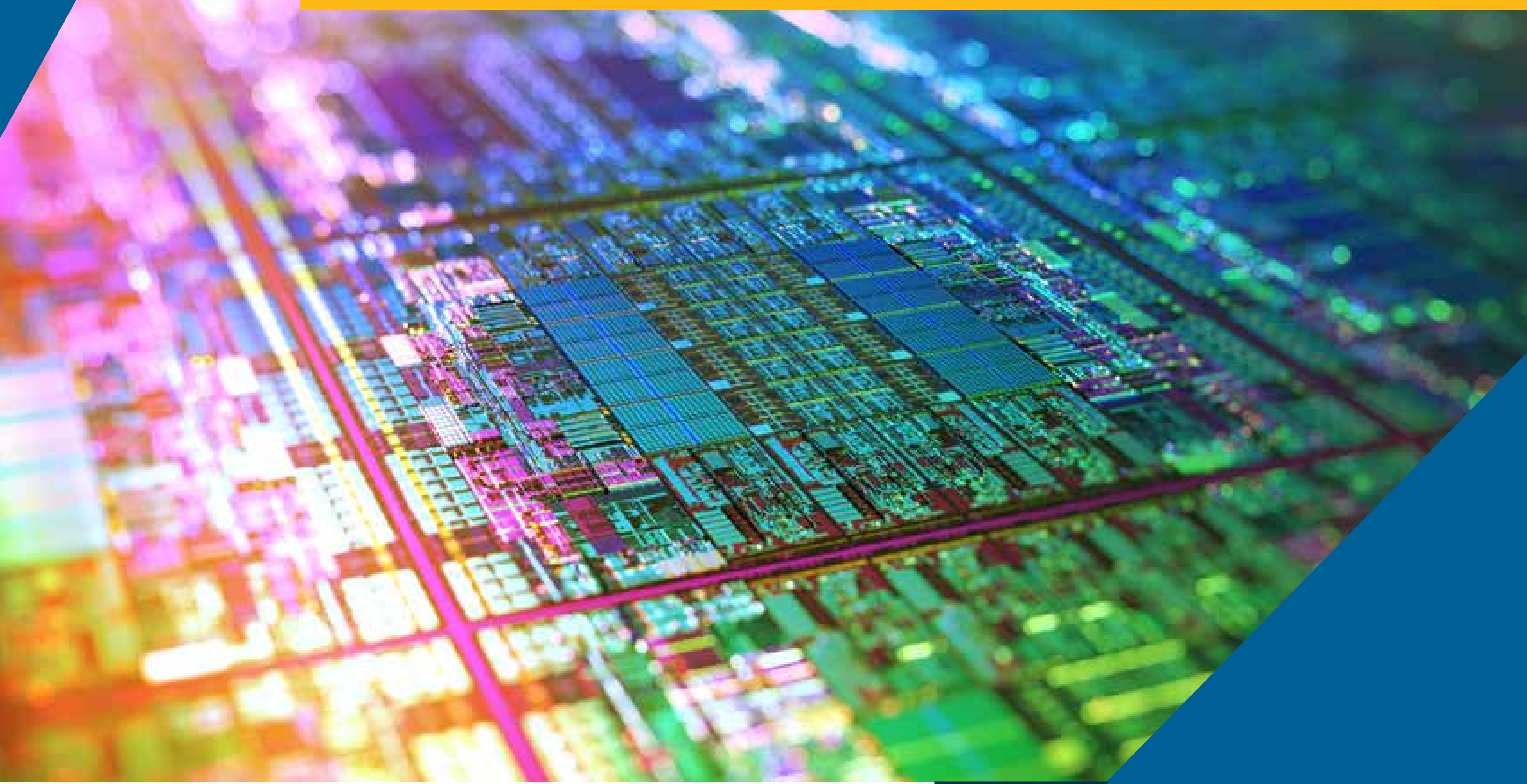
BUILD
ELECTRONICS
BETTER

AN ANALYSIS OF THE NORTH AMERICAN SEMICONDUCTOR AND ADVANCED PACKAGING ECOSYSTEM

Rebuilding U.S. Capabilities for the 21st Century



An IPC Summary Report — November 2021

Study Overview

IPC has undertaken a thorough, data-driven analysis of the global semiconductor and advanced packaging ecosystem and makes recommendations to address capability and capacity gaps within North America. This study is intended to help inform government policy and investment strategy to strengthen the North American advanced packaging ecosystem. This Summary Report is a synopsis of the key findings and recommendations of the Full Report, which runs 115 pages.

Key Findings

- After more than two decades of outsourcing, North America now finds itself in a worrisome predicament: it can design the most cutting-edge electronics but cannot manufacture them.
- The offshoring of manufacturing spans the entire electronics ecosystem, including the advanced packaging of semiconductor chips for which the North American share of global production is just 3 percent.
- To achieve greater innovation, resiliency, and security within the semiconductor supply chain, federal investments in semiconductors must be paired with robust, multibillion dollar federal investments in advanced packaging.
- Most urgently, the United States needs to invest in development and production of advanced integrated circuit (IC) substrates for which there are only nascent capabilities domestically.
- The United States has more than 25 outsourced semiconductor assembly and test (OSAT) companies, many with impressive capabilities. However, U.S. OSATs lack capacity to meet increased demand.
- Failing to strengthen U.S. advanced packaging capabilities while boosting production of chips will lengthen the existing semiconductor supply chain, as manufacturers will be forced to send their chips abroad for packaging and assembly.
- The U.S. must move toward a “silicon to systems” approach that strengthens the entire U.S. electronics manufacturing ecosystem (including printed circuit board manufacturing and hardware assembly) as a necessary means to a secure, resilient supply chain and ongoing U.S. leadership in technological innovation.

SEMICONDUCTOR ADVANCEMENTS

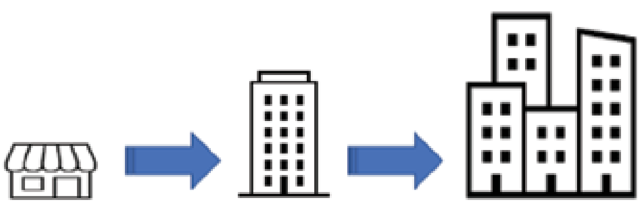
In the mid-1960s, future Intel founder Gordon Moore discerned that the number of transistors that could fit onto an integrated circuit could be doubled every two years, allowing the production of ever more powerful semiconductor chips with greater cost efficiencies. As an empirical claim, Moore's Law held true for more than half a century. But the days of keeping pace with Moore's law are over. Silicon advancements have slowed, along with economic efficiencies. Instead, semiconductor designers are increasingly taking advantage of advancement of electronic interconnection within the packaging to achieve greater functionality and economic efficiencies they previously realized through silicon scaling.

WHAT IS ADVANCED PACKAGING?

Semiconductor chips are fragile and must be protected from thermal and mechanical stresses during operation. To provide this protection, chips are "packaged" using several different materials, mainly plastics. Once packaged, chips become active logic devices that perform computing and/or memory functions. Chips are just one of many different types of essential components within an electronic system.

Protecting chips remains critically important, but advancements in packaging are now being driven by the need to leverage "on package integration" as an alternative technological path to the promise of Moore's Law. On-package integration is commonly referred to as heterogeneous integration which involves integrating multiple chiplets (logic or memory) in a single package. A chiplet is a functional circuit block fabricated on a wafer, typically in a smaller size than what would be possible in a system on chip. The chiplet can be applied to a substrate in a 2D configuration or stacked one on top of the other in a 3D configuration within a package to produce greater functionality and greater processing speed.

ELECTRONICS ADVANCED PACKAGING:
THINK OF A DENSE, MULTI-USE BUILDING



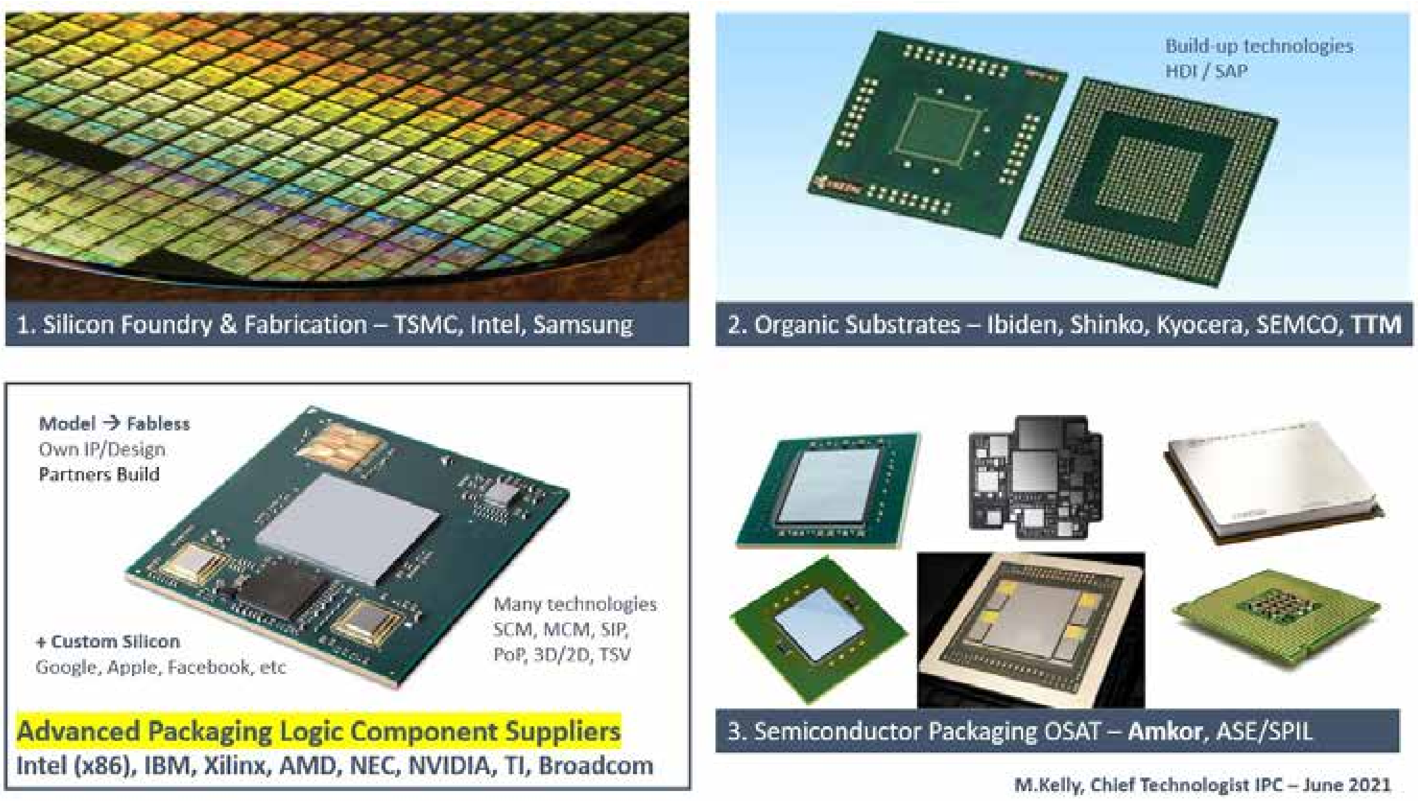
One way to understand advanced packaging is by comparison to urban design. Simple business districts are characterized by modest structures with one purpose and simple connections internally (electrical, plumbing, telecom) and externally (streets, public utilities). In denser urban settings, designers need to make more efficient use of limited real estate, leading to taller building with more complex internal feature (elevators, energy and security systems) as well as external connections to support an increased number of occupants and business activities (e.g., higher-capacity utilities, streets and highways, parking systems).

Likewise, simple electronics components may have relatively few internal parts and may be connected to one another via basic infrastructure such as printed circuit boards and wiring. More complex electronic systems require designers to pack more functionality into the semiconductor packages via more parts, layers, and interconnections. Connecting more chips within a multilayer package comes with new technological hurdles. Interconnects within a package can be as small as nine microns – on fifteenth the width of a human hair.

SEMICONDUCTOR MANUFACTURING ECOSYSTEM

Semiconductor manufacturing has three principal segments: semiconductor fabrication, IC-substrate fabrication, and OSAT assembly.

- **Silicon Fabrication:** Chip manufacturers produce thin pieces of silicon upon which thousands, millions or even billions of transistors are etched. These silicon chips are responsible for the computing power and/or memory commonly associated with integrated circuits and, by extension, all technologies that rely on electronics.
- **Integrated Circuit Substrates**: IC substrate manufacturers produce base layers used in the packaging of integrated circuit chips. The substrate connects chips with each other and with the printed circuit board (PCB), in addition to protecting, reinforcing, and supporting the IC chip.
- **Outsourced semiconductor assembly and test (OSAT):** OSAT companies offer IC-packaging and test services for chip manufacturers. Their role comes into play at the end stage of the semiconductor manufacturing process following wafer and IC-substrate fabrication. These companies offer packaging and/or assembly solutions that turn bare semiconductors into finished semiconductor packages. These solutions help to protect the tiny circuit on each chip as well as facilitate electrical connections and heat dissipation. After packaging, final testing is conducted to ensure that finished semiconductor packages meet quality, reliability, and performance requirements.



SEMICONDUCTOR SUPPLY BASE

The semiconductor ecosystem is bult upon a robust mix of local, regional, and global suppliers. Next-generation package designs and architectures are made possible by continuous improvements in base materials, manufacturing equipment, and process advancements that span all sectors of the supply chain. Addressing all these areas is necessary if the goal is to achieve a sustainable and resilient North American semiconductor ecosystem. IPC's advanced packaging full report discusses the need for strong materials, design, and equipment supply chain that underpins the supply base.

GLOBAL SEMICONDUCTOR INDUSTRIAL ASSESSMENT

Companies headquartered in Asia are global leaders across the entire semiconductor supply chain, with the top companies dominating market share in semiconductor fabrication (TSMC, Samsung); advanced IC-substrate fabrication (Unimicron, Ibiden, SEMCO, Nan Ya, Shinko); and OSAT assembly and test, (in which Taiwan is the leader with nine companies including ASE+SPIL and Powertech Technology). North America lags behind Asia in capacity, but technical capability is a source of concern as well. Asian manufacturers also dominate the printed circuit board (PCB) and electronic manufacturing services (EMS/ODM) sectors, where outsourcing and off-shoring have been prevalent over the past 20 years. Asia's dominance in electronics arises from the region's breadth of manufacturing capabilities from chips through advanced packaging through PCB fabrication and final hardware / system assembly capability.

	GLOBAL SHARE	
85%	Semiconductor Design	5%
12%	Manufacturing	75%
3%	Packaging	97%

North American electronics manufacturing capabilities.

Source: U.S. Department of Defense

NORTH AMERICAN ADVANCED PACKAGING ASSESSMENT

After more than two decades of outsourcing, North America now finds itself in a worrisome predicament: it can design the most cutting-edge electronics but cannot manufacture them. This trend spans across the entire electronics ecosystem, but it has been driven in recent years by the semiconductor industry's embrace of the "fabless" business model. A fabless company designs technologies for which it holds the intellectual property but outsources the manufacturing to third parties. For all the benefits of the fabless model, it places companies in the difficult, long-term position of being unable to physically produce semiconductor chips. As chip manufacturing has moved increasingly to third-party foundries offshore, so too have the supply chains that support and leverage silicon fabrication. Today, the North American share of advanced packaging of semiconductor chips constitutes just 3% of global production.

Semiconductor Fabrication

Chip plants run 24 hours a day, seven days a week. They do that for one reason: cost. Building an entry-level factory that produces 50,000 silicon wafers per month costs about $15 billion. Most of this is spent on specialized equipment, a market that exceeded $60 billion in sales in 2020. Three companies—Intel, Samsung and TSMC—account for most of this output. Their factories are more advanced and cost over $20 billion each. This year, TSMC is expected to spend as much as $28 billion on new plants and equipment.

Even more daunting, these facilities can become obsolete in five years or less. Chipmakers must generate significant profit to reinvest in their facilities to stay current with ever advancing technology demands. Only the biggest companies can afford to build multiple plants, which is important for companies engaged in high-volume manufacturing. The more a company manufactures, the better they get at it. Yield—the percentage of chips that are accepted and not discarded—is the key measure, and anything less than 90% is considered a problem. But chipmakers can only exceed that level by learning expensive lessons over and over and building on that knowledge. These brutal economics mean very few companies can afford to keep up and/or break in.

Overall, the level of recent or expected investment in U.S. semiconductor fabrication is strong although a significant percentage of that expected investment is premised on federal support. We strongly support the bipartisan effort to appropriate more than $50 billion for CHIPS for America Act. Failure to do so will signal a lack of U.S. commitment to U.S. semiconductor manufacturing and innovation.

IC Substrates

The lack of IC substrate manufacturing in North America is the biggest issue identified in this study. There is almost no capability in the United States to produce the most advanced IC substrates, called Flip Chip Ball Grid Array (FCBGA) or Flip Chip Chip Scale Package (FCCSP). The U.S. also has very limited capability and capacity to produce lower-end wire bonded substrates.

The U.S. needs to invest in IC substrates most urgently. There are significant barriers to entry for FCBGA manufacturing, including an estimated $1 billion investment per factory and a need to address a 20+ year market leader know-how gap, weak sub-tier supply, skilled workforce shortage (1,000 workers / facility), and lack of raw materials. We are aware of leading IC substrate manufacturers that are surveying opportunities in North America, and that domestic PCB suppliers are attempting to enter the market to produce substrates. While new entrants are expected, leveraging innovative new technologies, caution is advised, depending upon the complexity of substrates to be produced. Advanced IC-substrates require state-of-the-art know-how, equipment, materials, and processes to produce.

Adding domestic semiconductor fabs/foundries without a domestic IC-substrate supply and OSAT assembly will lengthen the supply chain, not shorten it. Chips produced in North America will still need to be shipped to Asia for substrates and assembly just as they are today. If the United States is spending $25 billion on semiconductors, then it should spend at least $1 billion on substrates to stand up world-class manufacturing facilities.

OSAT

Amkor is the only U.S.-headquartered OSAT provider in the top 20 globally; it is second overall. While Amkor is headquartered in the United States, it does not have assembly plants in North America. The U.S. also has more than 25 small and medium-sized OSAT companies, many with high capability. The main issue is limited capacity. North American facilities offer small to medium volume production, often for specific markets like the defense sector. Nearly all OSAT providers are currently running at full capacity, raising questions about their ability to meet increased demand for high performance computing and other leading-edge technologies.

At least one of the top 10 OSATs could be persuaded to locate operations in North America with a favorable mix of government and private support. Some EMS companies also are attempting to develop OSAT services in addition to their traditional offerings. Thus, while there are clear opportunities to be seized here, significant capital investment and government support will be needed to expand U.S. OSAT production capacity.

Companies that expand OSAT operations in the U.S. also will need to contend with a tight labor market with an inadequately skilled workforce. Addressing workforce training demands will require more urgent, extensive, and sustained partnerships between federal, state, and local governments, educational institutions and the private sector.

GLOBAL SEMICONDUCTOR ECOSYSTEM MAPPING

As part of this study, IPC created an online mapping tool for visualizing the location of market-leading companies in the semiconductor and advanced packaging ecosystem. The intent of the mapping tool is to show the regional and global ecosystems that are at work today. Layers can be turned on or off, showing the proximity between semiconductor fabs, IC-substrate suppliers, OSATs, and other layers of the supply chain.

Source: *IPC, An Analysis of the North American Semiconductor and Advanced Packaging Ecosystem" (report), November 2021*

KEY RECOMMENDATIONS

In the Full Report, IPC offers a complete list of 28 recommendations to rebuild the U.S. advanced packaging ecosystem and reinforce the effort to expand domestic semiconductor manufacturing. The following recommendations are the most pressing for policymakers and the public to understand.

1. **Domestic IC Substrate Capabilities Is Challenge #1:** The expansion of advanced silicon production in North America by 2024 will require complementary expansion in regional substrate and assembly production, or else the effort to reduce supply chain risks will be for naught. The core challenge is the lack of infrastructure to support substrate manufacturing, long two-year equipment lead times, and the lack of skilled labor at competitive cost. The U.S. Government needs to help establish a domestic commercial IC-substrate capability and capacity. Failure to do so will lengthen, not shorten, the semiconductor and electronics supply chain. The cost of standing up a high-volume IC substrate manufacturing facility with cutting edge capabilities is likely to cost $1 billion or more. New technologies, however, potentially offer low-volume, high-mix manufacturers new capabilities at lower price points.
2. **Support Domestic OSAT Champions:** The U.S. Government should identify EMS/ODM companies and existing North American OSAT companies that could potentially fulfill assembly requirements and increase capacity for North American advanced packaging needs. However, significant investment in infrastructure will be needed including Class 10K (or better) cleanrooms and advanced manufacturing technologies. We encourage the U.S. Government to support this sector through new and existing programs, like the DoD Manufacturing Technology (ManTech) Program.
3. **Critical Sectors:** The U.S. Government should focus a significant portion of its own investments and those it stimulates on the Aerospace, Defense, and High-Performance Computing markets. The volumes and demands represented by these markets (worth a combined $90+ billion) will help justify the investments needed to increase North American capability and capacity. These markets are also the most critical to U.S. national and economic security.
4. **National Electronics Manufacturing Institute:** The U.S. Government should invest in a manufacturing institute for electronic interconnection that serves to support innovation in advanced packaging, as well as printed circuit board fabrication and electronic assembly. The institute should emphasize the importance of "factory of the future" manufacturing.
5. **Allies and Friends:** The United States can complement the development of domestic supply chains with the development of strong, trusted global partners. It would be unrealistic and impractical to onshore the entire electronics manufacturing supply chain or locate it within a single region. Efforts like those underway in the US-EU Trade and Technology Council are critical to the emergence of secure, resilient, and dynamic supply chains for critical sectors.
6. **Pursue Next Generation Technologies:** The U.S. Executive Branch must continue to perform its deep-dive analysis of the semiconductor and electronics supply chains. The participating agencies should leverage this report and other sources of data and analysis — and draw upon the expertise of all key stakeholders — to identify specific needs and requirements for near-term and long-term technologies spanning semiconductors, advanced packaging, and assembly. The focus should be on leapfrogging current technologies to achieve next-generation semiconductor advancements including Silicon Integrated Photonics. Playing catch-up is a strategy for perpetual competitive disadvantage.

TOWARD A SILICON TO SYSTEMS APPROACH

Semiconductor chips—as marvelous as they may be—do not float in the air. They are useless on their own. So, too, are the advanced IC-substrates that the chips are bonded to. While they too are important and critical pieces of an electronic system, they are intermediate steps in a much larger process of designing and manufacturing final products and systems such as mobile phones, online games, HPC mainframe computers, and aircraft navigation. It is not until the final package is assembled — when semiconductor chips are bonded to substrates, encapsulated, and tested – when an advanced package becomes functional, valuable, and available to be integrated into electronic systems and products.

Advancements in semiconductor packaging also have direct impacts on PCB technology and fabrication. The more sophisticated IC packages become, the more complex PCB designs must become. Final system-level assembly by EMS/ODM providers is where the final product comes to life; it's where electronics are assembled, powered-on, burned-in, firmware/software loaded, and final system tests are performed. Both PCB and EMS/ODM providers play a critical role in final system delivery and availability.

A healthy, capable assembly ecosystem is needed to bring a wide variety of technologies together to manufacture finished products. Any disruptions or bottlenecks within this end-to-end ecosystem can lead to delays in new products and innovations. Therefore, it takes all elements within the supply chain–from silicon to systems–to successfully produce electronic hardware products and to meet customer and market demands.

REPORT CONTACTS

IPC

Matt Kelly (Author)
Chief Technologist
mattkelly@ipc.org

David Bergman
VP, Standards & Technology
davidbergman@ipc.org

Chris Mitchell
VP, Government Relations
chris.mitchell@ipc.org

TechSearch International Inc.

Jan Vardaman (Author)
President and Founder
jan@techsearchinc.com

BUILD ELECTRONICS BETTER

3000 Lakeside Drive, Suite 105 N
Bannockburn, IL 60015 USA
+1 847-615-7100 **tel**
+1 847-615-7105 **fax**
www.**ipc**.org

IPC is the global association that helps OEMs, EMS, PCB manufacturers, cable and wiring harness manufacturers and electronics industry suppliers build electronics better. IPC members strengthen their bottom line and build more reliable, high quality products through proven standards, certification, education and training, thought leadership, advocacy, innovative solutions and industry intelligence.