses a far greater threat to long-term reliability. Ionic species can initiate corrosion, electrochemical migration (ECM), and degradation in surface insulation resistance (SIR).

Flux, however, is not the sole source of ionic contamination. Additional contributors include:

- Handling (e.g., salts and oils from skin contact)
- Tooling materials such as tapes, gloves, and fixtures
- Component-level contamination from prior manufacturing steps

Modern analytical techniques, such as ion chromatography, frequently identify a range of ionic species present on production assemblies. Because ionic contaminants are inherently water-soluble, aqueous cleaning agents are particularly effective at removing them, provided that penetration and rinsing are enough.

Material Compatibility: Protecting the Assembly

Cleaning performance must always be balanced against the risk of material damage. A cleaning agent that removes residues effectively but degrades components, finishes, or equipment is not a viable solution.

At the assembly level, potential risks include corrosion or etching of sensitive metallizations, degradation or removal of component markings, damage to improperly cured labels or coatings, and adverse effects on sensitive components or conformal coatings.

At the equipment level, compatibility with seals, gaskets, and other elastomeric materials is equally important. Incompatible materials may swell, crack, or degrade over time, leading to equipment failure and contamination risks.

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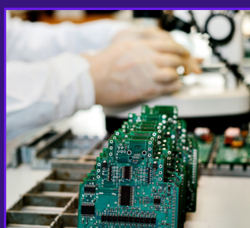
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Comprehensive compatibility testing should include both controlled laboratory exposure and dynamic testing under actual process conditions.

Environmental and Safety Considerations

The regulatory environment surrounding cleaning chemistries is placing increased emphasis on environmental impact and worker safety.

Key considerations include:

- Restrictions on volatile organic compounds (VOCs)
- Limitations on hazardous air pollutants and ozone-depleting substances
- Ongoing regulation of substances such as PFAS and trichloroethylene (TCE)
- Waste treatment and disposal requirements
- Worker exposure limits and hazard communication standards

Selecting a cleaning agent with a favorable regulatory profile not only ensures compliance but also reduces long-term operational risk and simplifies global implementation.

Rinsing and Drying: Completing the Process

Effective cleaning does not end with residue dissolution. Rinsing and drying are both critical in ensuring that contaminants and the cleaning chemistry are fully removed from the assembly.

Incomplete rinsing can leave behind cleaner residues that are just as detrimental as the original flux. This is especially problematic beneath low-standoff components, where trapped chemistry can lead to latent failures.

High-performance aqueous cleaning agents are designed to rinse cleanly with deionized water, minimize residue carryover, and enable complete drying without streaking, spotting, or moisture entrapment.

Process and Equipment Considerations

Cleaning chemistry must be compatible with the capabilities and limitations of the cleaning equipment in use. Whether the process involves inline spray-in-air systems, batch immersion systems, or ultrasonic cleaning, the chemistry must perform effectively under those specific conditions.

Critical factors include foam control in spray applications, stability and phase consistency at operating temperatures, compatibility with cycle times and throughput requirements, and ease of monitoring and maintaining bath concentration.

A well-matched chemistry enhances both cleaning performance and process efficiency.

Measuring Effectiveness: Static vs. Dynamic Testing

Evaluating cleaning performance requires a combination of testing approaches. Static testing provides a controlled method for screening chem-

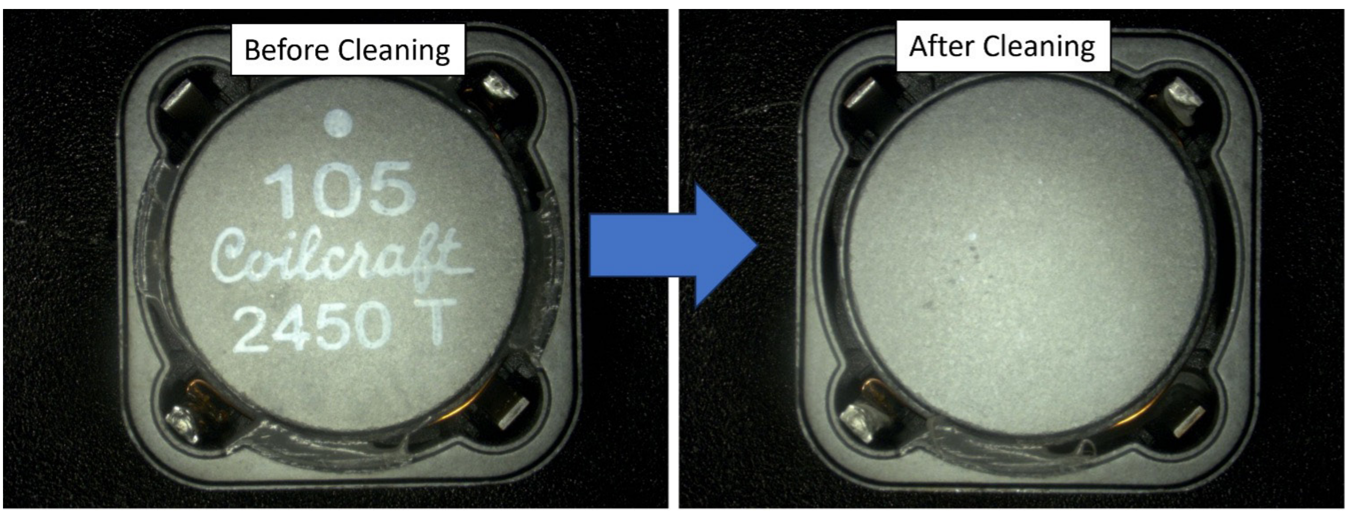

Figure 2: Examples of material compatibility failures involving component markings and coatings.

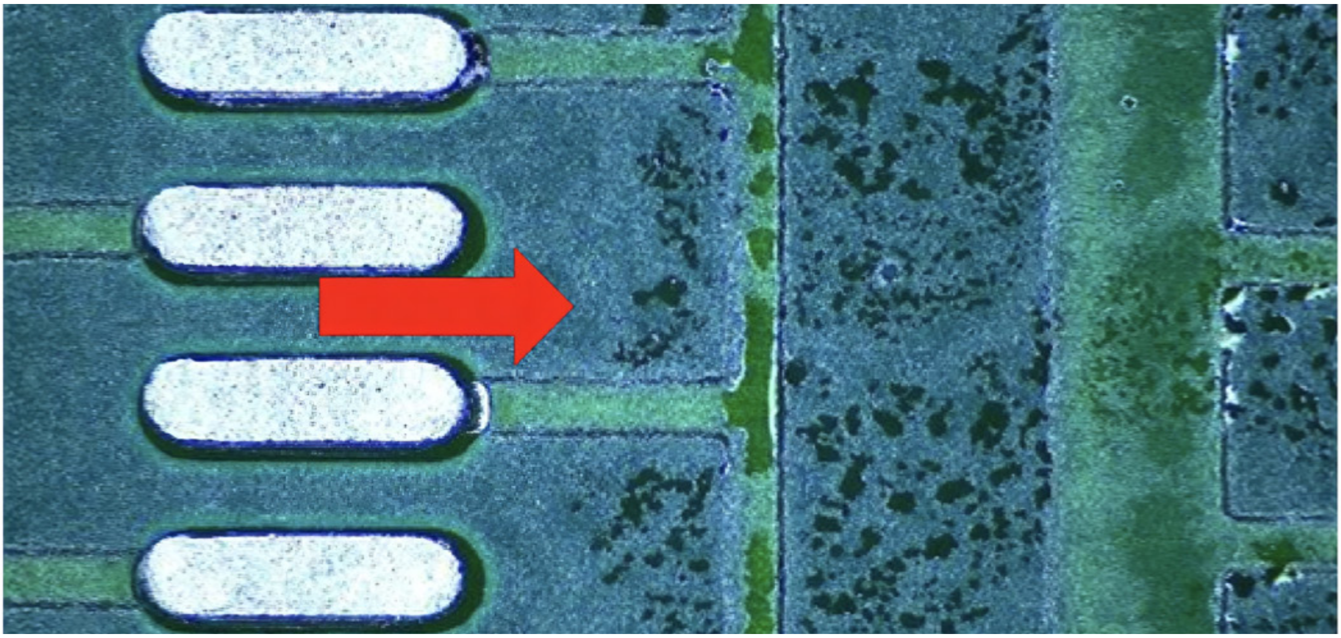

Figure 3: Example of poor rinsing beneath a low-standoff component.

istries through benchtop exposure and is useful for initial evaluation. Meanwhile, dynamic testing, conducted in actual cleaning equipment, accounts for real-world variables such as pressure, flow, temperature, and exposure time. Dynamic testing offers a more accurate representation of production performance. Both are essential components of a comprehensive qualification strategy.

Reliability Testing and Standards

Ultimately, cleaning effectiveness must be validated through reliability testing. Standards such as IPC-J-STD-001 emphasize the need for objective evidence demonstrating that cleaning processes support long-term performance. Common validation methods include SIR testing, electrical performance testing, and historical process data analysis. Supporting standards such as IPC-J-STD-004, IPC-5704, and IPC-CH-65 provide additional guidance on flux classification and cleanliness requirements.

Design for Cleaning: Enabling Success

Even the most advanced cleaning chemistry cannot compensate for poor design. As assembly geometries become more constrained, design decisions increasingly influence cleanability. Challenges are not limited to bottom-terminated components; features such as thick solder masks, poorly placed silkscreen, and continuous copper pours can restrict cleaning access and trap residues.

Good practices in designing for cleanability include introducing copper relief beneath components, optimizing solder mask geometry, and controlling silkscreen placement. Viewing these features in 3D during the design phase is essential to ensuring effective cleaning.

Conclusion

Selecting an aqueous cleaning agent for highly dense assemblies is a system-level optimization problem. Chemistry, design, process conditions, equipment, and regulatory requirements must all be considered together. When approached holistically, cleaning agent selection can significantly improve not only cleanliness but also process stability, product reliability, and long-term manufacturing success.

The choice of cleaning chemistry plays a central role in mitigating contamination risks. It is not merely a process variable; it is a strategic decision that directly impacts product performance. **SMT007**

Adam Klett, Ph.D. is director of science at KYZEN Corporation.

BY JAMES KIM, ARENTFOX SCHIFF LLP

The USMCA Six-Year Review

Why Electronics Manufacturers Should Be Paying Attention

For most of the past five years, the U.S.–Mexico–Canada Agreement (USMCA) has been the workhorse of the North American electronics supply chain. It is the legal backbone that allows a PCB fabricated in Asia to be populated in Mexico, tested in Texas, and shipped to a Canadian OEM without anyone paying a tariff at any of the three borders. That arrangement is now up for review, and the outcome will matter to anyone in electronics manufacturing who depends on cross-border production.

What the Six-Year Review Is, and Why July 1 Matters

USMCA's Article 34.7 requires the three governments to jointly review the agreement six years after it took effect. The deadline is July 1, 2026. Each country must decide one of three things: renew the agreement for another 16 years, withdraw (on six months' notice), or continue the agreement without renewing it, in which case the USMCA stays in force but enters annual reviews until 2036, when it expires unless all three governments agree to extend.

NAFTA, by contrast, had no formal review mechanism at all. It is one of the reasons it could not adapt to e-commerce, digital trade, or AI. The six-year review is a USMCA innovation, and even if it produces stress, the fact that it exists is a feature, not a bug.

The bad news: A clean, on-time renewal by July 1 now looks unlikely. U.S. Trade Representative Jamieson Greer has told the House Ways and Means and Senate Finance committees that he is not prepared to recommend renewal without meaningful changes, particularly to automotive

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kohyoungamerica.com america@kohyoung.com rules of origin, dairy market access, and what the administration calls "economic security" provisions aimed at Chinese inputs into North American supply chains. The most realistic scenarios at this point are a protracted negotiation that produces an amended agreement or a slide into annual reviews under sustained uncertainty.

Where the Negotiations Stand: Mexico Yes, Canada Not Yet

The pre-review process has split into two bilateral tracks rather than one trilateral negotiation. On the U.S.–Mexico side, USTR Greer and Mexican Secretary of Economy Marcelo Ebrard formally launched discussions in March, and formal bilateral negotiations began the week of May 25 in Mexico City. Mexico has been a relatively cooperative counterpart, by delivering on security commitments, accommodating U.S. requests on enforcement, and signaling openness to tighter rules of origin.

The U.S.–Canada track is a different story. Canada made early concessions last year—rescinding its digital services tax, discussing softwood lumber quotas, and increasing defense spending—but talks have stalled. A near-agreement on steel, aluminum, and energy reportedly collapsed in October 2025, and no formal U.S.–Canada renewal talks are currently scheduled. Canada's chief trade negotiator has publicly described July 1 as "kind of a checkpoint," not a strict deadline.

The Big Issues on the Table

Several themes dominate the U.S. negotiating position, and electronics manufacturers should track every one of them.

Steel and aluminum tariffs. The Section 232 metals tariffs (covered in the first installment of this series) loom over everything. Roughly 32% of Mexican USMCA-compliant goods and 37% of Canadian goods still face Section 232 duties, and the U.S. steel industry is pushing hard for steel to count as "North American" only if it is melted and poured in the region—not merely finished there. Deputy USTR Jeffrey Goettman has publicly endorsed that view, telling the American Iron and Steel Institute conference that the administration wants "unified tariff borders" with Mexico and Canada on steel, aluminum, autos, and other sectors so there is no opportunity for tariff arbitrage.

The "side door" concern. Goettman has identified one of the biggest U.S. priorities as shutting down what he calls "the side door"—Asian manu-


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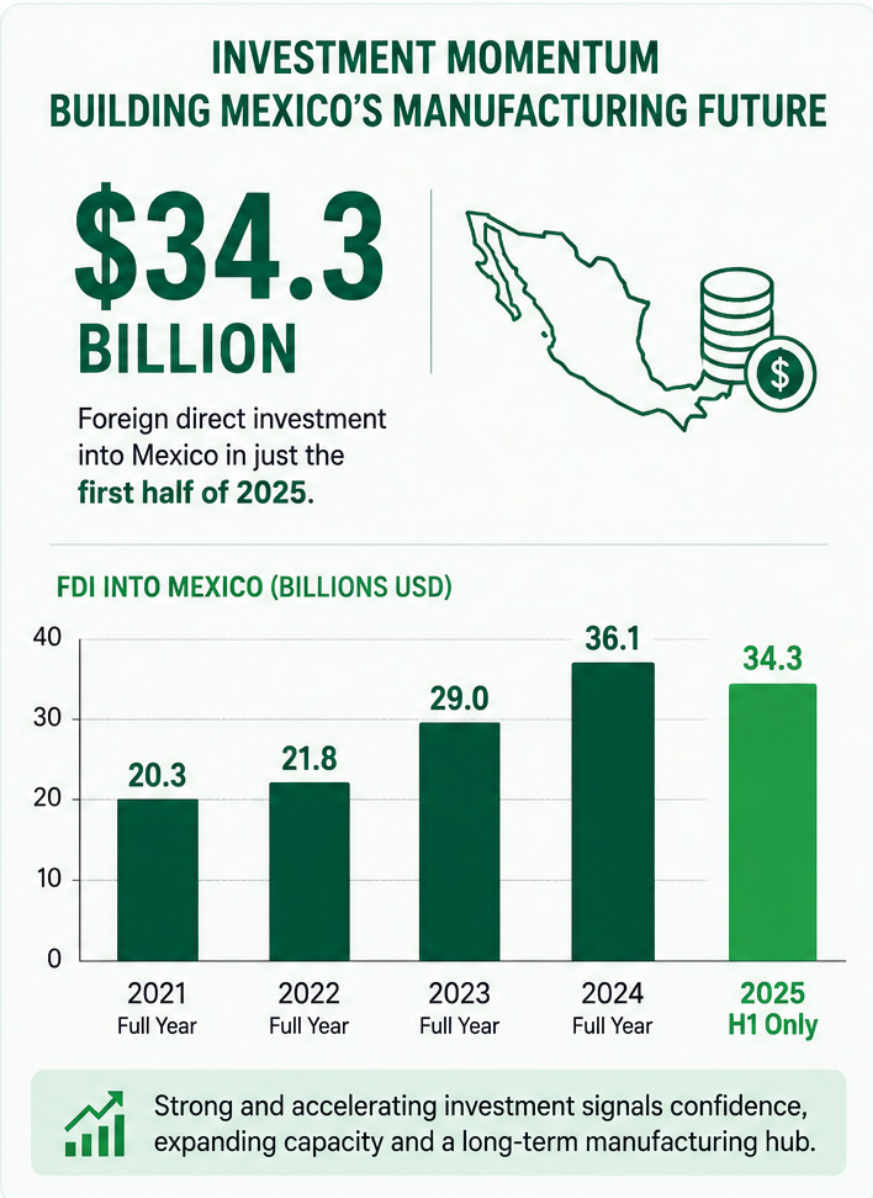


facturers, particularly Chinese, using Mexican and Canadian production platforms to access the U.S. market. Chinese foreign direct investment into Mexico has surged, and U.S. negotiators want rules of origin tight enough that goods built largely from Asian inputs cannot qualify for tariff-free entry.

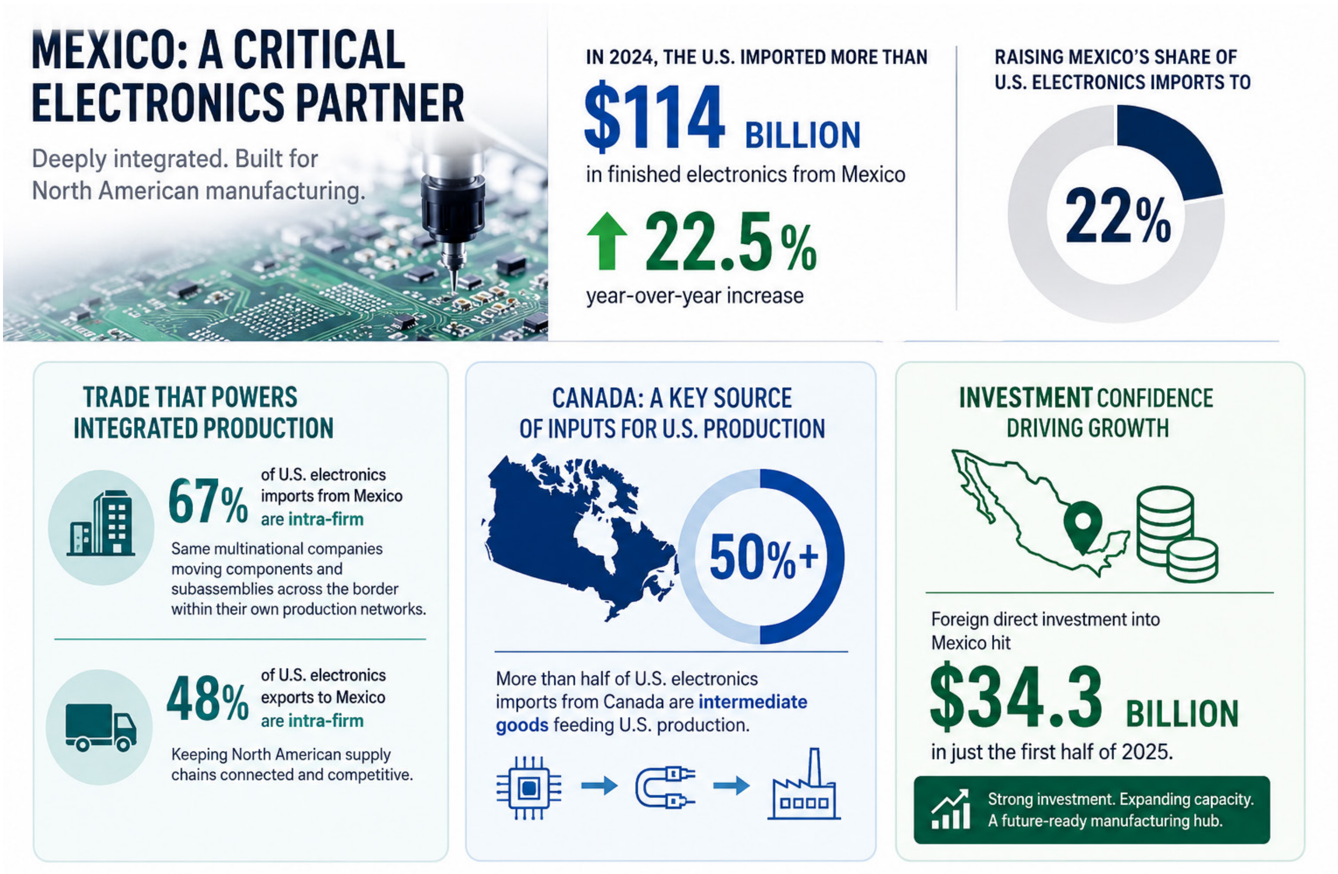
Higher RVC with a U.S. content target. The administration has signaled it will push to increase regional value content thresholds in "a number of strategic sectors," and (critically) that those RVCs will include a dedicated U.S. content requirement, not just a North American content requirement. This is a significant departure from current USMCA practice, which generally treats U.S., Mexican, and Canadian content as fungible.

Mexico's export promotion programs. USTR is also taking a hard look at Mexico's IMMEX, PROSEC, and Rule 8 (Regla Octava) programs, which together allow Mexican manufacturers, including the U.S.-owned maquiladoras that dominate electronics assembly, to bring in non-originating inputs at reduced or suspended Mexican duties. Critics argue these programs let Asian inputs effectively enter the U.S. market duty-free; defenders point out they support inputs that simply are not available in North America.

What the Electronics Industry Is Saying

The Global Electronics Association, which represents more than 1,700 North American electronics manufacturers and design firms, has been clear in its testimony to USTR and the U.S. International Trade Commission. Chris Mitchell, the Association's vice president for global government relations, testified in December 2025 that the electronics industry is "all in" on USMCA—or any comparable or improved successor—and urged policymakers to maintain tariff-free access for compliant trade, keep rules of origin workable for complex production, focus enforcement narrowly on circumvention, and invest in joint North American workforce and infrastructure.

The Association's data make a powerful case for why the integrated model matters. In 2024, the U.S. imported more than $114 billion in finished electronics from Mexico, a 22.5% year-over-year



increase, raising Mexico's share of U.S. electronics imports to 22%. Roughly 67% of U.S. electronics imports from Mexico and 48% of U.S. electronics exports to Mexico are intra-firm, meaning the same multinational companies are moving components and subassemblies across the border within their own production networks. More than half of U.S. electronics imports from Canada are intermediate goods feeding U.S. production. Foreign direct investment into Mexico hit $34.3 billion in just the first half of 2025.

The friend-shoring story is also better than the headlines suggest. Between 2017 and 2024, China's share of Mexico's electronics imports fell from 40.6% to 33.6%, as Korea, Vietnam, Taiwan, and Thailand grew their shares. Mexico is genuinely diversifying away from China, even as the U.S. negotiates harder on the "side door" question.

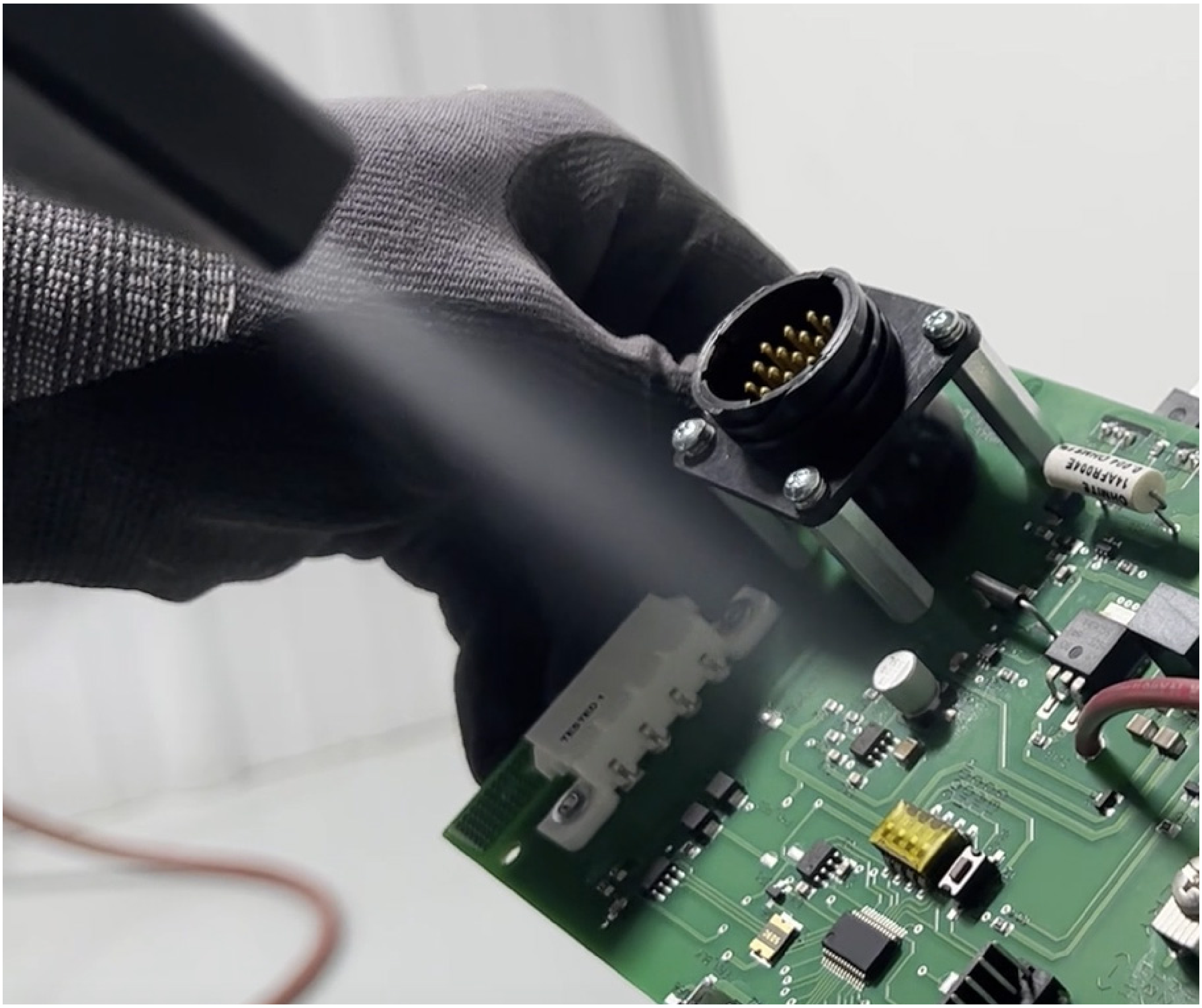
Why This Matters Now

The single most important issue for electronics manufacturers in this review is the rules of origin, because that is the direction where the U.S. negotiating push is most likely to head. For a sector built on cross-border, intra-firm production, even modest changes to the rules can reshape sourcing decisions and capital plans.

In the next installment, I'll dig deeper into the USMCA rules of origin for key electronics product lines, including Article 2.10.1 and General Note 11(p), a long-standing provision that recognizes the deeply integrated nature of the IT industry by treating a defined list of computer and IT goods as originating when shipped to the U.S. from Mexico or Canada. That provision, more than any other, embodies what is at stake in the 2026 review for the electronics industry.

James Kim is an international trade lawyer at ArentFox Schiff LLP. This series explores how trade policy, tariffs, and customs developments impact the electronics manufacturing industry.

BY JONATHAN DEAN, COLD JET



Dry Ice Blasting Offers *Alternative* Cleaning Method

Cleanliness is a critical factor in the production of every electronic component, from wafer fabrication to final product assembly. Unclean surfaces and parts can ruin entire batches of products, negatively affecting product performance, production yield rates, and overall operational costs. Any lapse in production quality or excessive downtime can be detrimental to an electronics manufacturing facility.

Traditionally, manufacturers have had to use abrasive cleaning methods such as chemical solvents and mechanical tools to remove contaminants from products after soldering and finishing. However, a faster method, dry ice blasting, has been used to great effect for cleaning electronic components and equipment, offering efficiency, safety, sustainability, and effectiveness across many use cases.

The Problem With Cleaning Components and Equipment

During the manufacturing process, byproducts are created that must be removed or cleaned up from the products before they can be delivered. Some of the most troublesome byproducts include flux and conformal coating. Also, equipment used in the manufacturing and testing phases of production requires cleaning to remain functional and accurate, reducing downtime and unnecessary product scrapping.

Flux Removal

Flux, the surface preparation, deoxidizer, and even a cleaning agent used during the soldering of components to circuit boards, is necessary to ensure products function adequately. Additionally, the production equipment used for soldering (especially wave soldering equipment) can be notoriously difficult to clean. Solder buildup over time requires thorough cleaning after every production cycle, and hand-cleaning with chemicals can be harmful to employees, products, and equipment.

Conformal Coating

Conformal coatings, such as acrylic, silicone, or polyurethane, are the protective layer applied to finished circuit boards and are necessary to keep electronics safe from the elements and heat. However, overspray on critical components must be removed to restore functionality. Additionally, faulty components that require replacement during QA testing necessitate conformal coating removal. If the coating cannot be successfully removed, the entire board is scrapped, which raises production costs.

Automated Testing Equipment

The circuit testing process can also get fouled up by leftover soldering flux and other contaminants, rendering probes, pogo pins, and test sockets less accurate when testing functionality. Less accurate testing can lead to more false positives for failure and increased rates of unnecessary product scrapping.

How Dry Ice Blasting Works

Dry ice blasting is an industrial cleaning solution utilized by multiple industries due to its inherent advantages over traditional cleaning methods, such as abrasive blasting techniques, hand tool cleaning, and chemical solvents. This technique cleans by accelerating dry ice (i.e., solid carbon dioxide) pellets at high velocity from an applicator device and impacting surfaces, weakening the bonds that anchor contaminants and removing them. Dry ice blasting works through three distinct steps, which we have named ICE:

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1. **Impact** of dry ice pellets creates a kinetic energy effect: Blaster machines use compressed air to accelerate the dry ice pellets at supersonic speeds through an insulated hose and out through specially designed nozzles that impact the top layer of contaminants, weakening their integrity.
2. **Cold** temperature creates a thermal effect: Dry ice has a resting temperature of -109°F (-78.5°C), and its contact with contaminants causes them to instantly shrink and embrittle to further break the bond.
3. **Expansion** of carbon dioxide through sublimation: When dry ice pellets strike the surface, they instantly sublimate, or transform from a solid into a gas; this transformation causes a rapid expansion of the gas to 800x its original volume, causing microscopic explosions that dislodge contaminant particles from surfaces.

These steps all occur in milliseconds, using the power of physics to remove contaminants rather than brute force or corrosion. The results of dry ice blasting can be seen instantaneously, leaving behind clean surfaces with no residue or waste.

Using the process described above, dry ice blasting can quickly remove flux, conformal coating, and other contaminants from electronic components through adjustability of cleaning power and specialized nozzles. Advanced blasters can adjust blast settings on the fly, such as pellet size (3 mm down to 0.3 mm), air pressure, and dry ice consumption rate, to find the right balance for cleaning even the most sensitive parts. Smaller pellet sizes at lower pressures can quickly and effectively remove flux and coating from circuit boards and other components, even in hard-to-clean spots. Additionally, precision nozzles can be used to clean only the areas you need so desired coatings are not accidentally removed.

Use Cases in Electronics Manufacturing

The following are examples of practical use cases for dry ice cleaning in electronics manufacturing:

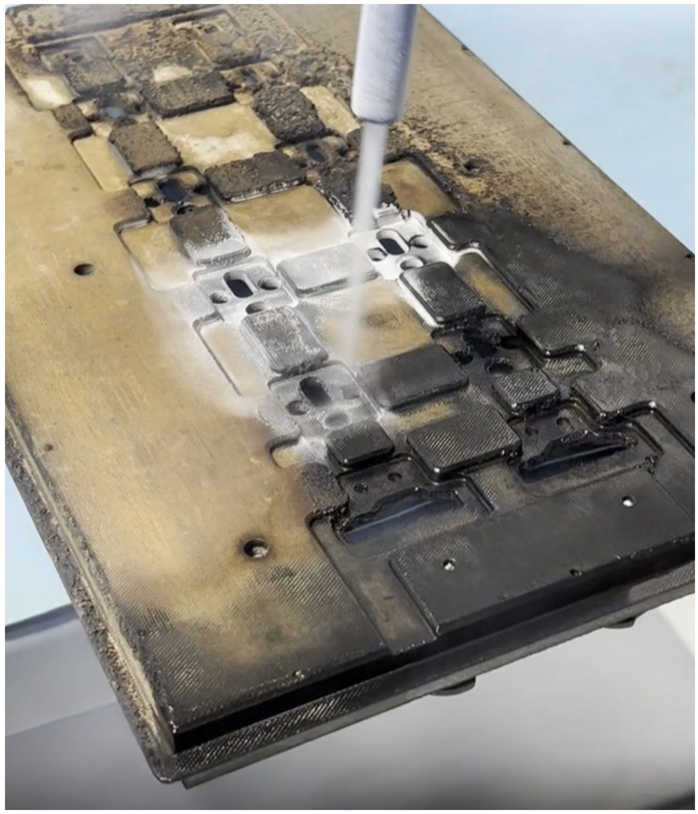
- Remove solder flux from circuit boards and soldering equipment as part of production
- Remove conformal coating overspray when needed, particularly in tight areas where failed-component reworks are required to reduce scrap
- Remove fouling from automated testing equipment (ATE) such as probes, pogo pins, and test sockets to improve accuracy and reduce scrap
- Decontaminate CVD reactors for polysilicon production
- Remove contaminants from wafer fabrication equipment, including wafer chambers, deposition tools, and polishing tools
- Decontaminate plasma-coated surfaces and fixtures to prevent defects from forming in microchips

- Surface preparation to prevent polishing compound build up on PTFE-coated aluminum chambers
- Clean vacuum pumps and implanters in-place and online between wafer fabrication cycles
- Remove fouling from semiconductor molds and dies in-place and online without cooldown or disassembly
- Product finishing, plastic deflashing, and adhesive removal from semiconductor parts after manufacturing

Advantages of Dry Ice Blasting

The notable advantages include:

- **More effective cleaning:** Dry ice blasting is aggressive enough to clean hard-to-reach places and flat spaces alike, delivering superior cleaning over manual methods.
- **Non-abrasive:** Dry ice rates a 1.5 out of 10 on the Mohs Hardness scale, meaning that solid CO_2 can clean sensitive electronic components without damaging them in the process.
- **Decreased downtime:** Soldering and coating equipment can be cleaned in-place while still online and does not require disassembly or cooldown. Additionally, production cleaning of circuit boards and other electronic components can be sped up significantly.
- **Increased safety for staff and environment:** Dry ice blasting is chemical-free and does not necessitate exposing employees to dangerous cleaning chemicals
- **No secondary waste:** Chemical cleaners must be properly disposed of after use; dry ice sublimates upon impact, leaving no residue or waste behind after cleaning.
- **Environmentally friendly:** Dry ice blasting uses dry ice pellets created from recycled CO_2 and does not add additional CO_2 to the atmosphere.
- **Automatable:** Dry ice blasting technology can be integrated into partial or fully automated cleaning solutions that can run 24/7 if needed as part of the production process.



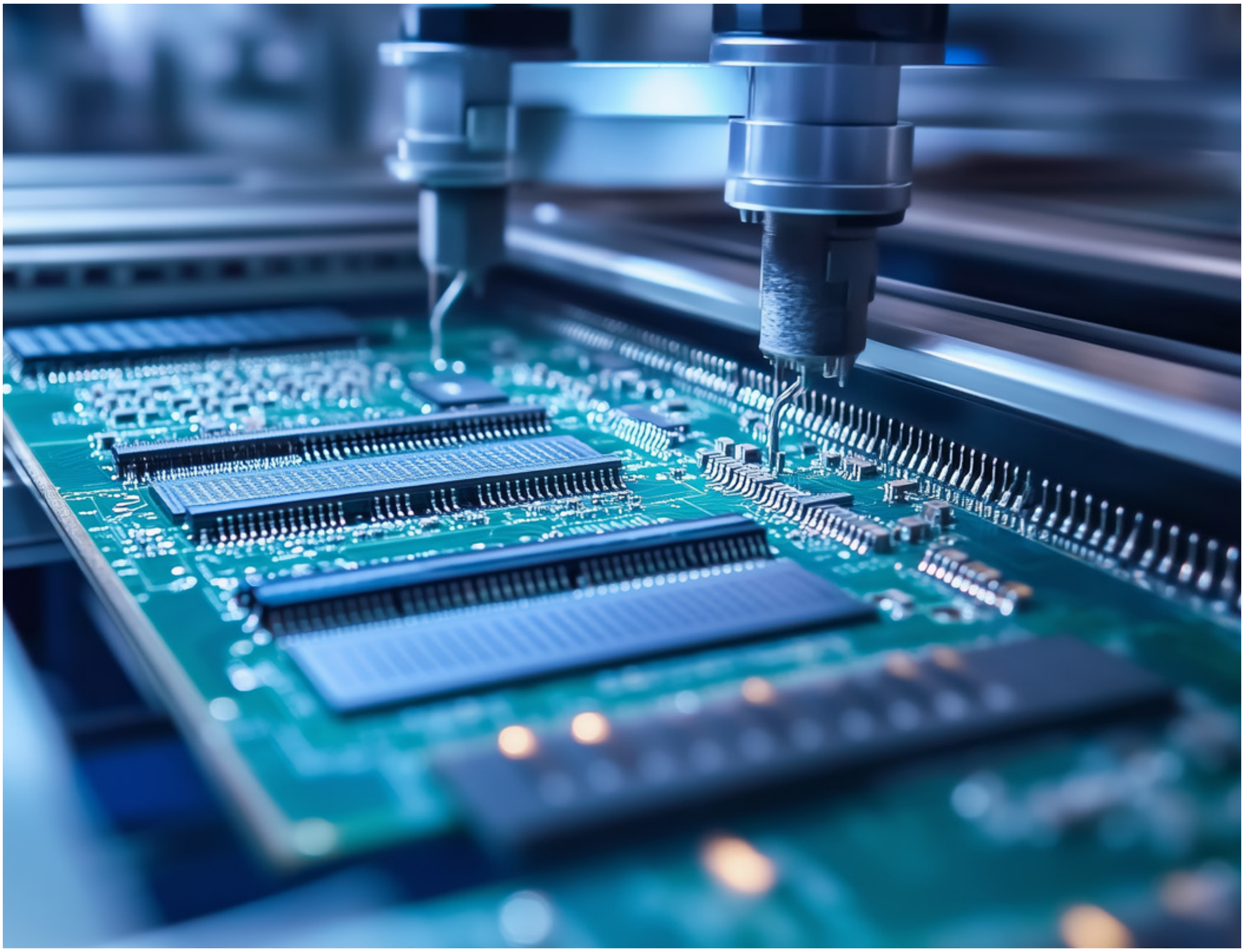
Success Across Multiple Industries

Electronics manufacturing is not the only industry that benefits from the cleaning power of dry ice blasting. This cold cleaning method's advantages make it highly versatile in the cleaning and manufacturing tasks it can tackle, seeing significant use in the following industries:

- **Heavy industry:** Mining, oil & gas, power, foundry
- **Manufacturing:** Automotive, plastics, rubber, packaging, electronics
- **Precision/regulated:** Medical, aerospace, food
- **Services/restoration:** Contract cleaning, remediation **SMT007**

Jonathan Dean is a web content writer for Cold Jet.

BY EBAD REHMAN, MACDERMID ALPHA ELECTRONICS SOLUTIONS



RIGHT-SIZING SILVER

An Application-driven Approach to Engineering Reliability

Rising cost pressure and metals market uncertainty are prompting manufacturers to rethink alloy composition to balance total cost of ownership, process yield, and mechanical performance.

Solder alloy selection directly influences cost structure, process stability, and long term reliability in electronics assembly. As manufacturing scales and product requirements advance, these decisions are increasingly revisited with a more focused objective: aligning materials with how products are built, processed, and used in real world conditions.

Silver-containing alloys have long served as a standard in lead-free assembly, supported by established performance and process familiarity. What is changing is how their role is being evaluat-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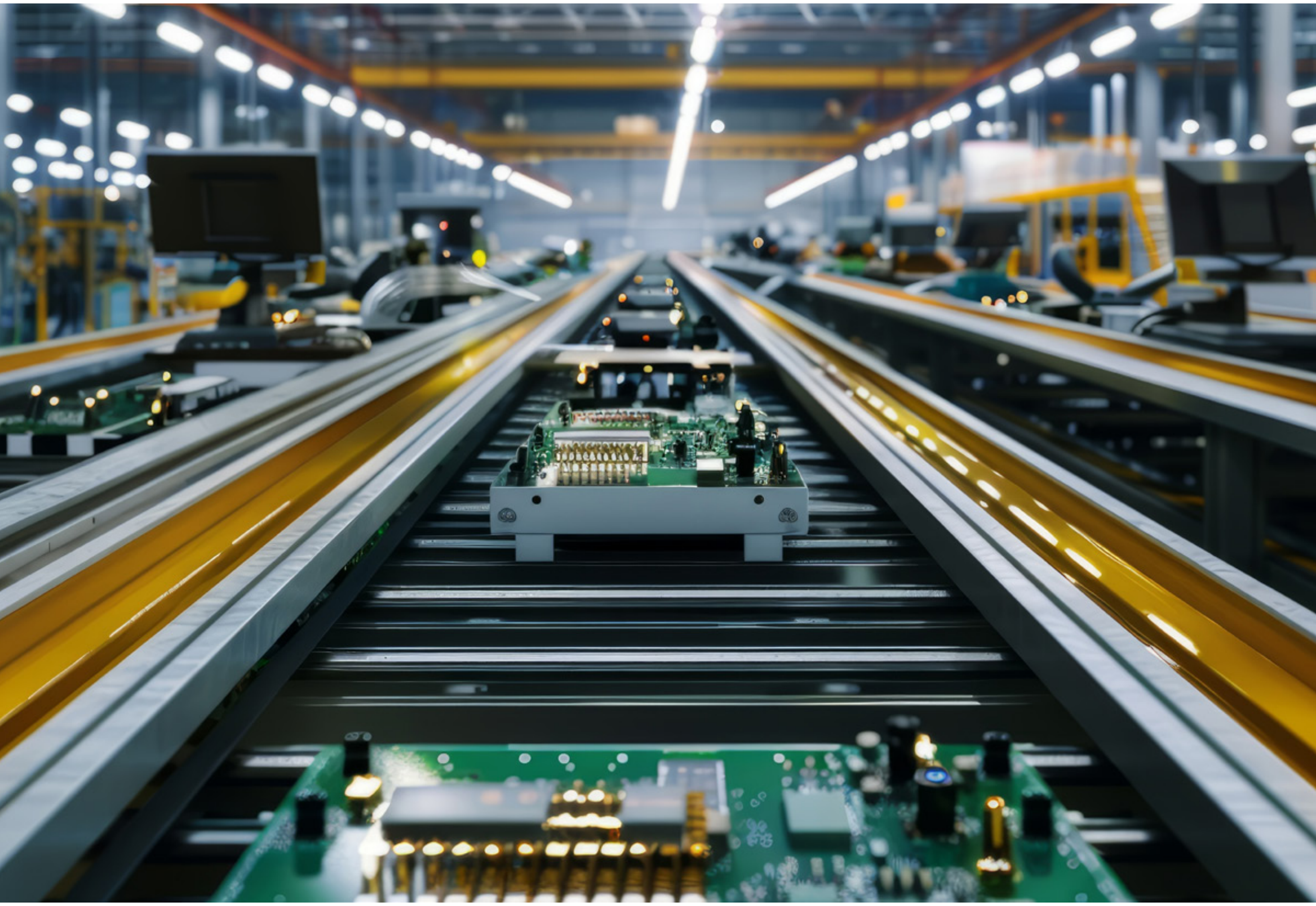
ed, as material selection is increasingly influenced not only by performance benchmarks but also by exposure to raw material volatility and the need to maintain stable, high-yield manufacturing. Within this context, manufacturers are revisiting silver-free solder pastes through a more balanced lens.

Balancing Cost, Yield, and Reliability in High-volume Assembly

Material cost is often the most visible factor in alloy selection, but it represents only part of the equation. Total cost of ownership (TCO) includes the impact of materials on yield, rework, throughput, and long-term reliability. In high-volume manufacturing, small variations in process performance can translate into meaningful differences in operational cost, directly affecting margin stability and production efficiency.

This is particularly relevant in high-volume markets such as consumer electronics and appliance systems, where competitive pricing, defined product lifecycles, and increasing functionality place sustained pressure on both cost structures and manufacturing performance. In these segments, materials are expected to support consistent yields and throughput while contributing to overall cost targets.

Silver contributes to the thermomechanical performance of traditional solder alloys at higher operating temperatures, while introducing cost sensitivity tied to global market conditions. Reducing reliance on these inputs can improve cost stability and provide greater predictability in material spend, particularly in high-volume environments where fluctuations in input costs can have an outsized impact on overall profitability.



At the same time, engineers must evaluate material changes in the context of process performance, where print consistency, stencil life, and reflow behavior directly influence yield and throughput. Materials that maintain stable performance across these parameters can help reduce variability and support more efficient production.

Mechanical Reliability Under Real-world Conditions

Reliability is best understood in the context of how products are used. In many applications operating below 100°C, mechanical stress becomes a primary driver of long-term performance, as products are routinely exposed to vibration and impact during transport, installation, and use.

These conditions are common in consumer electronics and appliance systems, where products are expected to maintain performance over their operational lifecycles despite repeated handling and operational stress. In high-volume assemblies such as appliance control boards or consumer devices, this repeated strain can make differences in mechanical performance more visible over time.

These conditions have increased the industry's focus on material behavior under mechanical loading, where resistance to fatigue, crack initiation, and propagation is critical. For assemblies operating below 100°C, thermal demands are typically moderate, shifting the reliability focus away from high-temperature degradation and toward mechanical durability.

In this context, optimizing solder joint performance for vibration and drop resistance becomes a strategic consideration, particularly in applications where product reliability and field performance directly influence brand perception, warranty costs, and lifecycle expectations.

Rather than relying solely on traditional alloy properties, materials are increasingly evaluated in the context of application-specific performance. This shift has driven renewed interest in alternative alloy designs that can better balance mechanical robustness with process stability.

Rethinking Alloy Design for Modern Assembly Requirements

Silver-free solder alloys are not new, but their design has evolved. Engineers often evaluated earlier generations primarily on cost, while more recent formulations reflect a broader objective that integrates cost efficiency, mechanical reliability, and process consistency.

This aligns with a broader trend in materials engineering, where the goal is not to maximize a single property but to achieve the right balance across multiple performance requirements, particularly in electronics assembly, where manufacturing efficiency and in-field performance must both be addressed.

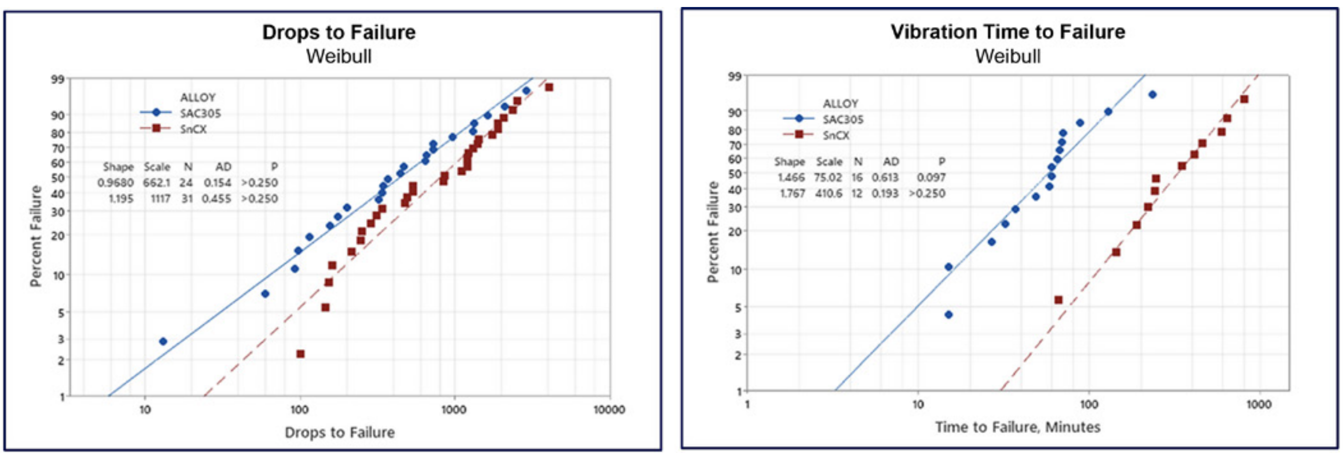


Figure 1: Weibull analysis illustrating improved drop shock and vibration performance relative to SAC-based alloys under defined test conditions.

Applying Silver-free Alloy Design in High-volume Assembly

This approach can be seen in materials such as ALPHA® OM-100 SnCX® 07, a no-clean, zero-halogen, silver-free solder paste developed for high-volume electronics assembly. From a cost perspective, the alloy offers up to 30% metal savings compared with traditional high-silver alloy combinations, helping reduce material spend and limit exposure to fluctuations in precious metal pricing. From a reliability standpoint, test data demonstrate up to a 50% improvement in characteristic life and up to a 40% improvement in drop shock and vibration performance compared with SAC305. At the same time, thermal cycling performance remains comparable to SAC305 alloys for applications operating between -20°C and 100°C, supporting reliability expectations without introducing additional risk.

> "This shift has driven renewed interest in alternative alloy designs that can better balance mechanical robustness with process stability."

Process Stability and Manufacturing Consistency

Material performance must translate into consistent results on the manufacturing line. For process engineers, this means predictable behavior during printing and reflow, as well as stability across extended production runs.

The material supports a wide print process window, consistent transfer efficiency, up to 16 hours of stencil life under typical ambient conditions, and is compatible with both air and nitrogen reflow environments.

In high-volume manufacturing environments, where throughput, uptime, and yield consistency are closely tied to operational efficiency, these characteristics enable manufacturers to capture cost and processing benefits without introducing additional complexity or variability.

Reframing Material Selection in Electronics Assembly

Material selection in electronics assembly continues to evolve as design, process, and procurement teams reassess priorities. There is an increasing focus on real-world performance, alongside strategies that enhance cost stability and improve resilience to market variability. Silver-free solder pastes sit at this intersection, offering a path to reduce reliance on precious metals while maintaining process stability and mechanical performance.

For assemblies operating below 100°C, particularly in high-volume consumer and appliance applications, silver-free solder materials provide a practical way to align cost, reliability, and manufacturability with current product requirements, production demands, and competitive market pressures. **SMT007**

To learn more about silver-free solder solutions, including ALPHA OM-100 SnCX 07, visit macdermidalpha.com or connect with a technical expert to identify the right solution for your application.

Ebad Rehman is global product manager, Solder Paste, at MacDermid Alpha Electronics Solutions.

Boeing, U.S. Navy Achieve Successful MQ-25A Test Flight ▶

During the two-hour flight, the unmanned aircraft successfully demonstrated its ability to autonomously taxi, take off, fly, land, and respond to commands from the Unmanned Carrier Aviation Mission Control System MD-5 Ground Control Station (GCS). Once airborne, the Stingray executed a pre-determined mission plan that validated its flight controls, navigation, and safe integration with the GCS.

EDIP Opens the Door: EU Funding Now Available for Defence Electronics Including PCBs and Substrates ▶

The European Commission has published a call for proposals under the European Defence Industry Programme (EDIP), and for European electronics manufacturers the message is clear: This is real money for real capacity, and PCBs and IC substrates are explicitly in scope.

Fincantieri to Build Spectre, a New Class of High-Speed Unmanned Surface Vessel ▶

Spectre is a new class of high-speed, multi-mission unmanned surface vessel (USV), developed by Saildrone. Spectre has been conceived to address the rapidly evolving operational requirements of modern naval forces and reflects the growing demand for autonomous naval platforms, capable of being deployed in numbers.

Boeing, Millennium Scale Space Production to Meet Growing Demand ▶

"We're aligning our space business to meet a market that is moving faster and asking for more flexibility," said Kay Sears, vice president and general manager of Boeing Space, Intelligence & Weapons Systems. "That means increasing production throughput, broadening the portfolio, and giving customers more options for how they field and scale capability over time."

Thales Secures Military Navigation with TopStar Smart Receiver ▶

Thales launches the TopStar Smart Receiver, a three-in-one ultra-compact solution providing land forces with resilient positioning, navigation, and timing capabilities, while maintaining radio communications in increasingly contested electronic warfare environments. TopStar Smart Receiver can be integrated into land vehicles, drones and munitions.

Northrop Grumman Delivers GPS-Jamming-Resistant Airborne Navigation System ▶

Northrop Grumman delivered the first production unit of the EGI-M navigation system, designed to provide military users with accurate positioning, navigation and timing (PNT) data. The system is now modernized to support successful missions in high-conflict areas across the globe. Military customers will benefit from a unified hardware and software navigation solution that can be seamlessly integrated into platforms.

Lockheed Martin Wins $105M U.S. Space Force Contract for GPS Ground Control Upgrade ▶

These upgrades strengthen the end-to-end GPS enterprise, ensuring continuous service for national defense and commercial users. Launch capabilities provided under this contract will allow for more M-Code-enabled GPS IIIF space vehicles to be available on-orbit, increasing signal resiliency for military users.

Leonardo DRS Launches Maritime Counter-UAS Capability to Defeat Aerial Threats at Sea ▶

Leonardo DRS, Inc. has successfully integrated its Maritime Mission Equipment Package (M-MEP) on an autonomous unmanned surface vessel (AUSV), delivering a new counter-unmanned aerial system (C-UAS) capability designed to detect, track, identify, and defeat aerial unmanned threats operating in the maritime domain. The solution provides a mission-ready layer of protection for ships, ports, littoral infrastructure, and expeditionary forces facing an increasingly complex drone threat environment.

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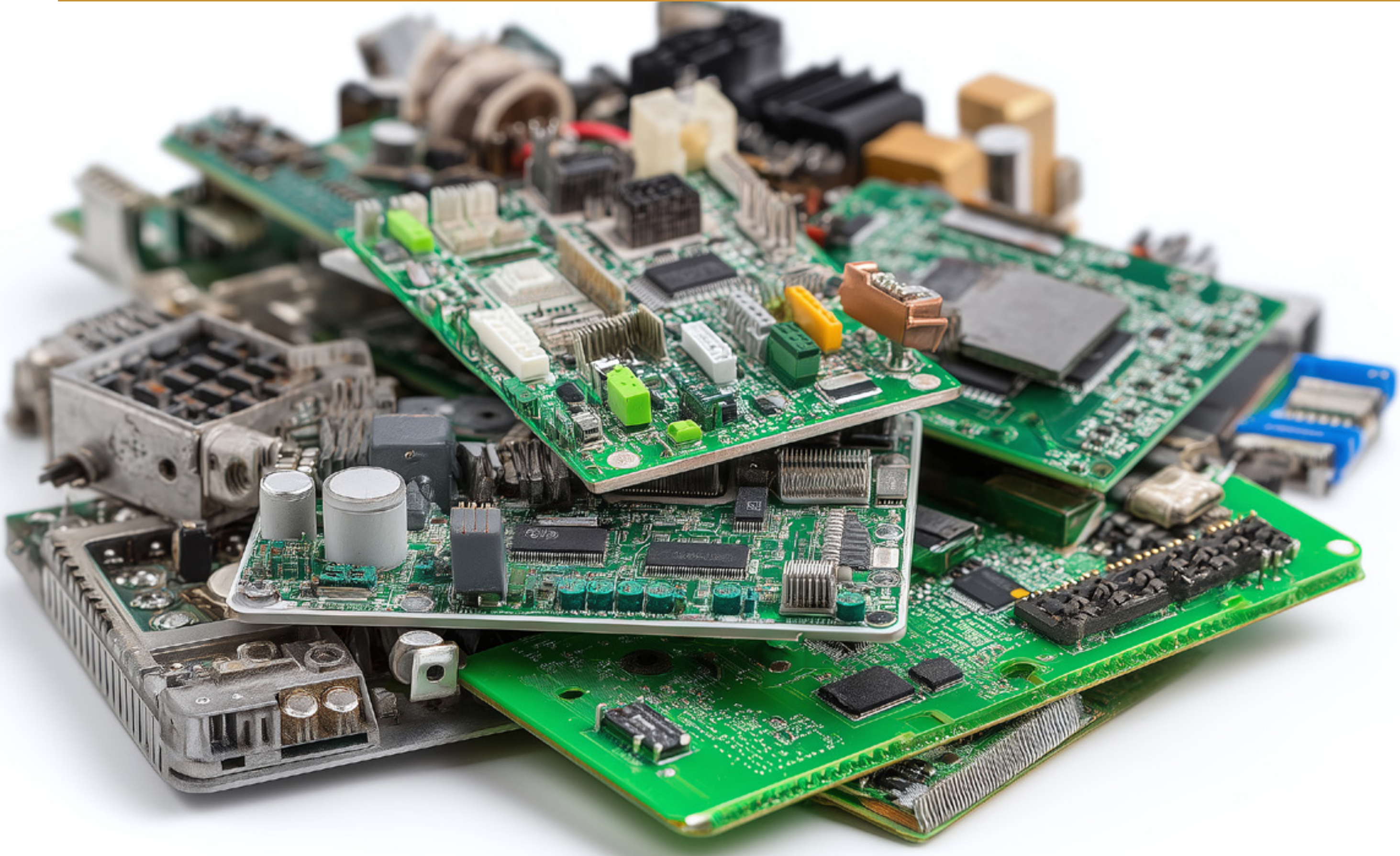

THE BUSINESS CASE FOR Component Reclamation

BY NASH BELL, BEST, INC.

Electronic waste is increasing globally at an alarming rate. By 2030, it is estimated that the world will generate approximately 82 million tons of electronic waste per year. Rapid technological advances, shorter product lifecycles, and supply chain disruptions often lead manufacturers to build bloated inventories of electronic products. Unfortunately, some of this inventory ends up as electronic waste when components become obsolete or surplus to forecasted requirements, including high-value devices.

Basic recycling practices can recapture valuable metals from electronic components such as gold and other high-value metals. For example, estimates suggest that 4,000 tons of electronic waste can generate up to 450 Kg (kilograms), or approximately 1,000 pounds, of recycled gold.

Pros and Cons of Electronics Recycling

Of the millions of tons of electronic waste discarded globally each year, less than 20% of the raw materials and electronic components in these devices are recycled. Consumer electronics is a numbers game, as many manufacturers compete for market share, and most companies may not have any economic incentive to build more durable devices that can last longer before they need to be replaced.


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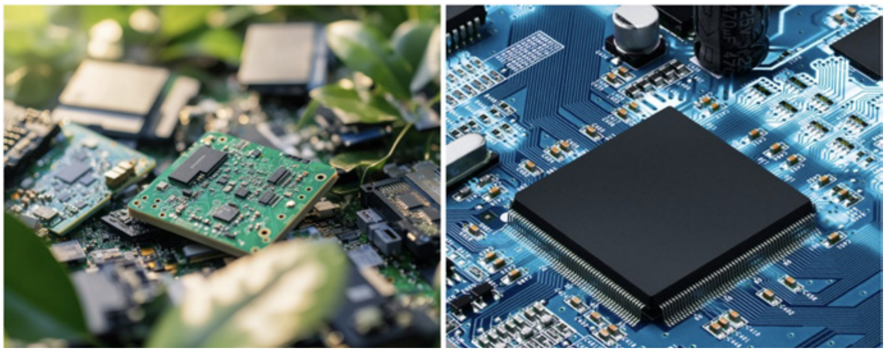


Figure 1: Example of discarded electronic waste and high-value quad flat pack device.

Additionally, most companies and consumers do not reuse these devices or their components at the end of their lifespans. This is mainly due to the difficulties of repairing these products, replac-ing obsolete components, or upgrading the soft-ware without overtaxing the hardware. While the business of recovering precious metals and other valuable materials from electronic waste is increasing, there are limits to recycling. In most cases, the printed circuit board and other devalued components are dumped into landfills or incinerated.

Extracting and recapturing valuable metals from recycled electronic components requires advanced recycling practices, such as bioleaching with microorganisms, hydrometallurgy (chemical leaching), or pyrometallurgy (smelting) at elevated temperatures.

Sustainability and Circularity

Electronic waste often contains hazardous materials that pose risks to human health and the overall environment. These toxins include mercury, lead, and brominated flame retardants (BFRs). A circular supply chain is a strategy for keeping these materials from being dumped into landfills together with electronic waste.

A circular economy closes resource loops and maximizes the lifetime value of materials. To achieve this, electronics manufacturers follow a take, make, use, repair, repurpose, redistribute, and then recycle circular model, whereas a linear economy follows a take, make, and dispose methodology. Recycling is part of circularity; however, the goal is to ensure that devices can be utilized by another manufacturer, preventing this need for as long as possible.

Another consideration in a circular supply chain is design-ing products that are easier and financially viable to repair and upgrade. Modular product design is a crucial aspect of promoting circularity. Designing products that are easy to repair and encouraging buy-back schemes empower end consumers to make more sustainable choices with their electronic purchases. Being able to repair devices easily encourages people to fix what they own instead of replacing them with-out thought.

Circularity goes beyond reducing discarded components. Many legacy components—parts older than 10 years—may not be available via franchised distribution. Sometimes, a single legacy chip may prevent scrap from a large, old industrial piece of equipment, enabling a successful, cost-effective repair.

Component Salvaging and Reclamation

When harvesting electronic components from printed circuit boards, several factors need to be considered. These include the type and level of physical damage to the component, the component's electrostatic discharge (ESD) level, electrical overstress (EOS), moisture sensitivity device (MSD) level, and the environmental conditions it has interacted with, together with other factors. Outsourcing the component salvaging process allows you to hire professionals who can effectively address these critical factors and leverage high-performance tools and processes to successfully locate, remove, and procure valuable components from discarded electronic products.

When selecting an outsource partner, several factors should be evaluated to ensure the integrity and quality of the component reclamation process. It is recommended to audit the outsourcing partner to verify that they have effective MSD processes aligned with J-STD-033 guidelines. It is also recom-mended that the outsource partner have numer-ous years of experience with BGA salvaging and follow all applicable MSD, EOS, and ESD safeguards.

Component Removal

After mechanical disassembly, most components can be recovered using hot air or infrared (IR) rework systems. Hot air systems deliver a controlled stream of heated air to raise both the component and the surrounding PCB to solder reflow temperature. Operators must carefully manage airflow, temperature, and dwell time to prevent thermal damage or PCB warping. Preheating the board before component removal is an effective practice that further reduces thermal shock and helps preserve component integrity.

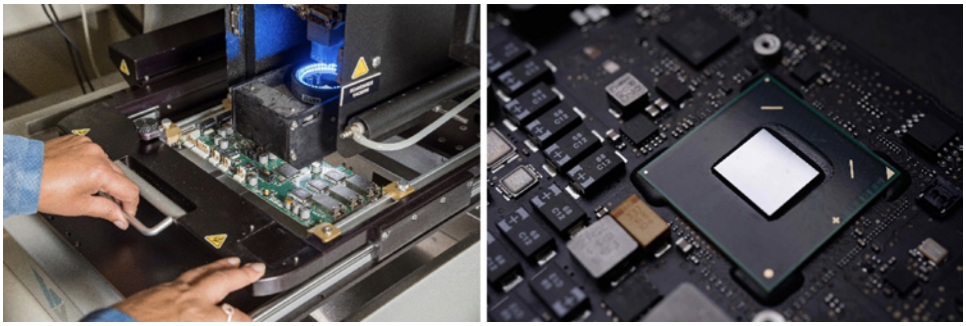


Figure 2: BGA removal with hot air rework system and salvaged BGA mounted on a new PCB.

Infrared systems, in contrast, radiate heat directly into the component, minimizing thermal exposure to nearby devices. The technique is highly dependent on variables such as component color, reflectivity, and board material, making precise calibration and profiling essential. Regardless of the method used, adherence to MSD handling procedures per J-STD-033 is crucial to prevent component failure during removal, and thermal profiling ensures heating remains within manufacturer-recommended specifications.

Specialized tools and equipment are required to reliably remove and salvage electronic components from printed circuit boards. These include high-quality professional soldering irons, hot-air or infrared component removal systems, robotic hot solder dip machines, inspection systems, stereo microscopes, cleaning systems, baking ovens, and various types of hand tools. Operators performing component salvaging must be highly trained in the proper knowledge, skills, and protocols of MSD and ESD safeguards to ensure components are not damaged during the removal, desoldering, and reclamation process.

Electronic component salvaging includes reclamation of various types of primarily surface mount devices, including ball grid array, land grid array, and quad flat no-lead components, which can be salvaged and reconditioned for use in the assembly of other circuit boards. The harvesting of electronic components from PCBs helps alleviate supply chain shortages of high-value or hard-to-source electronic devices. Following reconditioning, salvaged components are typically laser-marked for traceability and packaged on tape and reel per EIA-481 standards, or in trays for automated circuit board assembly.

IPC-7712, a component reclaim standard currently in development, aims to advance circularity within the electronics manufacturing industry and expand the ability of component reuse as opposed to recycling of electronic waste.

Conclusion

Electronic waste is a worldwide problem driven in large part by consumers' desires to acquire the latest technology. It is critical to implement environmental and eco-friendly practices by advancing component-salvaging procedures.

The importance of maintaining high-quality workmanship standards throughout the component reclamation process cannot be overstated. This serves to ensure the integrity of the component supply chain, facilitating environmentally responsible practices, and reducing reliance on energy intensive fabrication of new semiconductor devices and electronic components. **SMT007**

Nash Bell is president of BEST, Inc. To read past columns, **click here**.

BY MARCY LARONT, I-CONNECT007

EPTAC

The 'Ivy League' of High-tech Training

It's been an exciting time for EPTAC, an IPC training and certification center based in Salem, New Hampshire, which recently opened a new state-of-the-art training facility to much fanfare. To help celebrate this accomplishment, we spoke with some key individuals who tell the story of what truly makes EPTAC successful.

For over 35 years, EPTAC has built a reputation as a leading provider of IPC training and certification for the electronics manufacturing industry. It began in 1987 as a focused effort to deliver hands-on solder training and process expertise, and has evolved into a broad network of 24 training centers serving companies across North America.

What may surprise many is that EPTAC also offers professional services to manufacturers, including on-the-floor process audits and problem-solving. The opening of a new training facility in New Hampshire reflects the company's continued growth and ongoing investment in workforce development and high-reliability electronics education.

"We train the industry," said Jonathan Gilman, senior business development manager, who came to EPTAC nearly a year ago. He was a business owner and entrepreneur for over 30 years, during which time he did much of his own training. "That's one of the reasons this resonated with me."

He's impressed by EPTAC's "ridiculously high


Jonathan Gilman

standards. We are constantly looking for more people who meet our standards. We turn away more trainers than we accept. Our worst trainer rating is a 4.6 out of 5. To say we are the Ivy League of training excellence is not an overstatement."

Gilman is obviously proud of his employer. "When someone comes in for training with us, it is important that they understand it is about more than the PowerPoint," he said. "We have customers who come away from our training and say that they learned a lot about how to train, in addition to the course material that brought them in. That's quite a compliment."

He is primarily responsible for EPTAC Professional Services Group, a long-offered service that is now formalizing and expanding to meet the growing industry need. Solving "micro-problems" is a big value-add for manufacturers, he said, and broader than the standards to which they train and certify. "There is nothing we've said no to if it touches, at all, on IPC (standards)."

Helena Pasquito has been a trainer with EPTAC for 16 years but is a "legacy" in the industry. "I tell people I grew up in the industry, you know, back when dinosaurs roamed the Earth," she said. "In the 1970s, there was a push in electronics. Things were changing by the minute. It was truly the place to be." This was a time when electronics became big, not just for large companies and the government, but for everyone. Pasquito worked for Digital Equipment Corporation (DEC) while still in high school. "If you look at the archives of where the computer began, it was DEC and IBM."

DEC helped Pasquito earn her electronics technician certification, and she's cognizant that it was less common for women to earn degrees in electronics at that time. "DEC sent me to school as an 18-year-old, and I was pushing it forward," she said. "The education that I got at the beginning was just incredible. Who would have thought I'd still be soldering eons later?"


Helena Pasquito

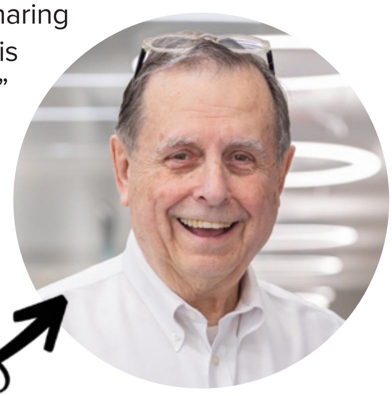
Her first turn at training came while working at MACOM Tyco, where she became an internal trainer and earned the Certified IPC Trainer (CIT) designation. MACOM touched all product classes, including aerospace and defense. "I was coming to EPTAC to get my certifications," Pasquito said. "You could be working on the beginning of cell phone technology in the morning, and then you could be talking to NASA in the afternoon. Boeing was also a big partner for us, both aircraft and satellite systems. On the third floor, we had DARPA, all the secret military applications. We were also one of the first companies to have dancing robots—Spot. It was so varied, and it was such a cool business."

MACOM sent her back to school for her second and third college degrees, in business and education, perhaps foreshadowing that training would become an even bigger part of her professional life.

After 16 years at EPTAC, the passion and enthusiasm have not diminished. "EPTAC is a great organization," Pasquito said. "I love working here. We have grown leaps and bounds over my 16 years. We're now, of course, in this beautiful space here in Salem, New Hampshire, with 14,000 square feet." She teaches almost everything that EPTAC offers, and is excited about the new, large classrooms. I teach IPC-A-600 for bare PCBs, 6012 for rigid boards, A-620 for cable wire harness, J-STD-001 soldering requirements and A-610 for assemblies, which is still my favorite, and something I was training others in long before coming to EPTAC."

Additionally, EPTAC does non-IPC training, custom training programs, and a five-day hand-soldering certificate, one of Pasquito's favorites. "I'm still soldering my heart out and sharing my wisdom and love for this technology in the process," she said.

Finally, I spoke with industry veteran and firecracker Leo Lambert. Though all EPTAC


Leo Lambert

trainers are superstars in their own right, Lambert brings it home with an abundance of passion and wise words for all. He's been with EPTAC since 1996 and is the face of the company, according to his colleagues. In fact, he may be the face of IPC standards and certification training in North America. He's also the author of "Learning with Leo," a popular *I-Connect007* column.

Lambert also started his career at DEC, getting involved in specifications when his boss asked him to attend some IPC committee meetings in his place. "Initially, the OEMs (chiefly DEC and IBM) wanted to get rid of their quality manuals, so it was decided to put all of that information into IPC specifications," he said. This first brought IPC manufacturing specifications into true prominence. "In 1994, the Department of Defense (DoD) under Secretary William Perry announced a shift from using exclusively military specifications to commercial," which upleveled the importance of IPC manufacturing specifications yet again.

In 1976, there were three big standards: IPC-J-STD-001, IPC-A-600, and IPC-A-610. Lambert said it was a lot easier to get consensus back then, with only 10–20 participants in a group meeting vs. more than 100 today. He's proud that, despite what may seem like constant change, the standards have held up well over time, and that 50 years later, he's still active in both creating new IPC standards and modifying existing ones.

Training is where it all began. "Industry volunteers wrote the first training program for IPC-A-600, folks like Dieter Bergman, Ralph Hersey, and me," Lambert said. "Training back in the day was an engineer doing a presentation or workshop, and someone saying, 'We need to do a training around that.' What started out as a workshop was broken down into steps to create a training program, and if you presented the paper, you were on the hook. That's how it started."

While it seems that technology is accelerating at an unprecedented pace, Lambert offers grounded and wise counsel. "The technology is not changing as fast as people think," he said. "What's changing is the density; the methodology is the same at the core. We have two cultures that are coming head-to-head: the semiconductor business on one side and PCBs on the other. Will we need new tools? Will we need new (manufacturing) methods? How do we manage them coming together?"

No matter how it plays out, Lambert said it's essential to stay involved in the standards process. "You have to be involved in standards!" he said.

Training at EPTAC has been so effective and has allowed for tremendous growth for over 35 years because of its focus on how they teach and train, and on how they deliver the content to the audience in front of them to ensure they get what they need, Lambert said.

"People don't learn today the way they learned 30 years ago," he said of each new generation. "We always need to be taking a look at different (training) methodologies, and we need to talk to, not only the industry companies that make the products, but also the educators. This needs to happen in late grammar school to early high school."

Even all these years later, what he enjoys most about training is seeing that aha moment with his students, when they really understand the concepts. He ended our conversation with a big Leo Lambert smile, encouraging everyone, "Enjoy what you are doing. Keep studying. Keep learning and share your knowledge."

EPTAC and its dynamic and talented training team are certainly doing that. **SMT007**

EPTAC Celebrates
New Expansive Training Center in New Hampshire

BY MARCY LARONT, I-CONNECT007

On a picture-perfect spring day in Salem, New Hampshire, on April 23, EPTAC marked a major milestone with the opening of its new 14,000-square-foot training facility and headquarters on 7 Stiles Road. EPTAC welcomed state and local officials, industry partners, business leaders, and customers for a ribbon-cutting celebration that felt equal parts ceremonial and personal. Remarks from President and CEO Burak Gokmen, along with good food and easy conversation, set the tone for an event defined by both growth and gratitude.

With 24 training locations in the U.S. and Canada, the expansion underscores EPTAC's continued momentum and its sharpened focus on serving high-reliability sectors including defense, aerospace, and medical devices.

From left to right, David Hernandez of the Global Electronics Association with Burak Gokeman, EPTAC President and CEO.

"This expansion strengthens our ability to deliver the hands-on training that today's manufacturers require," Gokmen said to the crowd of visitors. He emphasized the broader ecosystem behind workforce development and added that EPTAC will continue to deepen its "collaboration with industry, government, and education partners to help build a more resilient and highly skilled workforce."

As states compete for advanced manufacturing investment, that message resonated with policymakers as well. U.S. Sen. Jeanne Shaheen (D-N.H.) pointed to EPTAC's long-standing impact. "Today marks an important step forward for EPTAC as you continue to grow and innovate within the electronics manufacturing industry," she said. "For more than 35 years, EPTAC has played a vital role in training and certifying professionals across critical sectors, helping to ensure quality, reliability, and advancement in fields ranging from medical technology to aerospace. Your decision to expand here in New Hampshire reflects the strength of our state's workforce and our shared commitment to fostering economic growth and innovation. I commend the entire EPTAC team for your dedication and vision. Your investment in both your industry and our state's workforce will have lasting benefits for the region."

David Hernandez, vice president of education and workforce training at the Global Electronics Association, traveled to the event and echoed that sentiment. "EPTAC has a long and distinguished legacy of training for the electronics manufacturing industry," Hernandez said after the event. "They are a critical partner to the Global Electronics Association in addressing workforce challenges and ensuring the industry has access to a skilled workforce. Congratulations to them on their new building and expansion, and our great appreciation goes out to them for all the essential training work they do."

The new facility features four large classrooms, two lecture halls, and two fully equipped training areas designed for hands-on instruction. Across all its sites, EPTAC offers a flexible mix of in-person, onsite, and online training, working closely with customers to tailor programs for maximum impact.


eptac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BY STANTON RAK, SF RAK COMPANY

THE FOUNDATIONAL TECHNOLOGIES OF MATERIALS in EV Reliability

EV reliability is often discussed at the vehicle or system level, but many of the most persistent failures begin at the materials level. Semiconductor devices, ceramic substrates, die attach materials, wire bonds, clips, thermal interface materials, laminates, coatings, seals, and coolants define the electrical, thermal, and mechanical limits of the hardware.

Once EV architectures move toward higher voltages, switching speeds, and power density, and longer service life, those materials are pushed harder, and small weaknesses can turn into large field problems. Wide-bandgap devices can raise efficiency and reduce mass, but they also place more stress on gate oxides, passivation, interconnects, insulation systems, and cooling paths.[1,2,3]

This matters because materials failures rarely stay local. A single degraded interface can raise thermal resistance, increase current crowding, alter switching behavior, damage neighboring parts, and shorten the life of the assembly. In the field, the result may appear as reduced range, charging interruption, inverter shutdown, isolation fault warnings, intermittent behavior, derating, or complete module failure. Current crowding occurs when electrical current does not flow uniformly through a conductor, but instead concentrates in localized regions such as edges, corners, contact

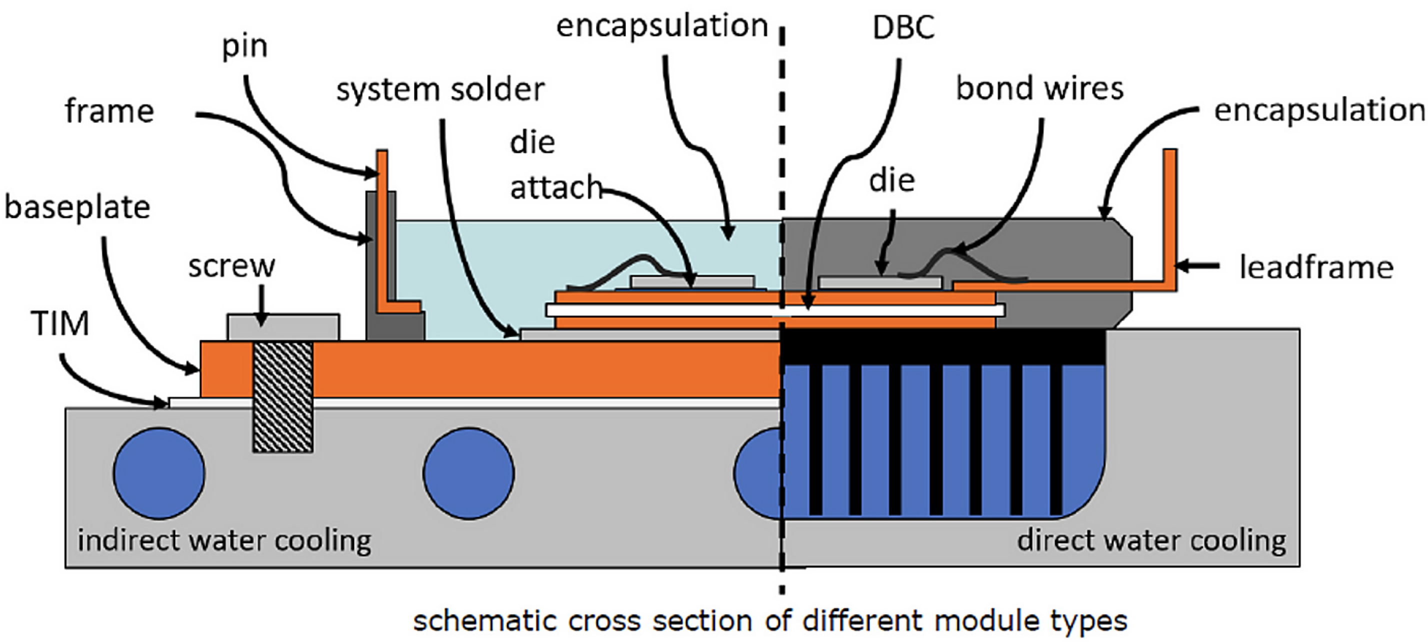

Figure 1: Examples of materials comprising a power module (Semikron-Danfoss).[4]

interfaces, or narrowed geometries.

This effect increases local current density, even when overall current levels appear to be within design limits. In EV systems operating at 400–800 V and at high current, it becomes even more severe because small design imperfections get amplified and lead to faster degradation. In his presentation at the EV Special Session at APEX EXPO 2025, Dr. Olaf Schoenfeld noted that material interfaces are a common source of reliability issues due to improper surface preparation and cleanliness.[5] In short, the road to reliability starts well before final assembly; it starts with what the system is made of.[1,3,6]

Wide-Bandgap Devices Raise Performance, and the Stakes

Silicon carbide (SiC) is now a leading material for EV traction inverters, onboard chargers, and DC-DC converters because it supports higher voltages and higher temperatures, and offers lower switching losses than conventional silicon. The U.S. Department of Energy identifies SiC as a key technology for high-voltage vehicle power electronics, offering higher efficiency and enabling faster charging and longer range.[3,7] Gallium nitride (GaN) also brings value in higher-frequency conversion, particularly where compact size and reduced passive content are attractive.[1]

Yet these gains come with reliability concerns that must be managed rather than assumed away. Reviews of SiC MOSFET reliability highlight gate oxide degradation, threshold-voltage instability, body-diode stress, limitations in short-circuit ruggedness, and defect-sensitive failure modes as recurring concerns.[1,2] A 2024 Ohio State reliability presentation also reported field failures in commercial SiC MOSFETs used in EV inverters, high-

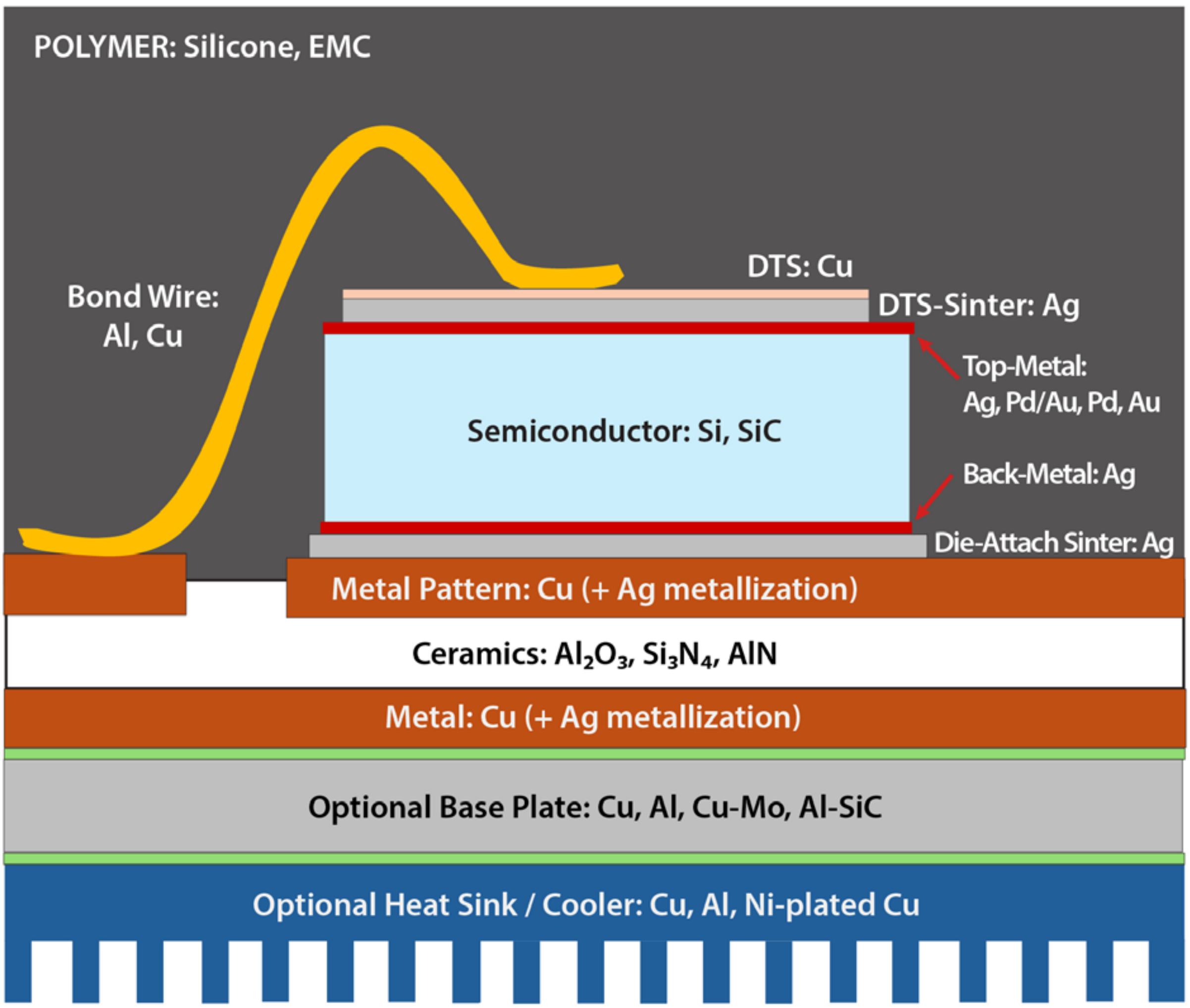

Figure 2: Material interfaces found in a power module die stack. (Source: Zestron)[5]

lighting gate oxide failure as a major challenge.[8] That does not mean SiC is unsuitable, but that material quality, screening, drive conditions, thermal control, and package design must be tighter than many engineers have been accustomed to in older silicon systems.

If those issues are not addressed, the failures are straightforward. A device that switches faster than the package or layout can support may generate overshoot, higher local heating, insulation stress, and premature aging. A gate oxide that drifts or weakens may alter switching response long before hard failure occurs. A device that survives lab qualification but carries latent defects may still fail early in vehicle service. These risks directly affect inverter durability, charging performance, warranty cost, and driver confidence.[1,2,6]

Substrates Carry More Than Heat

In EV power modules, the substrate is not just a heat spreader. It must provide electrical insulation, move heat away from the die, support copper circuitry, and tolerate repeated thermal cycling. Direct-bonded copper (DBC) on alumina, aluminum nitride, or silicon nitride remains widely used. Aluminum nitride offers much higher thermal conductivity than alumina, which makes it attractive for high-power designs, but it is mechanically less forgiving. Published work and industry technical reviews note that AlN-based DBC can face greater thermo-mechanical reliability limits during cycling, while alumina is tougher but thermally weaker.[9,10]

That tradeoff matters in EV duty cycles because traction inverters and power converters see repeated temperature swings during acceleration, regenerative braking, fast charging, and ambient weather changes. Cracking, copper-ceramic delamination, and solder or sinter fatigue can follow when thermal expansion mismatches are not properly handled.[7,11] The material choice becomes a balance among heat removal, insulation, mechanical durability, cost, and manufacturability. Silicon nitride is often discussed as an attractive middle path because it offers strong fracture toughness with good thermal performance, though usually at higher cost and with process complexity.[8]

What has gone wrong historically in power modules is well documented. Bond wires have often been identified as one of the weakest elements in module lifetime, and substrate-related fatigue is a known wear-out path under power cycling.[9,12] That history is one reason newer module designs are steadily moving toward stronger substrate systems and bond-wire-light or bond-wire-free topologies.

Interconnects Still Decide Lifetime

Interconnect materials and structures remain central to EV reliability. Traditional aluminum wire bonds are proven and widely used, but they are also vulnerable to heel cracking, lift-off, and fatigue during thermal and power cycling. Survey literature on power module reliability identifies bond wires as a common failure location and ties those failures to thermo-mechanical stress at the bond interface.[9,10] Additional studies show that bond quality and process parameters strongly influence degradation rate under cycling.[13]

This is why alternatives such as copper clips, ribbon bonds, and sintered die attach are gaining ground. Silver sintering is attractive because it offers high thermal conductivity and high-temperature stability compared with many conventional solders. At the same time, it is not a cure-all. Sintered joints still depend on surface condition, pressure, porosity control, and process consistency. Poorly controlled sintering can leave voids or weak regions that undermine the expected lifetime benefit.

Why does this matter? Because interconnect degradation often shows up first as rising electrical resistance and temperatures. That can turn a manageable packaging issue into a module-level failure. In an EV inverter or onboard charger, this may lead to power derating, thermal shutdown, or permanent damage to neighboring devices. The link between materials choice, process discipline, and field reliability is direct.

Thermal Materials Can Set the Failure Clock

Thermal management is one of the clearest examples of materials dictating system life. Even when semiconductor devices are highly capable, the actual junction temperature depends on the interfaces between die, substrate, baseplate, cold plate, and coolant loop. Thermal interface materials (TIMs) are often the weak link because their real-world performance can drift over time. NREL has noted that grease-based TIMs can suffer from application problems, pump-out, and dry-out, and that in-situ performance may be worse than supplier datasheet values.[14] NREL also reports that improved TIM performance can materially reduce thermal resistance in compact electronics.[15]

If a TIM pumps out, dries out, cracks, or loses contact pressure, the result is higher thermal resistance and higher junction temperature. That can reduce semiconductor lifetime, accelerate solder or sinter fatigue, and change switching behavior. In practical terms, what goes wrong may begin as a few extra degrees and end as a large reliability loss. This is one reason EV power electronics teams are paying closer attention to gels, pads, graphite systems, phase-change materials, and other alternatives, each with its own balance of thermal performance, compliance, aging behavior, and assembly tolerance.

High Voltage Makes Cleanliness and Insulation a Materials Problem

As EV platforms move toward 800 V architectures and charging systems push similar voltage ranges, contamination and moisture become more dangerous. Residues that might be tolerable in lower-voltage electronics can contribute to leakage current, electrochemical migration, dendritic growth, tracking, and insulation breakdown when bias, humidity, and field strength rise together. The Global Electronics Association's white paper on charging station electronics highlights high voltage, humidity, contamination, and thermal extremes as key stressors in outdoor charging systems.[16] Recent APEX EXPO work has also focused on high-voltage temperature-humidity-bias behavior and protective measures for printed boards and coatings.[17]

This is important because the consequences can be intermittent and hard to diagnose. A charger, inverter, or converter may pass routine checks and still fail in humid service. A board may appear electrically sound until contamination, condensation, and voltage interact in the field. For EV electronics, materials such as laminates, solder masks, coatings, sealants, and cleaning chemistries are part of the insulation system, whether designers label them that way or not.

PFAS: Useful Materials, Hard Questions

PFAS-related materials are now part of the EV reliability discussion for two reasons. First, PFAS chemistry has been widely used because fluorinated materials offer chemical resistance, thermal stability, dielectric performance, low surface energy, and durability in coatings, seals, wire insulation, processing aids, fluids, and related applications. The EPA has noted that fluoropolymers offer fire resistance and oil-, stain-, grease-, and water-repellency, and are used in sectors such as electronics and automotive.[18] Second, PFAS are under growing regulatory and market pressure due to concerns about persistence and associated environmental and health risks. The EPA and OECD both describe PFAS substitution as a major ongoing challenge, and ECHA has continued advancing the EU-wide restriction process.[19,20,21]

If PFAS are removed carelessly, the replacement material may have lower dielectric strength, higher moisture uptake, poorer chemical resistance, lower thermal endurance, worse friction and wear behavior, or lower long-term stability. In an EV environment, that can mean reduced insulation margin, swelling, cracking, softening, fluid incompatibility, shortened seal life, or coating performance loss. PFAS substitution is therefore not only a compliance issue, but also a design validation issue.[22]

What are the alternatives? There is no single universal replacement, making this a difficult topic. OECD work on coatings, paints, varnishes, lubricants, and hydraulic oils points to non-PFAS alternatives such as silicones, hydrocarbon and ester-based fluids, mineral oils, synthetic esters, polyalphaolefins, certain waxes, acrylics, urethanes, epoxies, and ceramic or sol-gel-based systems, depending on the function being replaced.[23] In dielectric and thermal-fluid applications, ester and hydrocarbon families are often discussed as PFAS-free options, though OECD notes that equivalent performance is not always established and substitution barriers remain significant.[20] In coatings, non-fluorinated silicone, epoxy, polyurethane, sol-gel, and plasma-deposited systems may work for some functions, but each comes with tradeoffs in repellency, processability, durability, service temperature, or repairability.[21]

The practical takeaway is that PFAS substitution should be treated as a function-by-function materials redesign exercise. The question is not, "What replaces PFAS?" but "Which PFAS function is being replaced, under what environment, with what test evidence?" That is the level at which reliable decisions get made.

Materials Matter Because Failures Compound

The broader lesson is that materials decisions do not stay confined to the materials team. They affect thermal headroom, insulation margin, switching behavior, environmental durability, manufacturability, service life, and safety. When materials are well selected and validated under realistic conditions, they deliver the benefits promised by EV platforms. When they are poorly selected or changed without enough validation, the system may still be launched, but it carries hidden life limits.

On the road to EV reliability, materials are the starting point. Wide-bandgap semiconductors, ceramic substrates, advanced interconnects, TIMs, coatings, fluids, and insulation systems all matter because they determine whether the electronics can survive real voltage, heat, contamination, and real-time in service. Reliability begins with materials, and in EV electronics, they still decide how the story ends. **SMT007**

Stanton Rak is principal consultant for SF Rak Company, and co-chair of the APEX EXPO Technical Program Committee.

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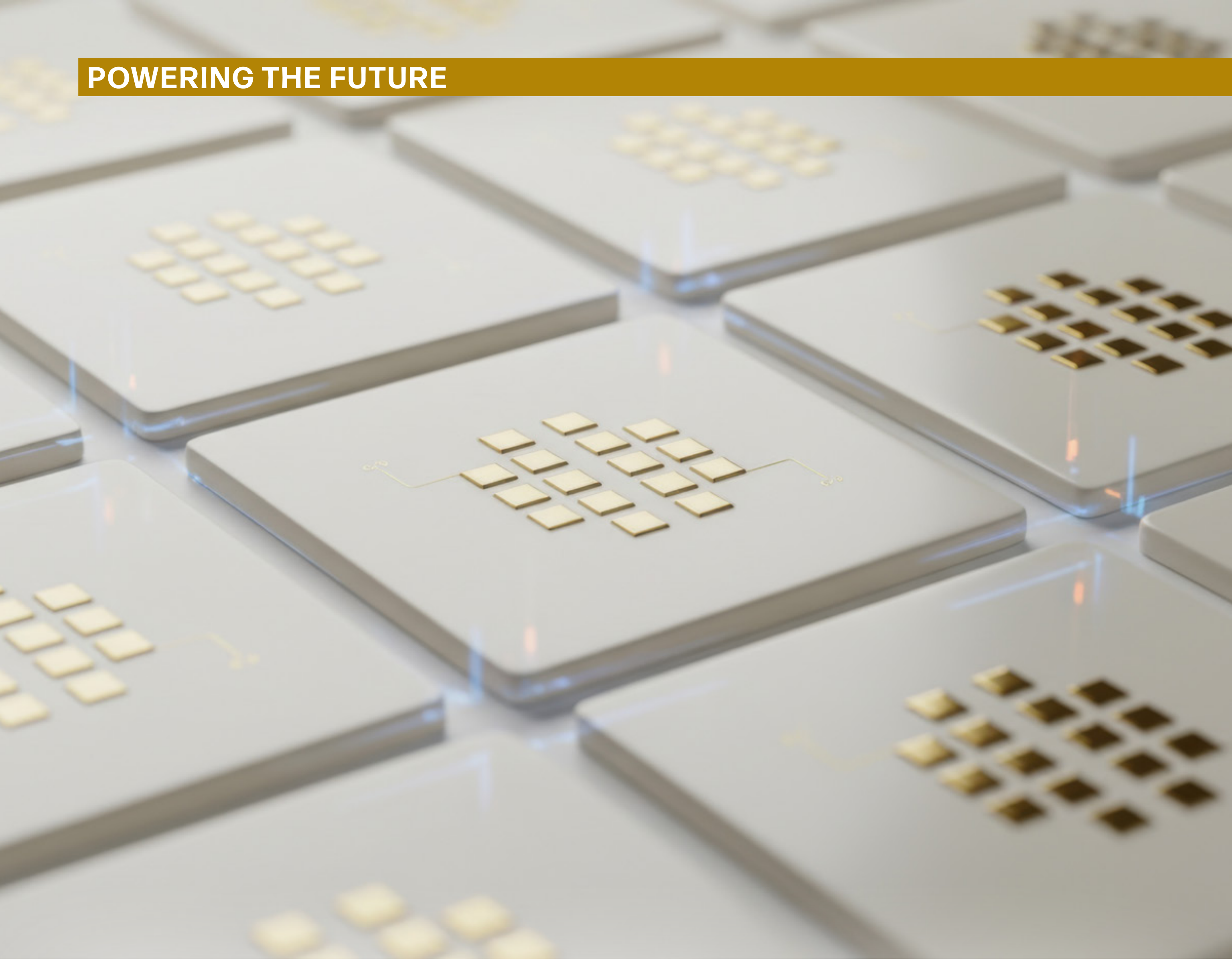
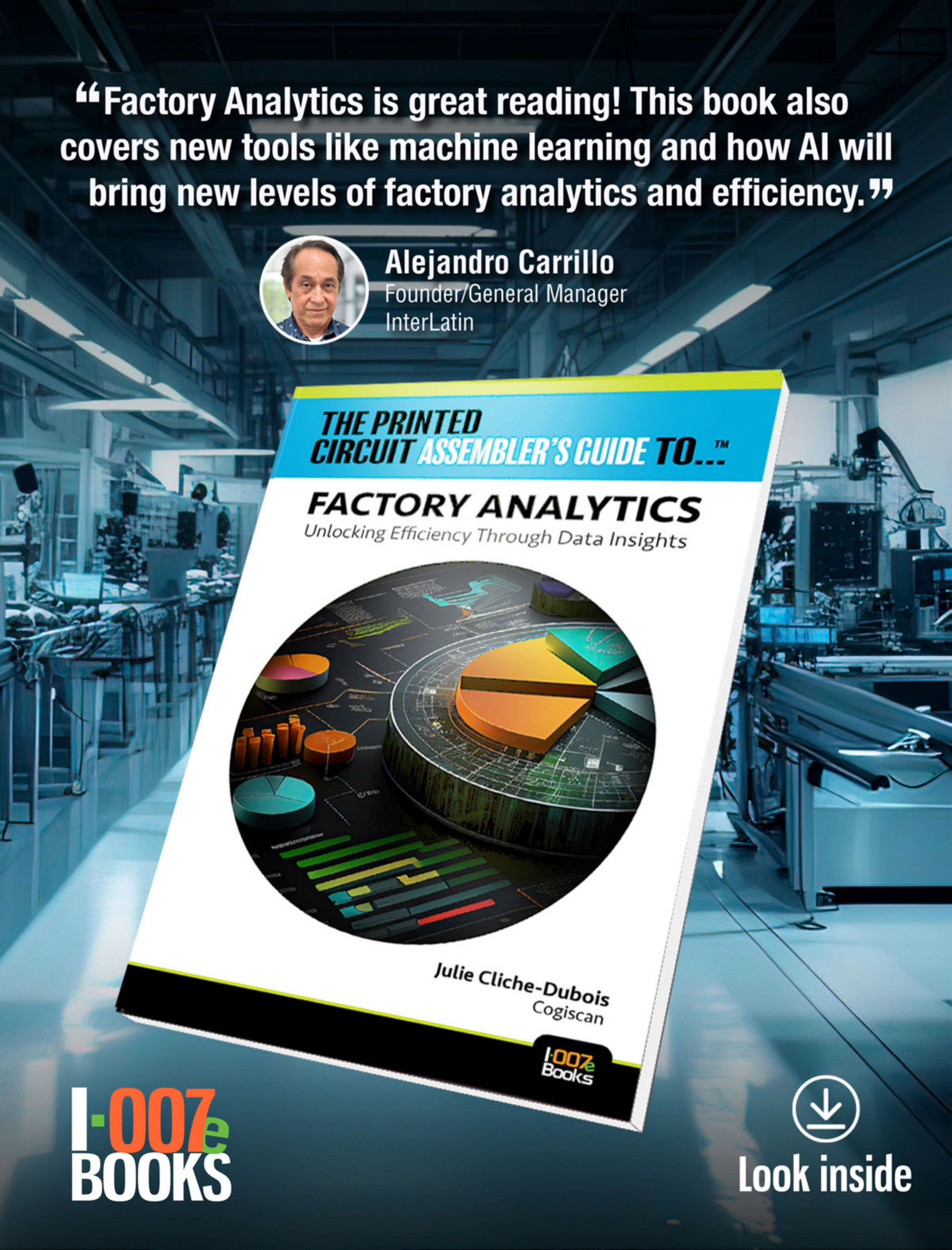


When Material Choice Defines RF Performance

BY BRIAN BUYEA, REMTEC INC.

In RF and microwave design, deciding on which materials to use determines whether your design merely works or truly performs. Yet, designers too often fall back on material selection that is familiar, available, or "good enough." However, once you move into higher frequencies, higher power densities, and tighter performance tolerances, "good enough" becomes the very thing that holds your design back. That's where ceramic substrates become a fundamentally different approach to solving RF challenges. For EMS providers, these material shifts directly impact assembly processes, thermal management strategies, and long-term reliability outcomes.


"Factory Analytics is great reading! This book also covers new tools like machine learning and how AI will bring new levels of factory analytics and efficiency."
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Look inside

The Reality of RF Design

RF engineering is unforgiving. At low frequencies, materials like FR-4 can perform adequately. The system tolerates a certain amount of loss, variation, and thermal inefficiency. But as frequency increases, that margin disappears. Variability that once went unnoticed now creates measurable and often unacceptable performance degradation. This physical shift forces every RF engineer to ask: Is the material helping the design or limiting it?

> "Choosing a material that aligns with the performance requirements of the application stabilizes the entire system."

Stability Where It Matters Most

One of the most critical factors in RF design is dielectric stability. Ceramic substrates, such as alumina and aluminum nitride, provide consistent dielectric properties across a wide frequency range. That consistency translates directly into predictable signal behavior, something every RF engineer depends on.

Traditional PCB materials, particularly FR-4, introduce variability. As frequency increases, dielectric loss rises and consistency drops. What works at one frequency or under one condition may not behave the same way under another. That variability creates uncertainty, and in RF design, uncertainty is risk.

The Thermal Equation

If electrical performance defines RF systems, thermal performance sustains them. As frequencies climb and power densities increase, heat generation becomes a dominant factor. Left unmanaged, it impacts everything from signal integrity to component lifespan. The difference between material systems becomes impossible to ignore.

Ceramic substrates inherently conduct heat far more efficiently than traditional PCB materials. Aluminum nitride, for example, offers thermal conductivity orders of magnitude higher than that of FR-4. Now, instead of trapping heat within the structure, ceramics act as integrated heat spreaders, reducing localized hotspots and maintaining more uniform operating temperatures. They also provide more stable electrical performance, longer component life, and greater overall system reliability.

Signal Integrity at Scale

Ceramic substrates address signal integrity challenges at higher frequencies by exhibiting lower dielectric loss, thereby reducing signal attenuation. These types of substrates maintain tighter control over impedance and minimize dispersion, allowing signals to propagate more cleanly and predictably.

By contrast, materials not designed for high-frequency performance introduce compromises, including increased loss, greater variability, and reduced efficiency. While those compromises may be manageable in lower-frequency applications, they are not manageable in RF and microwave systems.

Where Performance Becomes Non-negotiable

There are environments where failure is simply not acceptable. In defense systems, signal precision and durability must be maintained under extreme conditions. In aerospace applications, materials must withstand thermal cycling, vibration, and altitude variations without degradation. In telecommunications infrastructure, especially as frequencies push into millimeter-wave ranges, performance demands continue to rise.

In these contexts, material choice is about necessity. I've found that ceramic substrates deliver the level of performance required for these environments to function reliably. They provide stability where instability cannot be tolerated.

The Shift in Engineering Thinking

Engineers are not adopting ceramic substrates because they are new or novel, but because the demands of modern systems are changing. Reliability expectations, particularly in mission-critical applications, mean there is less room for inefficiency.

Traditional materials, while still valuable in many contexts, introduce limitations that are increasingly difficult to manage within these constraints. Ceramics, on the other hand, address these challenges directly by reducing variability, improving thermal management, and enhancing signal integrity. They simplify the design problem by removing variables that would otherwise need to be managed elsewhere.

A Different Way to Think About Materials

It is easy to frame material selection as a trade-off: cost vs. performance, familiarity vs. innovation, or simplicity vs. capability. But in RF design, that framing can be misleading because the true cost of a material is its impact on the entire system: loss, thermal inefficiency, and variability.

A material that introduces loss requires compensation elsewhere. A material that traps heat demands additional thermal management. A material that varies introduces risk that must be mitigated through design adjustments and testing. These are not isolated effects, and they can ripple through the system. Choosing a material that aligns with the performance requirements of the application stabilizes the entire system.

Final Thought

RF design has always been about precision, but as systems evolve, that precision must extend beyond circuit layout and component selection to include the materials themselves. They actively shape how signals behave, how heat is managed, and how reliably the system performs over time.

Ceramic substrates represent a shift in how engineers approach these challenges, not as incremental improvements, but as foundational solutions. In a field where performance margins are narrowing, that shift is inevitable. **SMT007**

Brian Buyea is president of Remtec Inc. To read past columns, **click here**.

BY ROB RONAN, RETRONIX

RETHINKING RESILIENCE

How Electronic Component Recovery Is Reshaping the Supply Chain

The first article in this series explored how semiconductor shortages exposed the fragility of global supply chains. But shortages are only one part of a broader challenge. The electronics supply chain has always been complex, but in recent years it has become something else entirely: unpredictable.

From pandemic-driven disruptions to geopolitical tensions and sudden demand spikes, manufacturers have been forced to confront the hard truth that traditional sourcing strategies are no longer enough. Resilience is now the priority, and increasingly, that resilience is being built not just through diversification and forecasting, but through a smarter approach to electronic components themselves.

The Perfect Storm of Supply Chain Challenges

Several structural weaknesses in the electronics ecosystem persist. Component shortages are longer-lasting, with lead times stretching from weeks into months or even years for certain semiconductors. Obsolescence has accelerated as product lifecycles shrink, leaving manufacturers scrambling to support legacy systems with dwindling component availability.

Secured sourcing has become critical in industries such as aerospace, defense, and medical, where traceability and authenticity are non-negotiable. Price volatility has made budgeting difficult, with spot market pricing often detached from historical norms.

Excess and waste remain persistent issues, as companies overbuy to hedge against uncertainty, only to be left with surplus inventory later.

Individually, these challenges are manageable. Together, they create a landscape where agility and innovation are essential.

Beyond Traditional Procurement

Historically, procurement strategies have focused on securing new components through authorised distribution channels. While this remains important, it is no longer sufficient on its own. Independent distribution has helped bridge gaps, but it also introduces risks.

As a result, many organisations are looking for alternatives that offer both reliability and certainty. This is where electronic component recovery enters the conversation.

At its core, component recovery is about extracting usable, high-quality components from existing assemblies, whether from excess stock, decommissioned equipment, or manufacturing surplus, and returning them to the supply chain. While the concept is not new, its relevance has grown significantly.

Recovered components can offer several advantages:

Availability: Hard-to-find or obsolete parts can often be sourced through recovery when they are no longer in production.

Cost efficiency: Recovered components can be more economical than sourcing through volatile spot markets.

Sustainability: Extending the life of components reduces electronic waste and supports circular economy goals.

Speed: Recovery processes can sometimes deliver parts faster than traditional procurement routes with long lead times.

However, these benefits depend entirely on the quality and integrity of the recovery process.

Component Recovery Industry Standard

For many engineers and procurement professionals, the idea of re-used components raises an immediate concern: reliability. This concern is valid. Electronic components are sensitive devices, and improper handling or recovery can compromise performance. The key difference is in how the recovery is performed.

While best practices have evolved over time, the absence of a unified global standard has, until now, left room for skepticism.

A new industry standard for electronic component recovery is currently being drafted, bringing together experts from across the electronics manufacturing and supply chain ecosystem. The goal is to define clear, repeatable processes that ensure recovered components meet stringent quality, reliability, and traceability requirements.

Importantly, the development of this standard is being guided by individuals with deep, practical experience in the field. I serve on the committee, and my involvement reflects a broader effort to ensure the standard is grounded in the realities of high-reliability recovery operations.

The emerging framework is expected to cover key areas such as controlled de-soldering techniques, inspection and test methodologies, handling protocols, and documentation requirements. For manufacturers and procurement teams, this will provide a much-needed benchmark helping to differentiate credible recovery processes from less rigorous alternatives.

In turn, standardization is likely to accelerate adoption. By reducing uncertainty and establishing a common language for quality, it enables organizations to integrate recovered components into their supply chains with greater confidence.

Looking Ahead

The electronics supply chain is unlikely to become less complex in the near future. If anything, emerging technologies and shifting global dynamics will introduce new layers of uncertainty. In this environment, resilience will depend on the ability to think differently about resources.

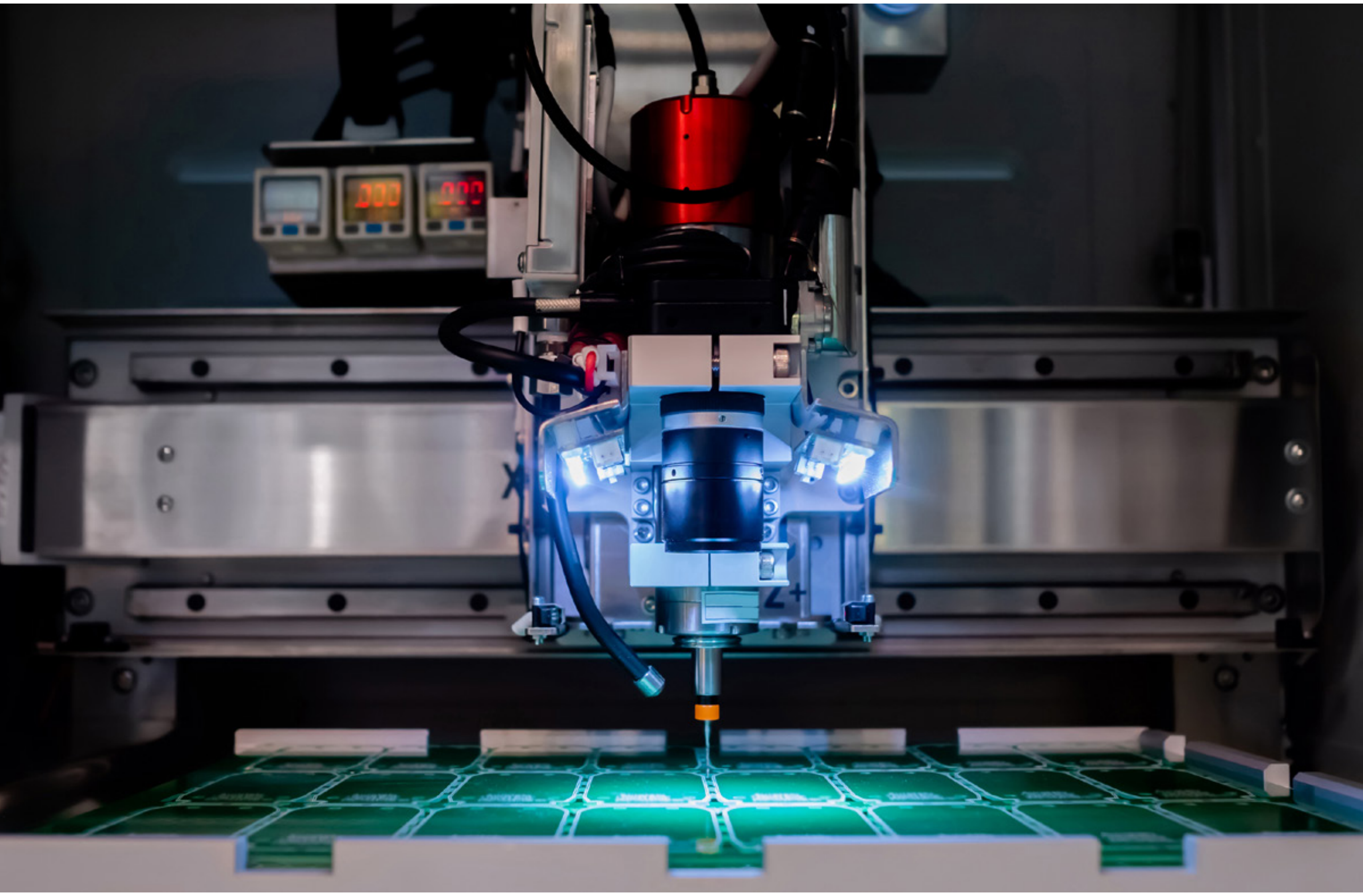
As the demand for component recovery grows, so does the importance of working with experienced partners who understand both the technical and commercial dimensions of the process. Not all recovery services are created equal. The difference lies in process control, testing capability, and a deep understanding of component behavior.

Organisations that specialise in this field, particularly those with a long track record and strong industry accreditation, are helping to set the benchmark for what high-quality recovery looks like. Their work is quietly enabling manufacturers to navigate shortages, manage obsolescence, and reduce waste without compromising on performance.

The smartest solution may not be to find new components but to make better use of the ones we already have.

Rob Ronan is the UK sales and support manager at Retronix Ltd.

When Traditional Depaneling Methods *Reach Their Limits*



BY JOSH CASPER, HORIZON SALES

PCB depaneling has traditionally been viewed as a relatively straightforward process in electronics manufacturing. Once the assembly process is complete, boards are separated from the panel and moved downstream for final assembly, test, or packaging. For years, manufacturers have relied on methods such as routing, V-score separation, and punch systems to handle this step efficiently and cost-effectively.

However, smaller board geometries, thinner substrates, flex substrates, and edge-mounted components are increasingly pushing traditional separation methods to their limits. Here, we'll explore why PCB depaneling requirements are changing, where traditional methods still fit well, and why laser depaneling is gaining attention in modern electronics manufacturing.

The Changing Demands of PCB Design

Modern PCB designs place far greater demand on the depaneling process than even a decade ago. Today's assemblies often include components placed closer to board edges, thinner PCB materials, complex board layouts, rigid-flex constructions, and higher density layouts.

These changes create new challenges during board separation. Mechanical stress that may have once been insignificant can now create cracked solder joints, damaged components, and/or board flex that affects long term reliability.

At the same time, manufacturers continue pushing for tighter panel utilization to maximize material efficiency. Narrow tabs, tighter spacing between boards, and unconventional board shapes leave less room for traditional depaneling approaches. As a result, depaneling is no longer the final mechanical step in the process. In many applications, it has become another critical consideration for product quality and reliability.

Where Traditional Depaneling Still Works Well

Traditional depaneling methods remain highly effective in many manufacturing environments.

V-score separation: V-score systems offer a fast and cost-effective solution for straight-edge board designs. For high-volume products with durable board constructions and adequate component clearance, these systems remain extremely practical.

Routing systems: Routing systems offer greater flexibility for irregular board shapes and remain widely used throughout the industry. Automated routers provide clean edge quality and can handle a broad range of PCB designs with relatively low programming and setup complexity.

Punch systems remain valuable in high-volume applications where repeatability and cycle time are priorities. Once tooling is developed, punch systems can provide extremely fast separation speeds.

These technologies serve the industry well, so the challenge is not that traditional methods no longer work, it's that PCB designs are increasingly entering areas where mechanical separation introduces new levels of risk.

Where the Challenges Begin

As components move closer to PCB edges, mechanical stress becomes more difficult to manage. Depaneling force that was once absorbed easily by larger, thicker boards now transfers directly into compact assemblies populated with fragile components. Several components can become more susceptible to stress-related damage during separation.

Thin materials and flex circuits create additional complications. These assemblies lack the rigidity needed to tolerate traditional mechanical handling, increasing the risk of board flex or deformation during depaneling. Board geometry is also changing. Irregular shapes, internal cutouts, and densely nested panel layouts can make mechanical tooling more complicated and less efficient.

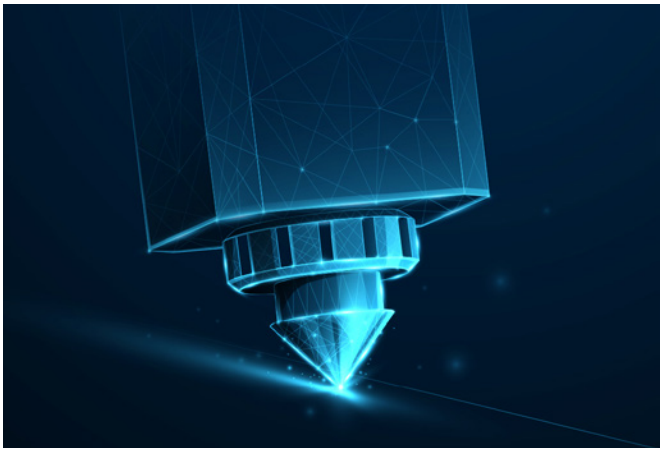
In many cases, manufacturers are discovering that the depaneling process itself has become a contributor to defects that are difficult to diagnose later in production.

Why Laser Depaneling Is Gaining Attention

Laser depaneling addresses many of these challenges by removing mechanical stress from the separation process. Instead of physically cutting or breaking the board apart, laser systems utilize focused energy to separate the PCB with minimal force applied to the assembly itself. This makes the technology particularly attractive for:

- Thin substrates
- Flex and rigid-flex circuits
- Densely populated boards
- Edge-mounted components
- Sensitive ceramic devices
- Small form factor products

Some advantages include flexibility, as complex board geometries that may require specialized router tooling can often be handled through software-driven path adjustments; and precision, as laser systems can create extremely narrow cutting paths while maintaining clean edge quality, allowing manufacturers to optimize panel utilization without introducing additional mechanical risk.



How Laser Depaneling Technology Has Evolved

A big misconception about laser depaneling is that the process simply burns through the PCB material. Years ago, that perception may have had some validity. Early laser systems were slower, generated larger heat-affected zones, and often struggled to manage certain substrate materials. Manufacturers often viewed laser depaneling as too slow, too aggressive, or too limited for broader SMT production environments.

However, the technology has advanced significantly in the past decade. Modern laser depaneling systems are designed around controlled material ablation rather than brute force cutting. Instead of melting through the substrate in an aggressive pass, today's systems remove small amounts of material in multiple controlled passes. This process dramatically reduces thermal stress while improving overall edge quality and process consistency.

The result is a much cleaner separation process with minimal discoloration, reduced carbonization, and significantly smaller heat-affected zones compared to earlier generations of equipment.

Speed improvements have also played a major role in broader adoption. In many applications, manufacturers now intentionally utilize multiple high-speed passes rather than a single deeper cut. While this may initially sound slower, the approach improves cut quality, reduces stress on the substrate, and creates a more stable overall process.

Cost reduction has also contributed to the growing accessibility of the technology. Earlier laser depaneling systems were often viewed as highly specialized solutions reserved for niche applications. As laser technology has matured, equipment costs have become more approachable while improvements in throughput and reliability have strengthened the overall return on investment. The reduction in scrap, tooling wear, fixture requirements, and stress-related defects can significantly offset the higher upfront investment.

This evolution has been particularly important for sensitive materials such as flex circuits, rigid-flex boards, thin substrates, and densely populated assemblies, where excessive heat or mechanical force can quickly create reliability concerns.

As a result, laser depaneling has shifted from being viewed as a niche process into a much more practical solution for modern electronics manufacturing environments with more board complexity and stress sensitivity.

Conclusion

Like any technology, laser depaneling is not the right fit for every application. Traditional routing and V-score systems still make excellent sense for many standard PCB designs, particularly in applications where board materials are thick and rigid, component edge clearance is generous, production volumes are high, and stress sensitivity is low.

Laser systems typically involve higher upfront investment and may introduce additional process considerations depending on material type and board construction. The key is understanding where the technology solves a meaningful manufacturing problem.

PCB depaneling requirements are evolving alongside the assemblies themselves. Laser depaneling is gaining attention not because traditional methods have disappeared, but because modern PCB designs increasingly demand lower stress, greater precision, and improved flexibility.

Josh Casper is president of Horizon Sales. To read past columns, click here.

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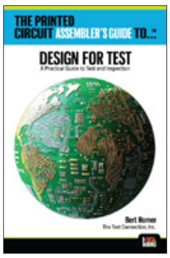

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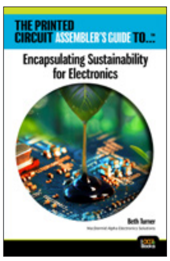

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