BUILD ELECTRONICS **BETTER**

# LEADERSHIP LOST?

## Rebuilding the U.S. Electronics Supply Chain


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- Technology and innovation
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This is the first in a planned series by the IPC Thought Leaders on gaps and challenges in the electronics manufacturing supply chain.

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# EXECUTIVE SUMMARY

The United States has lost its historic dominance in a foundational area of electronics technology, namely, the printed circuit board (PCB) fabrication industry.

In the halls of government, most of the attention is on semiconductors, due to the shortages triggered by the COVID-19 pandemic, combined with strong demand for all kinds of goods and services that contain chips.

Congress enacted the CHIPS for America Act in January 2021, creating new programs to spur more silicon fabrication in the United States. However, the actual funding for those programs is included in a follow-up bill, the Senate-passed U.S. Innovation and Competitiveness Act (USICA). On top of the CHIPS funding, USICA would boost federal R&D investment in 10 technology "focus areas," of which high-performance computing and semiconductors is just one. On the House side, committees are developing their own R&D proposals.

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If enacted, USICA would make an enormous investment in U.S. technology leadership. And yet it would not achieve enormous investment in U.S. technology leadership goal of making the U.S. more independent in electronics because it fails to address PCBs and the broader electronics ecosystem. To fully realize the promise of USICA, Congress and the Executive Branch should make clear that PCBs and related areas of electronics manufacturing are national priorities.

From a global competitive perspective, the United States and China have a comparable share of global semiconductor production, at 12% and 11%, respectively. A majority of the semiconductor market is supplied by three U.S.-friendly trade partners: Japan, South Korea, and Taiwan.

Meanwhile, the U.S. share of the PCB market has dropped from more than 30% to just 4% since 2000. China now dominates that market, supplying close to 50% of the global total. A loss of access to Chinese PCB production would cripple U.S. manufacturing, as computers, telecommunications networks, medical equipment, aerospace, cars and trucks, and other industries are already dependent on Chinese electronics suppliers.

Why has the PCB industry shrunk in the U.S.? PCB manufacturing is technically complex, requiring large investments in capital equipment and dozens of process steps for complex applications. Every aspect of the production of a given PCB must be customized, which hampers automation and scaling. Manufacturing activities that should be deemed as R&D are treated as regular operating expenses, cutting into profits and investment capital.

All these factors add up to an industry with very tight profit margins and little or no funds left over for R&D or capital expenditures.

On the industry side, rather than go in the direction of competing to provide commoditized PCB solutions in an unsustainable model that folds R&D into operational expenditures, the PCB fabrication industry needs to move toward sustained investment in R&D, standards, and automation, with a very long-term time horizon. On the government side, the U.S. Government needs to provide supportive policy, including greater investment in PCB-related R&D. With those twin tracks of action, the domestic industry could begin to access the funds and establish a technology roadmap to meet the needs of critical industries for the next two decades.

# PART 1

### *The USICA investment in domestic semiconductor manufacturing neglects a related supply chain risk: PCBs.*

The United States has lost its historic dominance in a foundational area of electronics technology, namely, the printed circuit board (PCB) fabrication industry.

PCBs are as integral to electronics as their better-known partners, the semiconductor chips. PCBs are found in virtually all electronics products. They are the physical platform upon which microelectronic components such as semiconductor chips and capacitors are mounted and interconnected. The semiconductors and other pieces of hardware and software found in every electronic system cannot function without the PCBs that interconnect them.

> **Given that all products that use semiconductors also require PCBs, and China is presently the dominant supplier of PCBs globally, this gap in U.S. technological investment and focus presents a major risk that needs to be addressed.**

In the halls of the federal government, most of the attention is on semiconductors, due to the shortages triggered by the COVID-19 pandemic and strong demand for all kinds of goods and services that contain chips. The pandemic also revealed the extent to which the world is dependent on Chinese-made electronics, as evidenced by the difficulty of ramping up U.S. manufacturing of ventilators when Chinese sources dried up.

Congress enacted the CHIPS for America Act in January 2021, creating new programs to spur more silicon fabrication in the United States. The actual funding for those programs is included in a follow-up bill, the Senate-passed U.S. Innovation and Competitiveness Act (USICA). On top of the CHIPS funding, USICA would boost federal R&D investment in 10 technology "focus areas," of which high-performance computing and semiconductors is just one. On the House side, committees are developing their own R&D proposals.

While USICA seeks to reestablish the U.S. as the global leader in semiconductors and other key technologies, the legislation does not address PCBs and electronics manufacturing more generally. Given that all products that use semiconductors also require PCBs, and China is presently the dominant supplier of PCBs globally, this gap in U.S. technological investment and focus presents a major risk that needs to be addressed.

Enacting USICA in its current form (as of December 2021) could lead to a situation in which the United States designs and manufactures more semiconductor chips but still must ship them offshore to be packaged and assembled into working electronics products and systems. And the lack of any parallel support for the PCB manufacturing sector could exacerbate its decline, making the United States more exposed to foreign dominance of the electronics supply chain, not less.

### *PCBs are complex and unique products.*

The printed circuit board is the foundation upon which electronic systems are built. Semiconductors, connectors, resistors, diodes, capacitors, and radio devices are all mounted upon the PCB and are interconnected by the metallic traces that run among them. From single-layered boards used in your TV remote, to six-layer boards used in a smartphone, to 60-layer, very-high-density and high-speed circuit boards used in super computers and servers, PCBs are at the heart of thousands of products we rely on every day.

Once considered low technology, the PCB has evolved into a high-technology, application-specific product. The term “printed circuit board” is actually a misnomer, because making one is not as simple as printing a piece of paper. PCB manufacturing requires multiple types of costly capital equipment, plus well-trained workers, and anywhere from 50 to 100-plus steps in the manufacturing process. Many high-speed, miniaturized PCBs are manufactured in cleanrooms under tightly controlled conditions.

Also contrary to common perception, PCBs are not off-the-shelf components. While major electronic parts distributors such as Avnet, Arrow, and Digi-Key may stock hundreds of thousands of semiconductors and other components that can be designed into products, none of them offers the PCB needed for a particular product, because all PCBs are custom-designed and fabricated to provide the unique electrical routing, impedance, and signal integrity required for each product’s performance. The PCB has a one-to-one relationship between design and use; the semiconductor has a one-to-many relationship in which one chip can be utilized in thousands of product designs.

This one-to-one relationship between PCB and application underscores the idea that the U.S. must remain in the business of PCB fabrication if it wants to maintain its ability to build a wide variety of critical products and systems. Unlike other components, there is no easy “drop in” replacement if a particular source of PCBs is cut off.

Without the custom PCB, there is no product, no system, no application. This means that any interruptions in global trade could present a real risk that the United States could lose the ability to produce many kinds of electronics. The U.S. already relies almost entirely on PCBs supplied from East Asia to produce communications and networking systems, motor vehicles, smartphones, medical devices, and many other kinds of electronics.

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### *U.S. PCB industry already on the brink of extinction.*

The best data available indicate the U.S. PCB industry is already in major decline and arguably on the brink of extinction.

In 2015, the Department of Defense (DoD) Executive Agent for Printed Circuit Board and Interconnect Technology executed through the Department of Commerce (DoC) a survey of the U.S. PCB industrial base. In 2018, the DoC Bureau of Industry and Security delivered its findings, characterizing the U.S. PCB industry as "dying on the vine."[1] A September 2018 report by the Interagency Task Force in Fulfillment of Executive Order 13806 reported, "the U.S. printed circuit board sub-sector is aging, constricting, and failing to maintain the state-of-the-art" technology.

According to IPC, in the late 1990s, more than 2,000 PCB manufacturers were in operation in the USA, but there are fewer than 145 remaining today, and the number is even fewer when counting only suppliers with domestic manufacturing capability, as opposed to brokers.

A November 2020 report by Prismark Partners estimated that worldwide demand for PCBs was $64.0 billion.[2] U.S. PCB production met 4% of the total demand (approximately $2.9 billion), while China accounted for more than 50% and the entire Asia-Pacific region provided 90% of PCB fabrication. In comparison, in 2019, the United States accounted for 11% of global semiconductor fabrication capacity, down from 13% in 2015, continuing a long-term decline from around 40% in 1990. Taiwan, South Korea, and Japan accounted for two-thirds of the world's semiconductor fabrication capacity, and China for 12%. (See Figure 1.)

## REPEATED WARNINGS GO UNHEEDED

**Major studies in 2005, 2015, 2017, and 2018 have all raised the alarm concerning the decline of the U.S. electronics manufacturing ecosystem.**

**2005:** National Research Council, Linkages; Manufacturing Trends in Electronic Interconnection Technology

**2015:** U.S. Department of Defense, Annual Industrial Capabilities Report to Congress for 2015

**2017:** U.S. Department of Commerce, U.S. Bare Printed Circuit Board Industry Assessment

**2018:** Interagency Task Force, Assessing and Strengthening the Manufacturing and Defense Industrial Base and Supply Chain Resiliency of the United States

While China has stated its intention to become the global center of semiconductor manufacturing, it is already the global center for PCB fabrication, having prioritized electronics manufacturing for decades. The U.S. Congress and the Executive Branch should do the same and take urgent action to reverse the erosion of the U.S. PCB fabrication industry before it is too late.

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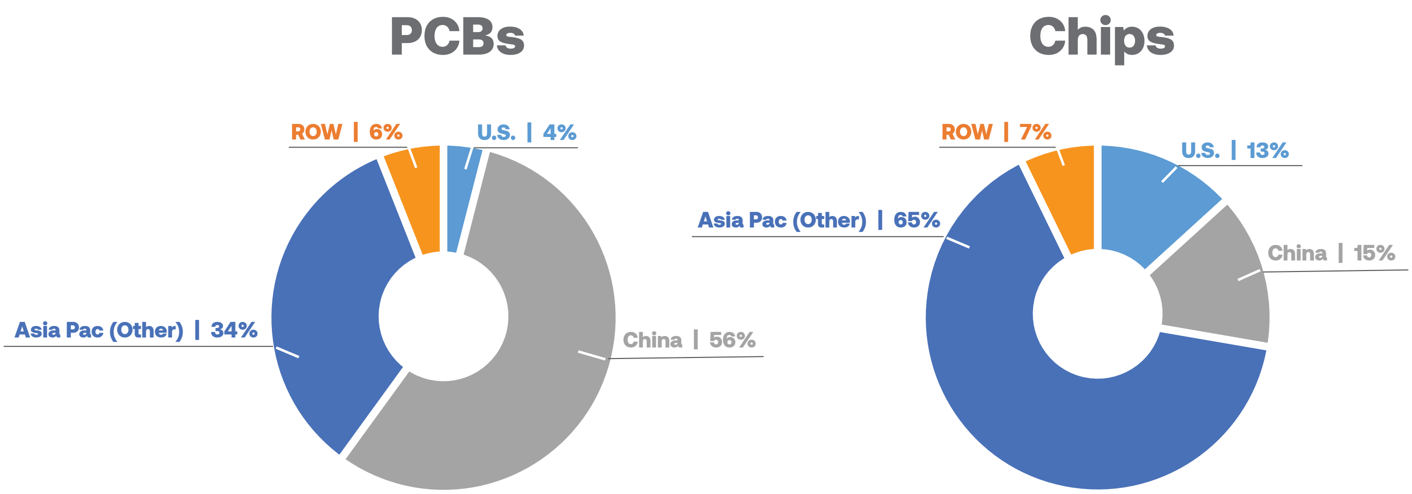
[1] U.S. Department of Commerce, Bureau of Industry and Security, Office of Technology Evaluation; "U.S. BARE PRINTED CIRCUIT BOARD INDUSTRY ASSESSMENT," 2017, https://www.bis.doc.gov/index.php/documents/technology-evaluation/2378-u-s-bare-printed-circuit-board-industry-assessment-2017/file

[2] Prismark Partners, The Printed Circuit Report, November 2020, https://cd20be63-c67d-4de1-902d-c43a175fa814.filesusr.com/ugd/950e51_4a6c8b54e07349cfa2521bc69709bf7d.pdf

**Figure 1. Shares of the Global Market for PCBs and Semiconductors**




*Source: Author's summary based on multiple sources.*

## *International trade data tell the same story.*

Figure 2 compares aggregate industry data for semiconductors versus PCB fabrication. U.S. exports of semiconductors were worth $46.2 billion in 2020, the fourth-highest product category among U.S. exports behind only airplanes, refined oil, and autos. Semiconductors constituted the largest share of U.S. exports of all electronics product exports, with a U.S. vs. rest-of-world trade surplus of almost $2 billion.

Meanwhile, the U.S. PCB fabrication industry exports about $1.6 billion worth of product and imports about $2.1 billion, leaving a trade deficit of about $530 million. A trade deficit of this magnitude is further evidence of the crumbling foundation of domestic PCB fabrication.

Furthermore, the $53 billion in revenue generated by U.S. semiconductor companies could be put at risk if the domestic PCB fabrication industry fails and the chips sector becomes even more dependent on foreign packagers and assemblers.

**Figure 2: Comparison of Data on Semiconductor and PCB Industries, 2020**

| NAICS Code 334413: Semiconductor and Related Device Manufacturing | NAICS Code 334412: Bare Printed Circuit Board Manufacturing |
|---|---|
| This U.S. industry comprises establishments primarily engaged in manufacturing semiconductors and related solid state devices. Examples of products made by these establishments are integrated circuits, memory chips, microprocessors, diodes, transistors, solar cells and other optoelectronic devices. | This U.S. industry comprises establishments primarily engaged in manufacturing bare (i.e., rigid or flexible) printed circuit boards without mounted electronic components. These establishments print, perforate, plate, screen, etch, or photoprint interconnecting pathways for electric current on laminates. |
| Total Companies: 1,613 | Total Companies: 815 |
| Verified Companies: 1.231 | Verified Companies: 622 |
| Est. Employment: 113,975 | Est. Employment: 22,375 |
| Annual Payroll: $12,348,381,000 | Annual Payroll: $1,097,037,000 |
| Total Revenue: $53,052,319,000 | Total Revenue: $4,472,629,000 |
| SBA Size Standard: Maximum 1,250 Employees | SBA Size Standard: Maximum 750 Employees |
| Import (USD): $44,255,560,650 | Import (USD): $2,126,788,898 |
| Export (USD): $46,250,685,079 | Export (USD): $1,596,741,121 |
| Balance of Trade (USD): $1,995,124,429 | Balance of Trade (USD): ($530,047,777) |

***Source:** U.S. Census Bureau, North American Industry Classification System (NAICS), https://www.census.gov/naics/*

## *Impacts of a Chinese trade cutoff would be catastrophic.*

If the United States were to lose access to Chinese PCB fabrication, the impacts would be immediate and severe. Pandemic-related supply chain disruptions were one wake-up call; long-running and recently rising tensions involving China, Taiwan, the two Koreas, and Japan raise the prospect of future trade interruptions. In such a scenario, China's PCB fabrication could be cut off, presenting a very real crisis.

With only a handful of domestic facilities producing more than 10,000 PCB core layers per week, the U.S. lacks the PCB fabrication capacity to satisfy the domestic demand for iPhones, let alone the country's total PCB needs. In the event of trade break with China, U.S. PCB fabrication capacity would likely be consumed by increased demand from DoD, leaving the balance of the electronics industry scrambling. Supplies of all kinds of electronics-based products would dry up, with a domino effect of severe impacts on daily life. The crisis also would drain resources from research and development, further hobbling the U.S. economy and global standing.

### *How to improve USICA or any other federal R&D and competitiveness legislation.*

If the USICA or other pending R&D proposals are enacted as currently written, the future may be one in which semiconductors are more likely to be designed and fabricated domestically, but then still sent offshore to be packaged and assembled into applications that require PCBs. This will continue to be a risk as long as the U.S. and its allies are unable to produce enough PCBs to meet its requirements in defense, healthcare, ICT, and other critical infrastructure sectors.

To fully realize the promise of USICA and reduce dependence on foreign suppliers, electronics manufacturing should be explicitly covered by the “key technology focus area” that includes semiconductors. Failure to do so would be like reviving a declining auto industry by ramping up production of auto engines. This modest change could make a major difference in whether the legislation achieves its stated goals.

> **If the USICA or other pending R&D proposals are enacted as currently written, the future may be one in which semiconductors are more likely to be designed and fabricated in the U.S. but still sent offshore to be packaged and assembled into electronic systems.**

Likewise, any federal R&D legislation that authorizes a National Advanced Packaging Manufacturing Program should ensure that PCBs and electronic interconnection are considered a foundational technology in that effort.

# PART 2

## *PCB industry faces more technical challenges as chip packages shrink.*

The PCB industry has kept pace with "Moore's Law" for the past 50 years. Moore's Law refers to the 1965 prediction of Intel founder Gordon Moore that the number of transistors in a dense integrated circuit could be doubled about every two years, leading to exponential increases in computing power over time. Moore's Law held up for about half a century, contributing powerfully to productivity growth in many sectors.

Just as the performance of processors doubled about every two years, PCBs saw advances as well. For example, over the last 50 years, the holes (called vias) that are drilled in PCBs and plated to create electrical paths within the PCB have shrunk exponentially from 0.25 inches to 20 microns (20 millionths of a meter). The width of electrically conductive traces on PCBs shrank from 0.10 inches to just 1 mil (one one-thousandth of an inch).

All this improvement has been the result of decentralized, incremental research and development processes at the manufacturing level. But the relatively easy gains have been realized.

As component geometries continue to shrink and become denser, the challenges of routing electrical signals among tiny chips and other components becomes much more difficult. The PCB fabrication industry now faces far more customization and much wider variety in the size of boards, the number of layers, and the width of conductive traces and spaces in between them.

## *Need for PCB customization underscores need for greater R&D and capital expenditures.*

The semiconductor industry has been able to increase automation by standardizing key elements such as the size of silicon wafers (from which semiconductors are made) and the width and spacing of electrical conductors (such as traces or vias).

Figure 3 illustrates the timing and economics associated with technical improvements in semiconductors since 2004. As chip features known as "nodes" have decreased in size over time, the density of computing power on each semiconductor wafer has increased, and the price per chip has generally decreased. These impressive achievements are enabled by significant capital investments to implement automated processes, which are possible due to standardization of wafer size, materials, and feature sizes.

**Figure 3: Economics of Chips by Size of Nodes**

| Line | Node (nm) | 90 | 65 | 40 | 28 | 20 | 16/12 | 10 | 7 | 5 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Mass production year and quarter | 2004 Q4 | 2006 Q4 | 2009 Q1 | 2011 Q4 | 2014 Q3 | 2015 Q3 | 2017 Q2 | 2018 Q3 | 2020 Q1 |
| 2 | Capital investment per wafer processed per year | $4,649 | $5,456 | $6,404 | $8,144 | $10,356 | $11,220 | $13,169 | $14,267 | $16,746 |
| 3 | Net capital depreciation at start of 2020 (25.29% / year) | 65% | 65% | 65% | 65% | 65% | 65% | 55.1% | 35.4% | 0.0% |
| 4 | Undepreciated capital per wafer processed per year (remaining value at start of 2020) | $1,627 | $1,910 | $2,241 | $2,850 | $3,625 | $3,927 | $5,907 | $9,213 | $16,746 |
| 5 | Capital consumed per wafer processed in 2020 | $411 | $483 | $567 | $721 | $917 | $993 | $1,494 | $2,330 | $4,235 |
| 6 | Other costs and markup per wafer | $1,293 | $1,454 | $1,707 | $2,171 | $2,760 | $2,990 | $4,498 | $7,016 | $12,753 |
| 7 | Foundry sale price per wafer | $1,650 | $1,937 | $2,274 | $2,891 | $3,677 | $3,984 | $5,992 | $9,346 | $16,988 |
| 8 | Foundry sale price per chip | $2,433 | $1,428 | $713 | $453 | $399 | $331 | $274 | $233 | $238 |

*Source: Saif M. Khan, AI Chips: What They Are and Why They Matter, April 2020, p. 44, https://cset.georgetown.edu/publication/ai-chips-what-they-are-and-why-they-matter/*

Standardization is an enabler of automation. While it is possible to correlate the processes of PCB and semiconductor fabrication in that they are both imaging processes with subtractive (“etching”) and additive (“printing”) metallization steps, the geometries involved in semiconductor fabrication are much smaller, with far less variability, than in PCB fabrication.

For example, semiconductor factories often specialize in a particular size wafer such as a 300-mm wafer fab. Each wafer can be the source of many thousands of chips. In contrast, a PCB fabricator will customize according to demand, producing any size, any layer count, and any feature size desired by the customer, which increases variability, lowers lot size, and virtually eliminates mass production opportunities. In the PCB fabrication arena, volume is simply another factor in long list of endless customizations.

In the PCB fabrication arena, volume is simply another factor in a long list of endless customizations.

The table on page 8 reveals that R&D investment per wafer increased as the industry advanced from 90 nanometer to 5 nanometer technology over the 2004 to 2020 period. Also note that the term “Mass Production” refers to when smaller feature sizes became standardized, leading to expanded output of advanced semiconductors.

During that same time period, the PCB industry continued to accommodate the profusion of electronics devices and systems through massive customization at ever-shrinking feature size. This was made possible largely through agile innovations, risk taking, iterative process improvements, and sheer ingenuity. These same attributes – applied strategically over a ten-year horizon – would make investment in the PCB fabrication industry a wise move with big payoffs.

The prevalence of PCB customization has hampered efforts to increase yields through automation. There is no analogous industry with such wide-ranging customization options coupled with the level of process complexity. Every order is akin to a research project, starting afresh on nearly every aspect of the PCB: scale, materials, feature sizes, interconnect methods, metallization options, final finishes, and quality standards. In addition, the industry standard for timing – from order to shipment – can be as little as one to three days. All these factors translate into higher capital costs and lower profits than almost every other link in the electronics supply chain.

To appreciate the complexity of the fabrication process, consider an order of 12 units of a standard, eight-layer PCB. To begin, there are dozens, if not hundreds of material choices for each core layer. For any given material, there are 1,000s of combinations of thicknesses and foil constructions. For each layer, adjustments can be made to feature sizes, hole sizes, and interconnection methods. There may be 10,000 nets (points of connection) on the completed, laminated PCB, and each order will likely come with dozens of quality specifications and other requirements. If the PCB is for a new application, the production team will apply lessons learned from similar products to identify the materials and techniques required – or to obtain approval to utilize another material that happens to be in stock.

## KEY IPHONE TECHNOLOGY NON-EXISTENT IN U.S.

**To cite another example of slippage in U.S. PCB manufacturing, the modified semi-additive process (mSAP) utilized to produce "stacked" PCB technology in the iPhone is nearly nonexistent in the United States, as there is insufficient mass demand for it in other products. This technology is likely to dominate the future of application-specific PCBs as well as other key pieces of electronic systems, and yet there is currently no U.S. domestic manufacturer with this capability, nor any support from U.S. government policy to develop it domestically.**

The physical requirements of creating a novel PCB are also remarkable. For example, the computer-aided manufacturing (CAM) department has to calculate scaling requirements to adjust for the thermal expansion that occurs throughout 42 process steps, including multiple imaging, etching, plating, lamination, drilling, more plating, coating, printing, more plating, and testing processes. The industry-standard turn-around time means this unique order will need to be completed perfectly within 48 hours for $4,000 for a lot of 12, eight-layer boards.

In another wrinkle, each custom order can have unexpected developments that are discovered during quality control. For example, in the middle of the production process, inspection of a cross-section could reveal that the core of one layer didn't shrink by the expected percentage given the material type and copper features involved. This would require a review of the entire project with the CAM group and the head of engineering; development of new scaling factors; and then changes to the instructions to the laser-directed imaging equipment before production could resume. Meanwhile, the initial run of product would need to be scrapped, cutting into the profit margin; and the production and testing schedule would need to be expedited because the shipment deadline is unchanged.

> **What can be done? Just like the semiconductor sector, the PCB fabrication industry needs to move toward sustained investment in R&D, standards, automation, and an industry-government partnership, with a very long-term time horizon.**

U.S. PCB fabricators receive such orders several times every business day, requiring them to maintain millions of dollars' worth of equipment and sophisticated, proven production processes to take each order from start to finish.

All these factors add up to an industry with very tight profit margins and little or no funds left over for R&D or capital expenditures.

What can be done? Just like the semiconductor sector, the PCB fabrication industry needs to move toward sustained investment in R&D, standards, automation, and an industry-government partnership, with a very long-term time horizon.

# PART 3

## *Much of PCB fabrication needs to be understood as R&D.*

The U.S. PCB fabrication industry has long been a shining example of American ingenuity and applied R&D, from the 1950's through today. However, a major shortfall throughout that period is that the PCB industry does not define itself as an R&D enterprise. As we will show here, PCB fabrication has become dominated by research and development with some select, low-volume production.

Figure 4 demonstrates the disparity between the R&D investment by semiconductor companies versus PCB fabrication companies. It also shows revenue per employee, which is a direct indictor of the lack of automation presently implemented in the PCB Industry. (See Figure 3.)

**Figure 4. Disparity in R&D investment, semiconductor versus PCB fabrication companies**

| | R&D Expense as a % of Revenues | Revenue Per Employee |
|---|---|---|
| **Semiconductors** | | |
| Intel | 17.4% | $ 684,846 |
| Microchip | 15.4% | $ 292,210 |
| AMD | 20.3% | $ 774,841 |
| Analog Dev | 18.1% | $ 409,120 |
| Xilinx | 28.6% | $ 674,751 |
| **PCB** | | |
| TTM | 0.9% | $ 126,067 |
| Sanmina | 0.3% | $ 232,921 |
| Eltek | 0.0% | $ 121,861 |
| Unimicron | 4.8% | $ 109,562 |
| Zhen Ding | 3.9% | $ 181,508 |
| Dongshan Precision | 3.1% | $ 206,843 |

*Source: Author's summary based on multiple sources.*

The need for large investments in new manufacturing technologies and chip designs has meant that semiconductor companies spend far more on research and development than manufacturers in general. In 2016, R&D as a share of domestic sales was 11.6% for U.S. semiconductor manufacturers and 20.3% for semiconductor machinery manufacturers, compared to 5.4% for all U.S. manufacturing industries. Intel, the largest U.S.-based chipmaker, spent $13.4 billion on R&D in 2019, an amount equal to 19% of worldwide sales. According to SIA, industry-wide investment rates in R&D have ranged between 15% and 20% of sales over the past decade, and they have remained consistently high regardless of annual trends in sales.

In contrast, and although each PCB order is unique, the constant experimentation and custom manufacturing work described in Part 2 is not treated as R&D but rather as part of the business of producing PCBs. R&D is a tax-deductible activity, whereas the customization involved in each PCB order is not.

PCB manufacturers need to re-evaluate their business model and their value proposition. Specifically, they need to better allocate costs between customization per order and R&D. Rather than attempting to provide commoditized solutions in an unsustainable model in which R&D is treated as operational expenditures, a better model would be to invest in standardization through appropriate R&D spending.

## *PCB fabrication meets IRS and DoD definitions of R&D.*

The PCB fabrication process also arguably meets the Internal Revenue Service's four-part test for whether expenses can be treated as R&D. [3] Those four tests are:

1. **Permitted purpose:** The activity must be related to developing or improving the functionality, quality, reliability, or performance of a business component (i.e., product, process, software, technique, formula or invention). **PCB industry match: Yes.**
2. **Technological in nature:** The business component's development must be based on a hard science, such as engineering, physics and chemistry, or the life, biological or computer sciences. **PCB industry match: Yes.**
3. **Elimination of uncertainty:** From the outset, the organization must have faced technological uncertainty when designing or developing the business component. **PCB industry match: Yes.**
4. **Process of experimentation:** The company must have evaluated multiple design alternatives or employed a systematic trial and error approach to overcome the technological uncertainties. **PCB industry match: Yes.**

Likewise, the PCB fabrication process also resembles the DoD definition of R&D.

The Manufacturing Readiness Level (MRL) concept was developed by the DoD to assess the maturity of a manufacturing process throughout its conception, development, deployment, and support progression phases. MRLs are based on a scale from 1 to 10, with 10 being the most mature.

A review of Figure 5 demonstrates that MRLs 1 through 7 match the description of R&D as well as the process of both semiconductor and PCB fabrication.

Domestically, most existing PCB fabricators for defense customers are dealing exclusively in MRL 1-5 programs. Very few PCB Orders rise to the definition of MRL 10, "full rate production." Yet nearly all PCB fabricators do not treat their daily endeavors as R&D. Their processes are still dependent on individual experts' involvement in each aspect of the development process, creating a high degree of variability. Coupled with small lot sizes, this makes a strong argument for low MRLs and treating PCB fab as more of an R&D enterprise.

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[3] U.S. Internal Revenue Service, "Audit Techniques Guide: Credit for Increasing Research Activities (i.e. Research Tax Credit) IRC § 41* - Qualified Research Activities," June 20005, https://www.irs.gov/businesses/audit-techniques-guide-credit-for-increasing-research-activities-i-e-research-tax-credit-irc-41-qualified-research-activities

### Figure 5: Manufacturing Readiness Levels (MRL)

| Level | Definition | DoD MRL Description |
|---|---|---|
| 1 | Basic Manufacturing Implications Identified | Basic research expands scientific principles that may have manufacturing implications. The focus is on a high-level assessment of manufacturing opportunities. The research is unfettered. |
| 2 | Manufacturing Concepts Identified | This level is characterized by describing the application of new manufacturing concepts. Applied research translates basic research into solutions for broadly defined military needs. |
| 3 | Manufacturing Proof of Concept Developed | This level begins the validation of the manufacturing concepts through analytical or laboratory experiments. Experimental hardware models have been developed in a laboratory environment that may possess limited functionality. |
| 4 | Capability to produce the technology in a laboratory environment | This level of readiness acts as an exit criterion for the MSA Phase approaching a Milestone A decision. Technologies should have matured to at least TRL 4. This level indicates that the technologies are ready for the Technology Development Phase of acquisition. Producibility assessments of design concepts have been completed. Key design performance parameters have been identified as well as any special tooling, facilities, material handling and skills required. |
| 5 | Capability to produce prototype components in a production relevant environment | Mfg. strategy refined and integrated with Risk Management Plan. Identification of enabling/ critical technologies and components is complete. Prototype materials, tooling, and test equipment, as well as personnel skills have been demonstrated on components in a production-relevant environment, but many manufacturing processes and procedures are still in development. |
| 6 | Capability to produce a prototype system or subsystem in a production relevant environment | This MRL is associated with readiness for a Milestone B decision to initiate an acquisition program by entering into the EMD Phase of acquisition. Technologies should have matured to at least TRL 6. The majority of manufacturing processes have been defined and characterized, but there are still significant engineering and/or design changes in the system itself. |
| 7 | Capability to produce systems, subsystems, or components in a production representative environment | System detailed design activity is nearing completion. Material specifications have been approved and materials are available to meet the planned pilot line build schedule. Manufacturing processes and procedures have been demonstrated in a production representative environment. Detailed producibility trade studies are completed and producibility enhancements and risk assessments are underway. Technologies should be on a path to achieve TRL 7. |
| 8 | Pilot line capability demonstrated; Ready to begin Low Rate Initial Production | The system, component or item has been previously produced, is in production, or has successfully achieved low-rate initial production. Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full-Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes. Major system design features are stable and have been proven in test and evaluation. |
| 9 | Low-rate production demonstrated; Capability in place to begin Full Rate Production | The system, component, or item has been previously produced, is in production, or has successfully achieved low-rate initial production (LRIP). Technologies should have matured to TRL 9. This level of readiness is normally associated with readiness for entry into Full-Rate Production (FRP). All systems engineering/design requirements should have been met such that there are minimal system changes. |
| 10 | Full Rate Production demonstrated and lean production practices in place | Technologies should have matured to TRL 9. This level of manufacturing is normally associated with the Production or Sustainment phases of the acquisition life cycle. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in full-rate production and meet all engineering, performance, quality and reliability requirements. Manufacturing process capability is at the appropriate quality level. |

*Source: AcqNotes, Production, Quality & Manufacturing: Manufacturing Readiness Level, https://acqnotes.com/acqnote/careerfields/manufacturing-readiness-levelmanufact*

## *How industry and government can work together to reinvigorate PCB fab.*

Taking full advantage of R&D tax credits could help many companies fund the investments required to achieve consistent yields and sufficient capacities of advanced PCB fabrication. Typically, 6 percent to 8 percent of a company's annual qualifying R&D expenses can be applied, dollar for dollar, against its federal income tax liability. Various activities may qualify for the credit, including but not limited to:

- Developing processes, patents, formulas, techniques, prototypes, or software;
- Improving or redesigning existing products;
- Hiring scientists, designers or engineers that are engaged in qualified activities;
- Devoting time and resources to creating (manufacturing or developing) new or innovative products;
- Developing intellectual property; and/or
- Paying certain amounts for salaries, supplies, contract research and cloud hosting.

> **As an industry, PCB fabricators need to change how they view and measure the business; take advantage of R&D tax credits; and bolster internal capital investments. If those moves could be combined with significantly increased U.S. Government support of PCB R&D, the domestic industry could access the capital needed to establish a technology roadmap to meet the PCB needs of critical industries for decades to come.**

As an industry, PCB fabricators need to change how they view and measure the business; take advantage of R&D tax credits; and bolster internal capital investments.

If those moves could be combined with significantly increased U.S. Government support of PCB R&D, the domestic industry could access the capital needed to establish a technology roadmap to meet the needs of critical industries for the next two decades. These steps can return the U.S. to its former role as the leader in electronics technology.

The USICA and related proposals to boost U.S. investment in R&D aim to reinforce and revive the United States as the global leader in semiconductors, while improving strategic autonomy. Expanding the scope of these bills and the subsequent public-private R&D programs to include PCB fabrication is an even more pressing challenge. This is not a matter of pitting the semiconductor and PCB industries against one another; it is quite the opposite. The U.S. government and all stakeholders need to recognize that each sector is vitally important to the other, and the success of both is critical to reestablishing long-term strength and resiliency.

## About the Author

Joseph O'Neil has nearly 30 years of experience in the Electronic Manufacturing Services (EMS) sector. Joe is currently advising clients through his firm, OAA Ventures, which he founded in 2015 following the acquisition of Hunter Technology Corp by Sparton Corporation. OAA Ventures provides consulting and advisory services to electronic manufacturing service providers, printed circuit board fabricators and technology start-ups. In addition to his consulting engagements, Joe serves as Chairman of the IPC Education Foundation, and has served on the IPC Board for over 12 years. Joe was formerly the CEO and Owner of Hunter Technology which grew from 80 to 360 employees during his tenure. Joe earned his Bachelor of Business Administration (B.B.A.) with emphasis in Finance and Management from Loyola Marymount University.

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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.