OPPORTUNITIES FOR SMALL AND MEDIUM-SIZED PCB FABRICATORS TO COMPETE ON THE WORLD STAGE

By Mike Carano
Chairman, IPC Thought Leaders Program

Electronics are a global driver for the world's economy. They are omnipresent in everything from life-saving medical equipment to safety and security systems, telecommunications, and automobiles. Electronics manufacturing involves significant job creation within the industry itself as well as in other industries through improved productivity and constant innovation. Applications such as wearables, augmented and virtual reality, and high-end graphics and video are just a few of the electronics-based innovations coming our way.

In many respects, the technological advancements that make these electronics possible are nothing short of amazing. And the heart of the electronic system is the printed circuit board. Without the printed circuit board, there is nowhere for semiconductor chips and other components to go. As the saying goes, "Chips don't float," meaning the printed circuit board is the interconnection of the entire electronics system. Trusted manufacturers of these complex interconnection substrates are needed to support mission critical applications.

And yet the manufacturing landscape for printed circuit boards has largely shifted to Asia; and domestic expertise has shrunk along with the industry's footprint in North America.

Significant investments in printed circuit board technology and manufacturing are critical to the continued strength of the strategically vital U.S. electronics manufacturing sector, and they would be remarkably less costly than investments in the "golden child" – the semiconductor industry.

WHAT LED TO THIS SITUATION?

Prior to the Asian Shift of 2000-2001, just over $11 billion worth of printed circuit boards (PCBs) were produced in the United States. Along with Japan, the U.S. enjoyed a leadership position in this very critical and enabling technology.

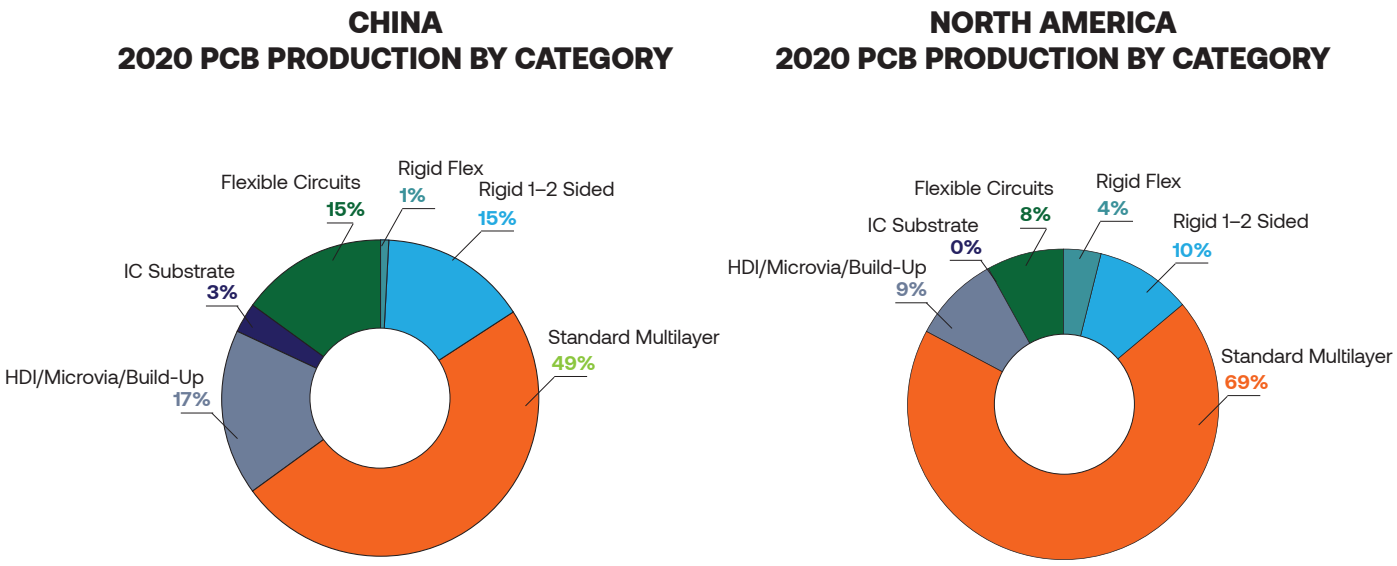
Today, just over $3.5 billion worth of PCBs are produced in the United States. The decline was due in part to the original equipment manufacturers (OEM), which as recently as the mid-1990s produced their own captive interconnects to support their hardware. However, as technology advanced, many OEMs decided to shutter their PCB fabrication facilities and switch to merchant fabricators. These fabricators were primarily overseas, and over the last two decades, China has risen to become the dominant force in the PCB industry.

The loss of OEM in-house fabrication led to a loss in technological leadership. Large OEMs had been staffed with engineering and manufacturing talent that disappeared with the transition to overseas merchant fabrication. In addition, the OEM captive facilities had possessed everything needed to lead and take advantage of advancements in R&D, materials, and processing. However, once the outsourcing decision was made, the U.S. lost those technological capabilities as well, including in the areas of high-density interconnect (HDI) and automation.

Today, there are fewer than 200 PCB fabricators in North America, down from approximately 1,500 in the 1990s. Many of these individual manufacturing sites were under the umbrella of a handful of companies. Beyond this core group of 10 to 12 large firms, the U.S. printed circuit board manufacturing is now concentrated in many small, single-site facilities with less than $15 million in annual revenue. The high-volume production has found its way to China and other countries in Asia.

In addition, Figure 1 shows how China has positioned itself in the areas of HDI/microvia/build-up technology as well as flexible circuits. HDI/microvia/build-up technologies are critical for miniaturization, enabling next-generation telecom, high-performance computing, and IC substrate/semiconductor packaging. Flexible circuits, especially high-volume reel-to-reel production, serve multiple end markets including automotive, medical and computer/laptops.

Figure 1. China and North America PCB production by category



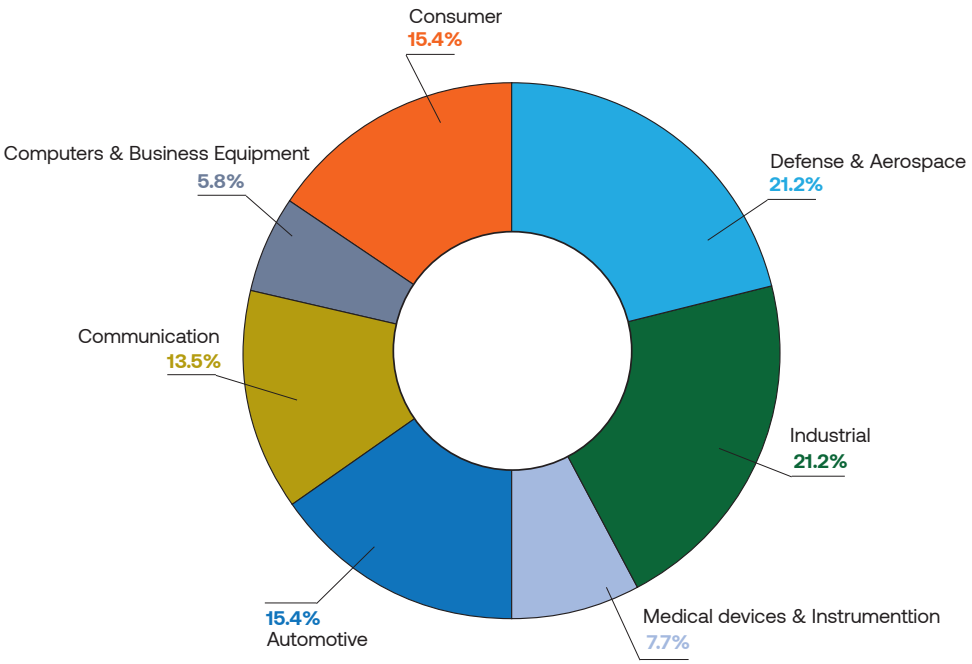
Source: World Electronic Circuits Council, WECC Global PCB Production for 2020, August 2021.

While the Asian Shift may mean a dimmer future for the PCB industry in North America, there are some opportunities. Figure 1 indicates the importance of high-layer-count PCBs, flexible circuits, rigid-flex, and high-density (HDI) technologies in North America. Fabricators have some of the capabilities to support these technologies currently. Thus, there is a footprint that needs to be expanded further.

END MARKETS FOR PCBS

While the consumer and low-end computer and office equipment segments may not offer growth opportunities for the U.S. PCB fabrication base, there are opportunities in telecommunications and internet infrastructure; aerospace and defense (A&D); industrial automation (think Smart Factory and CFX); and other "protected" industries and applications including data transfer, cyber security, and servers/data storage.

Figure 2. Primary PCB End Markets Served by OEMs



Source: IPC, PCB Technology Trends Survey 2018, February 2019, https://www.ipc.org/TOC/Tech-Trends-2018-TOC.pdf

TECHNOLOGY TRENDS

By most estimates, the top 100 electronics companies in the world produced more than $2.4 trillion worth of electronic equipment in 2020. This is significant for several reasons:

- The top 100 firms drive the technology for everything else; and
- Most of these firms are headquartered in the United States; but
- Most PCBs are manufactured elsewhere.

Today, the most advanced technologies related to high-end PCB fabrication are no longer being developed in North America. When the leading OEMs decided they would shutter their PCB fabs in favor of buying on the outside, much of the R&D capability went along with it. For example, HDI technology was invented in the United States. It is a great enabler because it allows faster signal speeds, smaller form factors, and lower overall system costs. Yet, the majority of HDI production – as well as of the interconnect (IC) substrates that HDI depends on – resides in Asia. This is a major concern because the technology hubs follow the production footprint. This includes specialized equipment, materials, chemistry and of course PCB assembly. Further compounding this situation is the now well-publicized computer chip shortage.

Embedding components into IC substrates was invented in the 1950's and 60's in North America. It was a laboratory exercise at the time. Today it is another multi-billion-dollar technology. But it's not about the dollars. It's about the technology. HDI and embedded components are enabling technologies. They are the building blocks for the next generations of hardware. And we have lost the ability to build such products in North America.

Worse, many procurement managers would like to commoditize the PCB, with the expressed goal of driving down price. Fortunately, thanks to the U.S. International Traffic in Arms Regulations (ITAR), and the U.S. Department of Defense's PCB requirements, several protected market segments, e.g., aerospace and defense, internet of things, and high-performance computing must be manufactured in the U.S. and North America through the Trusted Suppliers Network.

And the opportunities do not end there. The trend towards evolving and enabling technologies including artificial intelligence (AI), wearables, additive manufacturing, and Factory of the Future, offers North American PCB firms with ample means to expand their business. However, this requires these firms to step up their game in terms of technology capabilities.

AREAS OF OPPORTUNITY

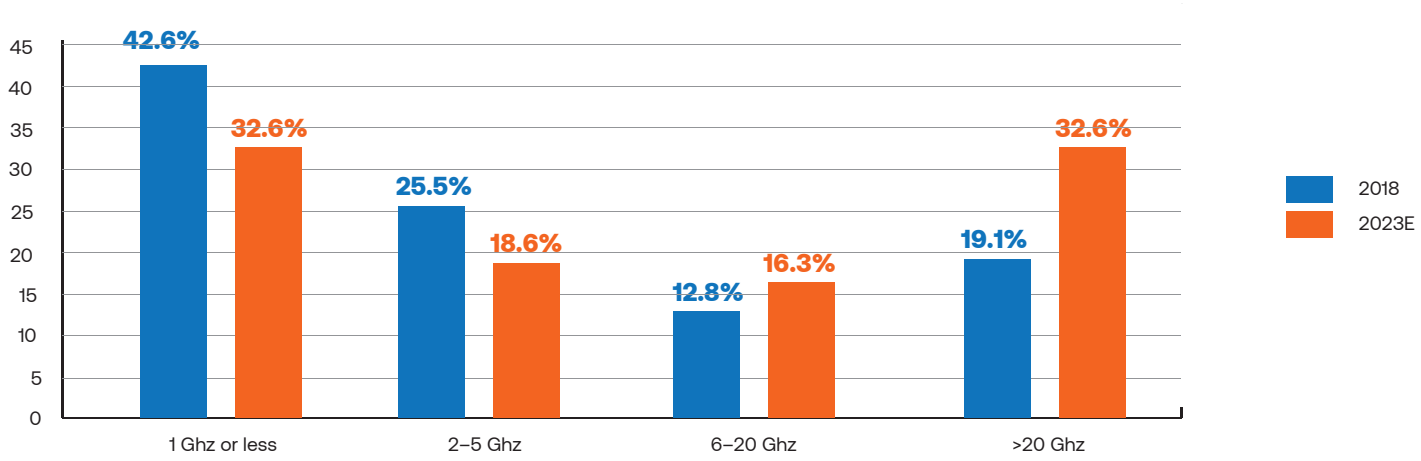
As the famous philosopher Yogi Berra once said, "It ain't over until it's over." Among the many major changes taking place in the electronic interconnect industry are opportunities for small and medium sized companies to step up their technology game.

First, for these firms to even hope to be successful, they must constantly be asking what is happening in their own industry and in other industries that can affect their business. For example, how does artificial intelligence (AI) affect the electronics industry? With products being developed for very high-frequency applications, what will that mean to materials and electronics fabrication? Fabricators need to ensure that processes and materials are coming together to support advanced manufacturing.

The maximum frequency at which OEMs' products operate is expected to increase over the next five years (see Figure 3). Major OEMs in the telecom space anticipate going to 77 GHZ and beyond. They also expect increases in maximum product life expectancy of more than 25 years. This is particularly crucial for PCBs because it will drive reliability requirements even higher.

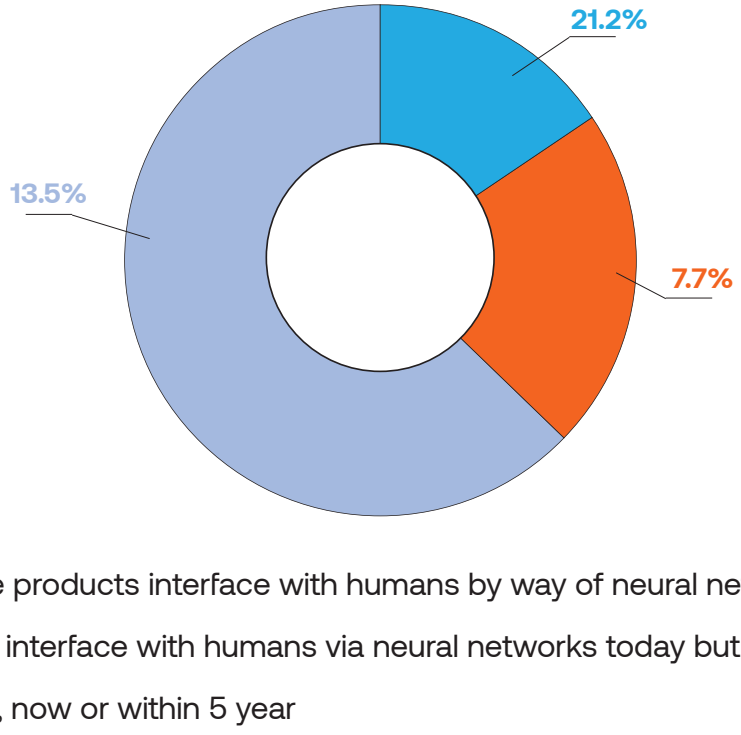
Figures 4 and 5 indicate additional areas of opportunity.

Figure 3. Average Maximum Frequency, Five Year Expectation



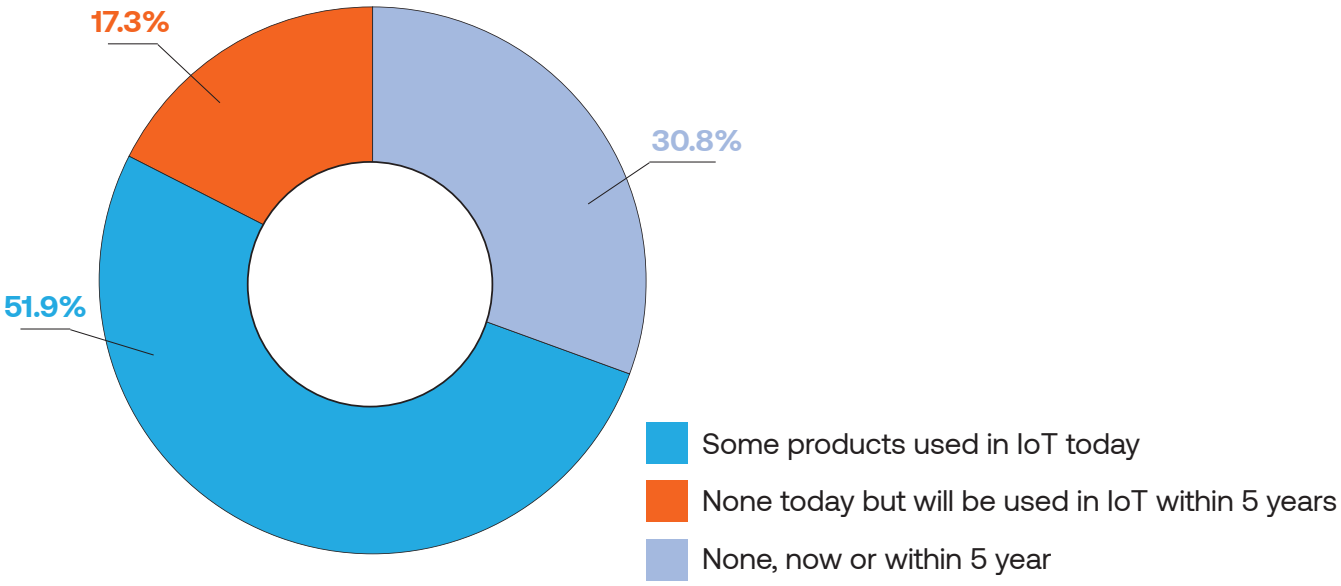
Source: IPC, PCB Technology Trends Survey 2018, February 2019, https://www.ipc.org/TOC/Tech-Trends-2018-TOC.pdf

Figure 4. OEM Trends, Neural Networks



Source: IPC, PCB Technology Trends Survey 2018, February 2019, https://www.ipc.org/TOC/Tech-Trends-2018-TOC.pdf

Figure 5. More than half of the OEMs surveyed make products for the IoT



Source: IPC, PCB Technology Trends Survey 2018, February 2019, https://www.ipc.org/TOC/Tech-Trends-2018-TOC.pdf

However, while these tech trends are driving opportunities for the PCB fabricator, they also present significant challenges. When this author interviewed nine board fabricators, the following concerns were cited most:

- Higher layer counts / more HDI / thicker boards
- Finer lines and spacing – sub 2 mil L/S
- Finer pitch
- Ultra HDI
- Small components and micro BGAs
- Higher aspect ratios
- Stacked blind vias and reliability issues
- Thinner dielectrics
- High-speed materials-processing
- Copper via filling capability

In addition, with profit margins already being squeezed by increases in the cost of raw materials and transportation, these firms will continue to have difficulty in attracting and retaining skilled workers. Workforce development and retention have been impediments to growth for years. What can be done?

A PATH FORWARD

A change in mindset will be needed for most North American-based PCB fabricators to move into higher-end advanced technology and manufacturing. One cannot enhance quality and jump up the technology curve without making strategic investments. They will need to upgrade and develop the workforce, and not only engineers but also manufacturing personnel who need to understand the critical aspects of workflow, quality, and time-to-delivery. They will also need to increase manufacturing capacity. And yes, there is a cost to that. However, a loss of market share, excessive reliance on overseas fabrication, and dwindling technological advances are the unacceptable alternatives.

Currently, industry and government actors are planning investments of at least $50 billion into state-of-the-art semiconductor chip making facilities in the United States. Even so, these facilities, when up and running, will provide only a portion of U.S. chip needs.

And this begs another question: Where will these chips go? Electronic systems require not only chips but also organic substrates, advanced multilayer boards, as well as assembly and test (OSAT). If we are serious about the future of the tech industry in North America, it is time to recognize that without circuit boards and IC substrates, there is no semiconductor industry.

For the United States to jump the technology curve and enhance the competitive positioning of the PCB fabrication base, we must embrace HDI and Ultra HDI as the standard design set for advanced electronics manufacturing. But it is not a simple technology to master. It will require significant investment in capital equipment, workforce training, and development and adoption of new processing technologies including semi-additive and alternatives to conventional metallization. Fabricators must master key technologies and processing if they wish to be a credible supplier of this growing technology, including:

- Tooling and materials selection;
- Small hole drilling and micro-drilling;
- Laser via formation;
- De-smear, metallization and hole plugging;
- Fine-line and tight-registration, image transfer and etching;
- Blind-via plating (super fill copper); and
- Quality control and qualifications (test vehicles, reliability verification).

All that said, the scope of investments necessary to jump start the U.S. PCB industry is significantly lower than those needed for semiconductor facilities. Based on primary research conducted by this author over the past several months, the key lies in increasing both manufacturing capacity and advanced technical capabilities for the top 100 PCB fabrication entities in the U.S. For each facility, the advanced capabilities necessary to increase yields and technical capabilities can be purchased for $10 million to $12 million. This includes state-of-the-art laser drilling equipment, Laser Direct Imaging, the latest technology for registration and subtractive processes, and complete upgrades for via filling, metallization and in-house quality control. The suggested investments and relative costs are shown in Table 1.

Table 1. Investments Needed to Position PCB Fabs for Future Success

Equipment/Technology	Cost (per facility estimate)
Combo UV/CO2 laser via drilling systems (x2)	$1,350,000
Laser Direct Imaging (x2)	$1,500,000
Copper via fill plating	$150,000
High Speed Mechanical drills (x2)	$900,000
Lamination presses (state of the art) X2	$1,200,000
Etching/Developer upgrades	$400,000
Registration systems	$250,000
Direct Metallization (horizontal)	$375,000
Flying Probe Tester (X2)	$400,000
Horizontal processing (Develop, etch, Strip-oxide)	$1,200,000
Via fill (paste fill) and planarizer	$600,000
Electroplating line upgrades	$400,000
Plasma systems	$500,000
Engineering/IT systems upgrades	$450,000
In-house reliability testing (IST, CITS)	$350,000
TOTAL	**$10,025,000**

Source: Author's research

The estimates shown in Table 1 add up to approximately $10 million. Granted this is a snapshot of the capital expenditures required to increase one facility's capacity and advanced manufacturing capabilities; however, it represents a critical starting point. It does not include investments in increasing the manufacturing footprint through buildouts or lease-hold improvements.

How would a small to mid-sized PCB fabricator that already has reasonable capabilities in-house be able to make this investment? One idea would be to subsidize the top 100 firms identified by key OEMs and mil-aero-qualified fabricators with tax incentives and low- to no-interest loans. Assuming the investments identified in Table 1 are made by the 100 firms, the grand total is still just $1 billion – significantly less than the cost of a single $10 billion chip-making facility.

Another possible strategy is for firms to apply for R&D tax credits and, if possible, take advantage of accelerated depreciation on the new investments.

Policy makers would be wise to impose a few more requirements on firms that receive such funds and incentives, including paying their workers a livable wage and providing medical and dental benefits; providing a safe working environment; and increasing its workforce commensurate with the added investment.

The near-term objective would be to double the manufacturing capacity for high-reliability complex printed circuit boards and IC substrates in the United States over the next three years, followed by another 50 percent increase in capacity by the year 2027.

SUMMARY

While these capacity-expansion goals may seem overly optimistic, given the existing PCB interconnect fabrication footprint already existing in the United States, it is quite feasible. The initiative would involve leveraging the existing, installed base to increase capacity and further advance its manufacturing technology.

If the federal government as well as the major chip manufacturers are serious about semiconductor fabrication in the U.S., then they will need to drive significant investment in printed circuit board manufacturing and the workforce as well. END