



TOWARDS A ROBUST
ADVANCED
PACKAGING
ECOSYSTEM

FROM JOHN W. MITCHELL

Governments internationally are developing policy initiatives and marshaling resources to make their semiconductor industries more globally competitive, better equipped to handle growing demand, and able to deliver next-generation technologies that will raise living standards, spur economic growth, and help solve some of the world's vexing problems.

Historically, much of the technology community's collective attention has been on silicon scaling, or incorporating more features into each chip. Today, scaling is becoming increasingly difficult and companies have been looking for other avenues for performance improvement. Advanced packaging is now eclipsing silicon scaling as the key driver for semiconductor component innovation, but more work needs to be done to ensure that government initiatives reflect this technology trend. Marrying investments in chip fabrication with investments in advanced packaging will be critical in the development of robust semiconductor ecosystems.

Building advanced packaging ecosystems will require difficult strategic decisions, more coherent manufacturing policies, and greater collaboration among industry and government on R&D and workforce development. Many of the capabilities to support advanced packaging are not widely available in the United States or Europe. Governments, then, need to think ambitiously by taking short-term steps to build capabilities and capacities while investing in longer-term R&D to support semiconductor needs in areas like self-driving vehicles, 5G and 6G wireless communications, IoT, and high-performance computing.

Creating these robust semiconductor ecosystems should be a goal around which we can all rally!



John W. Mitchell | IPC President & CEO

EXECUTIVE SUMMARY

1. Leaders across the semiconductor supply chain agree advanced packaging is a key priority and driver of future innovation.

- a. Nearly all (94%) of electronics industry leaders report that improving the performance of semiconductors is increasingly reliant on advanced packaging.
- b. A large majority (84%) of electronics industry leaders believe government initiatives to bolster the semiconductor supply chain require significant investment in advanced packaging capabilities.

2. Governments can do more to bolster advanced packaging capabilities

- a. Industry leaders feel the government does not understand the importance of advanced packaging. Only 29% of leaders in the semiconductor supply chain believe policymakers appreciate the importance of advanced packaging in semiconductor innovation.
- b. Industry leaders believe government efforts to bolster advanced packaging capabilities will lead to a more resilient industry and advance technological innovation. Some 82% of semiconductor leaders believe government initiatives to bolster the semiconductor supply chain are a first step in supporting technological innovation and supply chain resiliency.
- c. Industry leaders agree the government should take a more holistic approach to bolstering the semiconductor industry. Some 83% of semiconductor leaders believe governments should endorse a silicon-to-systems policy framework that enhances the capabilities of the electronics manufacturing ecosystem.

3. Additional infrastructure investment is needed in order to successfully develop a robust advanced packaging ecosystem

- a. Just 8% of industry leaders believe the U.S. has sufficient capacity and technology to support the advanced packaging market segment.
- b. Some 78% of industry leaders believe the advanced packaging community needs to focus on R&D, and 76% believe the community should also focus on education and workforce development.
- c. Over half of industry leaders believe the advanced packaging community should focus on standards development.
- d. Industry experts report the three most important technology drivers for innovation in advanced packaging are: next-generation substrate technology that supports finer features; development of next-generation substrate materials; and equipment and process advancements. These areas should be the central focus of advanced packaging investment.

4. Industry is likely to purchase domestically available, cost-competitive advanced IC-package substrates and IC-package assembly from U.S. suppliers.

- a. Only 6% of respondents report they are not likely to buy cost-competitive advanced IC substrates if they were available from U.S. suppliers.
- b. Only 7% of semiconductor leaders report they would not be likely to use cost-competitive advanced IC packaging assembly if it were available in the U.S.

INTRODUCTION

Technology demands are becoming ever more complex. The tools and devices we have long relied on are no longer sufficient, and new approaches are needed to meet ever-changing demands in healthcare, financial services, manufacturing, transportation, and other industries.

Autonomous robots, self-driving vehicles, high-performance computing, augmented and virtual reality, factories of the future, and AI-infused experiences are just a few of the advanced technologies that will shape our lives and livelihoods in the years to come. But as industries race to adopt these new tools, the electronics industry faces significant challenges.

How can technology deliver faster speeds, greater processing capabilities, lower latency, and higher data throughput? And how can the technology industry deliver all of these features in a smaller package with lower power consumption and longer battery life?

Over the last 50 years, silicon scaling was the answer to greater technological performance, but today silicon scaling can no longer meet the needs of increasingly sophisticated applications. The new king in the semiconductor industry is advanced packaging. Increasingly, it is the catalyst for innovation.

To further the advanced packaging discussion among industry and government leaders, IPC has produced the following report based in part on the findings from an online quantitative survey fielded in September 2022. The global survey panel consisted of 87 senior electronics industry executives and technology leaders with expertise spanning semiconductor fabrication/foundries, IC-substrates, advanced packaging assembly & test (including OSAT), printed circuit boards (PCB), and final system assembly (EMS).

The following report presents new research exploring what is needed to propel advanced packaging forward. Advanced packaging is a key ingredient in defining the next generation of innovation. With its help, new technology solutions are enabled and available to solve many of the world's most pressing challenges. But in order to achieve these goals, companies and governments will need to determine how to cultivate robust regional advanced packaging ecosystems to support the expected surge in chip production globally.



**TECHNOLOGY
DEMANDS ARE
BECOMING
EVER MORE
COMPLEX.**

ADVANCED PACKAGING IS NEEDED FOR ADVANCED TECHNOLOGIES



Semiconductor chips are sensitive to thermal and mechanical stress, so they must be safeguarded. Chips are “encapsulated” with a variety of materials, including polymers, to provide this protection. Once packaged, chips become active logic devices that execute computing and/or memory functions. Within electronic systems, these logic devices are just one of many different types of critical components.

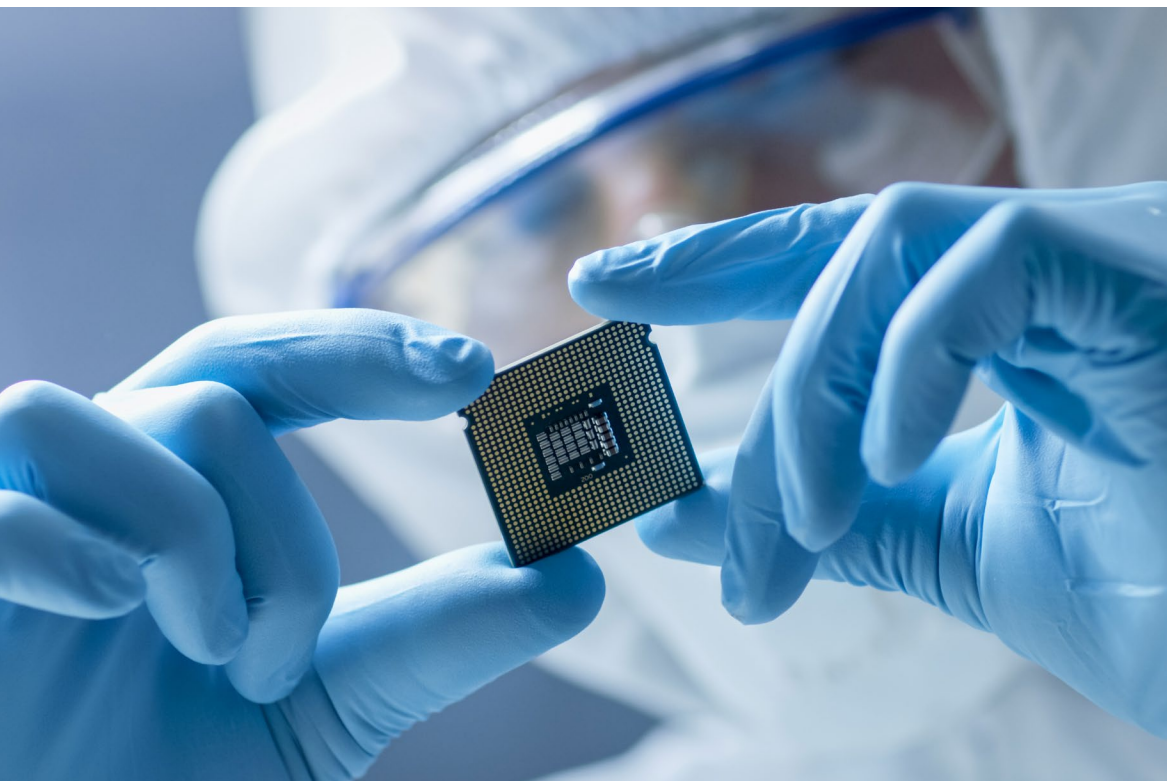
Decades ago, Gordon Moore, founder of Intel Corporation, realized that the number of transistors able to fit on an integrated circuit could be doubled roughly every two years. This meant

that ever more powerful semiconductor chips could be produced at greater cost efficiency – and indeed, for more than 50 years, Moore’s Law proved an accurate reflection of technology trends.

Recently, however, silicon scaling advancements have begun to slow, along with their economic efficiencies. As a result, the semiconductor industry is adopting new, innovative techniques to achieve greater production efficiency and technological capabilities through the use of cutting-edge advanced packaging.

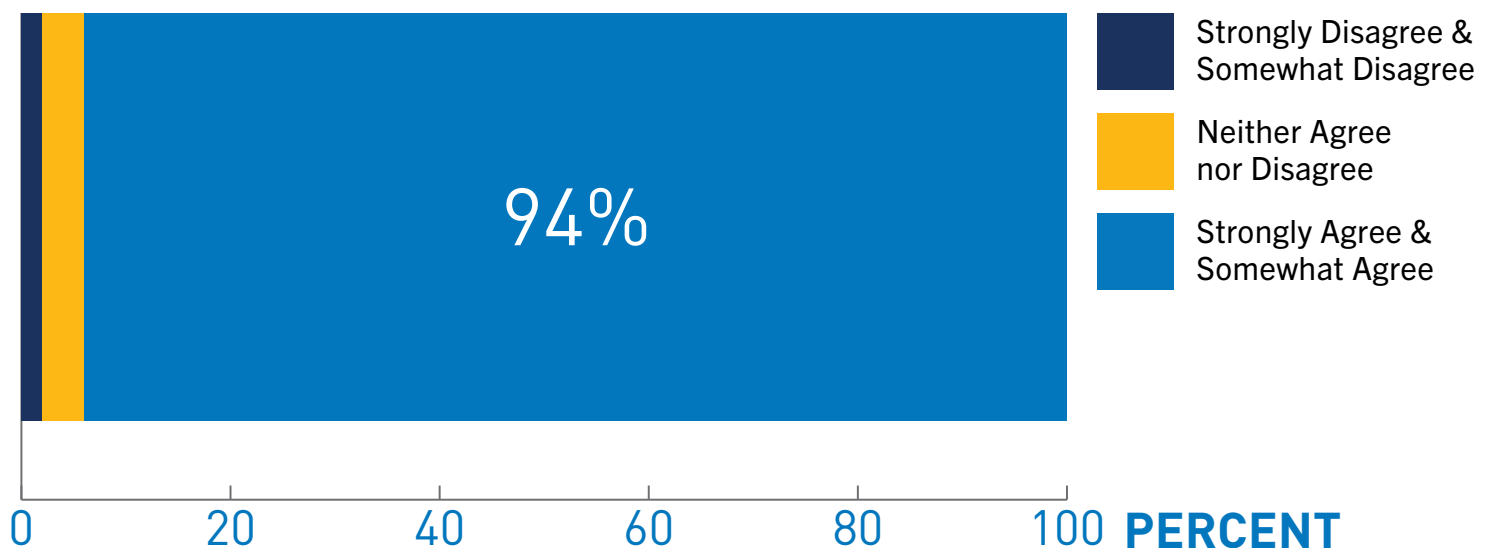
Demand for advanced packaging is not solely being driven by an extension of Moore’s Law. The electronics industry is increasingly being driven by “More than Moore,” the trend to expand functionality in ways that do not necessarily scale according to Moore’s Law. For example, data speed is increasingly a critical feature for myriad applications in AI and machine learning. It is also important in areas like 5G and advanced driver assistance systems (ADAS) that are seeking to minimize latency. The semiconductor industry is turning to advanced packaging techniques, primarily chiplet-based designs and heterogeneous integration approaches, to deliver the increasingly demanding performance requirements of tomorrow’s technology.

Nearly all (94%) of electronics industry leaders agree that advanced packaging is driving innovation in the semiconductor industry. Advanced packaging has become a key priority for industry leaders as it has become increasingly necessary for advanced technologies in terms of capabilities, capacity, and economics. Advanced packaging is enabling companies to scale in a more cost-effective way. Development of leading-edge process technologies is extremely expensive,



with each new node requiring billions of dollars in investments. For example, at 7 nanometers, CMOS scaling is often prohibitively expensive. Most companies cannot carry the development and wafer costs, so they put together solutions using different technologies. Advanced packaging techniques, like SiP, enable companies to integrate multiple chips from different foundries within a single package.

IMPROVING THE PERFORMANCE OF SEMICONDUCTORS IS INCREASINGLY RELIANT ON ADVANCED PACKAGING



ADVANCED PACKAGING TECHNIQUES

Moore's Law continues to drive down the size of wires and transistors, which in turn means that the distance a signal needs to travel from one end of a chip to the other is increasing. The speed of these signals can be enhanced, while the energy needed to deliver those signals can be reduced, through the use of "fatter pipes." These fatter pipes take the form of through-silicon vias, interposers, bridges, or simple wires. Additionally, depending on what kind of package is used, there will be fewer physical effects to worry about, and components manufactured at different process nodes can be more easily combined.

Examples of advanced packaging techniques include multi-chip modules, system-in-package, 3D ICs, 2.5D ICs, heterogeneous integration, fan-out wafer-level packaging, and chiplet-based packaging.

Multi-chip modules refers to a package that contains more than one chip, or die. The term is often used interchangeably with system in package (SiP). Multi-chip modules can range from two chips to an entire system on a single substrate. SiP is an advanced packaging technology that combines multiple integrated circuits (ICs) into a single package. SiP packages can contain a variety of components, including processors, memory, and I/O devices.

3D-ICs are an advanced packaging technology that allows for the stacking of multiple integrated circuits (ICs) to create a three-dimensional (3D)

structure. In a 3D-IC, each die in the stack is vertically interconnected to the others through a process known as die-to-die interconnects, which are typically made of copper or carbon nanotubes. 2.5D is an advanced packaging technology that combines multiple dies into a single package. The dies are interconnected using an interposer, which is a thin die that connects the dies together.

Heterogeneous integration (HI) refers to the integration of multiple dies with different functions into a single package. Heterogeneous integration is a key enabler of the Internet of Things (IoT), as it allows for the integration of multiple sensor types and communication standards into a single device. This type of integration is necessary to meet the demands of the IoT, which requires devices to be small, low-power, and able to communicate with each other using a variety of different protocols.

Fan-out wafer-level packaging (FOWLP) is an advanced packaging technology that is used to package semiconductor devices. In FOWLP, the interconnects between the die and the external world are routed outside of the die footprint. This routing can be done using a variety of methods, including micro-vias, stitching vias, or trenches. Chiplet-based packaging refers to the integration of multiple dies into a single package. The dies are interconnected using an interposer, which is a thin die that connects the dies together.



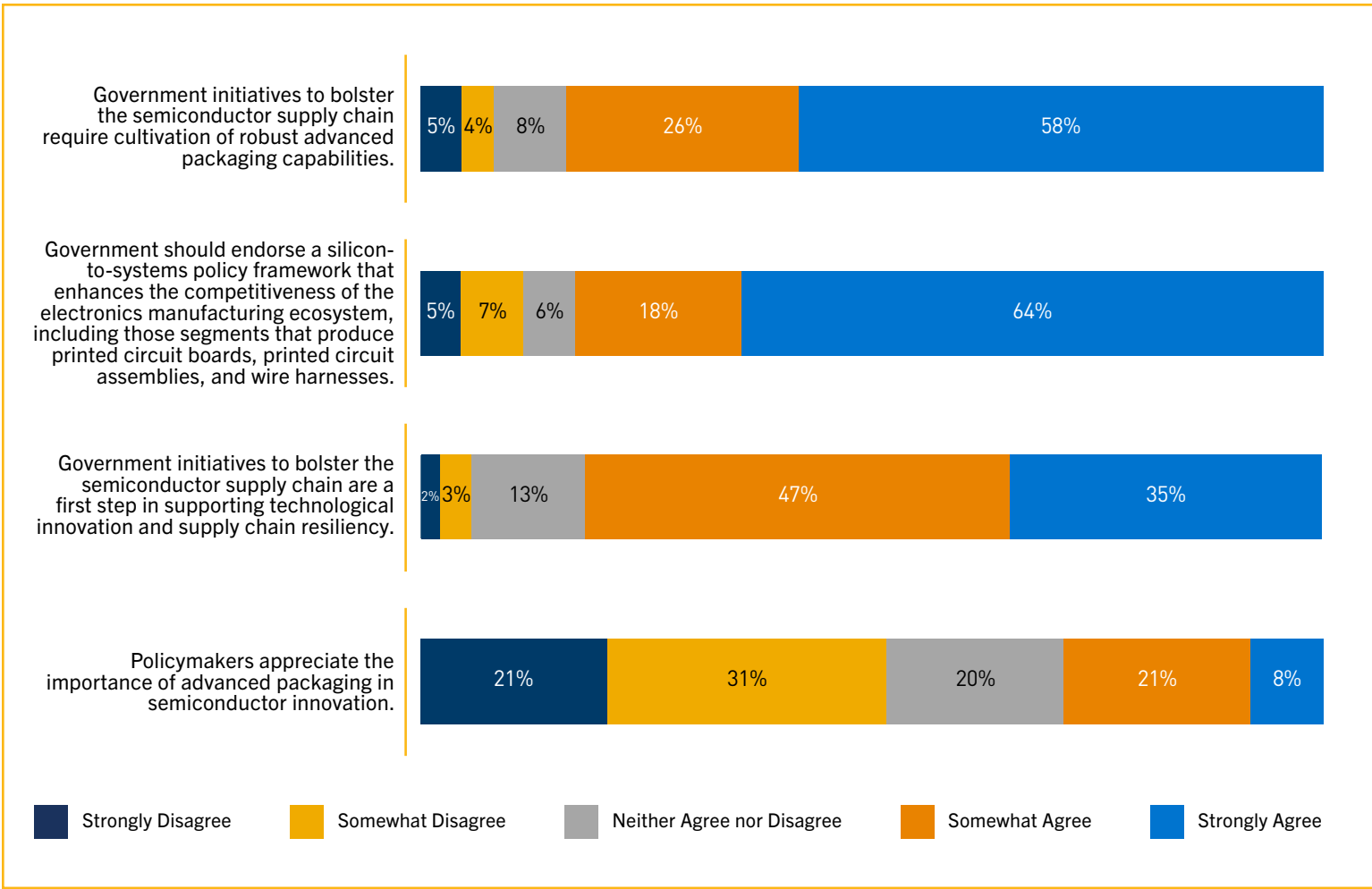
GOVERNMENTS CAN DO MORE TO BOLSTER ADVANCED PACKAGING CAPABILITIES

Semiconductor stakeholders express wide agreement that technological advances are increasingly being driven by advanced packaging capabilities. They also largely agree that policymakers are missing this important consensus about the future of innovation. Less than one-third (29%) of leaders in the semiconductor supply chain believe policymakers appreciate the importance of advanced packaging in semiconductor innovation.

More than eight in ten (84%) semiconductor supply chain leaders believe government initiatives to bolster the semiconductor supply chain require significant attention and investment in advanced packaging capabilities. In the U.S., the CHIPS and Science Act includes at least \$2.5 billion, but as much as \$7 billion, for advanced packaging. This crucial funding initiative has received relatively

little attention outside of the electronics industry. But the semiconductor supply chain believes this investment will be crucial in strengthening the domestic semiconductor industry.

Governments need to support advanced packaging capabilities in order to realize the broader goals of their semiconductor investments. It is not enough to just build semiconductor fabs. If the focus is only on domestic chip production, then once produced, those chips will need to be sent elsewhere for final component assembly, integrating the semiconductor chip, IC-substrate, and final packaging assembly constructions. This will result in lengthening the supply chain, not shortening it, which leaves the electronics industry less resilient and ultimately less capable to deliver the cutting edge innovations of tomorrow.



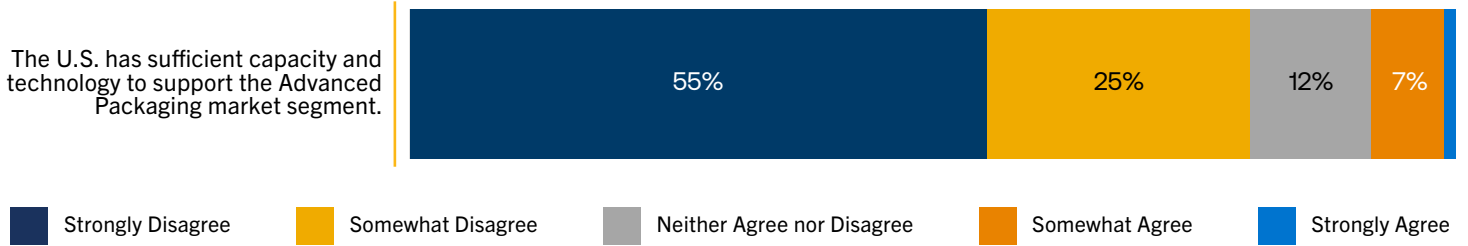
Notably, roughly eight in ten (82%) semiconductor leaders believe government initiatives to bolster the semiconductor supply chain are a first step in supporting technological innovation and supply chain resiliency. Advancements in semiconductor packaging also have direct impacts on PCB fabrication and electronic hardware assembly. The more sophisticated IC packages become, the more complex the corresponding 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. So as the industry manufactures ever more sophisticated semiconductor chips, governments should ensure that their domestic industries have the capability and capacity to assemble these components onto

printed circuits for integration into end systems. An electronics industry is only truly resilient if it can offer the full suite of resources needed to produce advanced electronics.

To this end, approximately eight in ten (83%) semiconductor leaders believe governments should endorse a silicon-to-systems policy framework that enhances the full capabilities of the electronics manufacturing ecosystem. Semiconductor chips—as marvelous as they may be—are useless on their own. So, too, are the advanced IC-substrates that chips are bonded to. While uniquely important in an electronic system, they are intermediate steps in a much larger process of designing and manufacturing final products and systems for use in the defense, networking, aerospace, automotive, and medical sectors. Governments should affirm policy frameworks that bolster the entire ecosystem that turns silicon into systems.

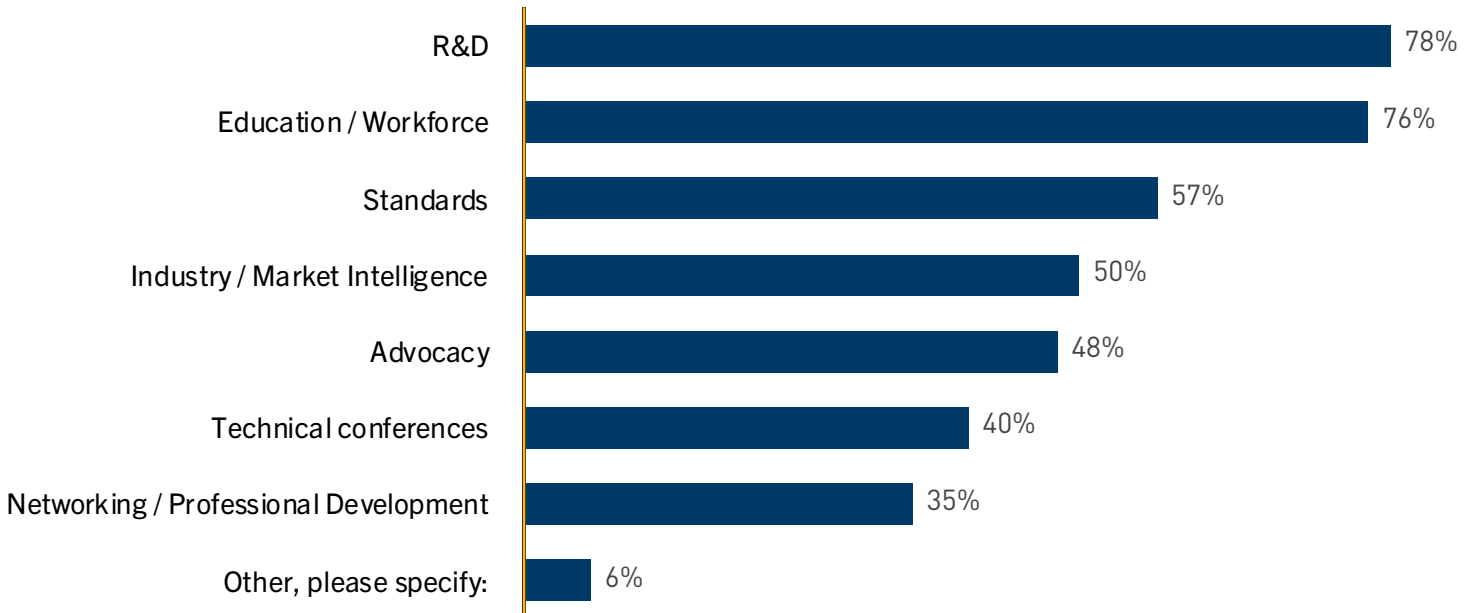
FURTHER INFRASTRUCTURE INVESTMENT IS NEEDED NOW

Industry experts agree that the electronics industry needs additional infrastructure in order to successfully develop a robust advanced packaging ecosystem. For example, just 8% of industry leaders believe the U.S. has sufficient capacity and technology to support the advanced packaging market segment. It is clear that investment in capacity is broadly needed.



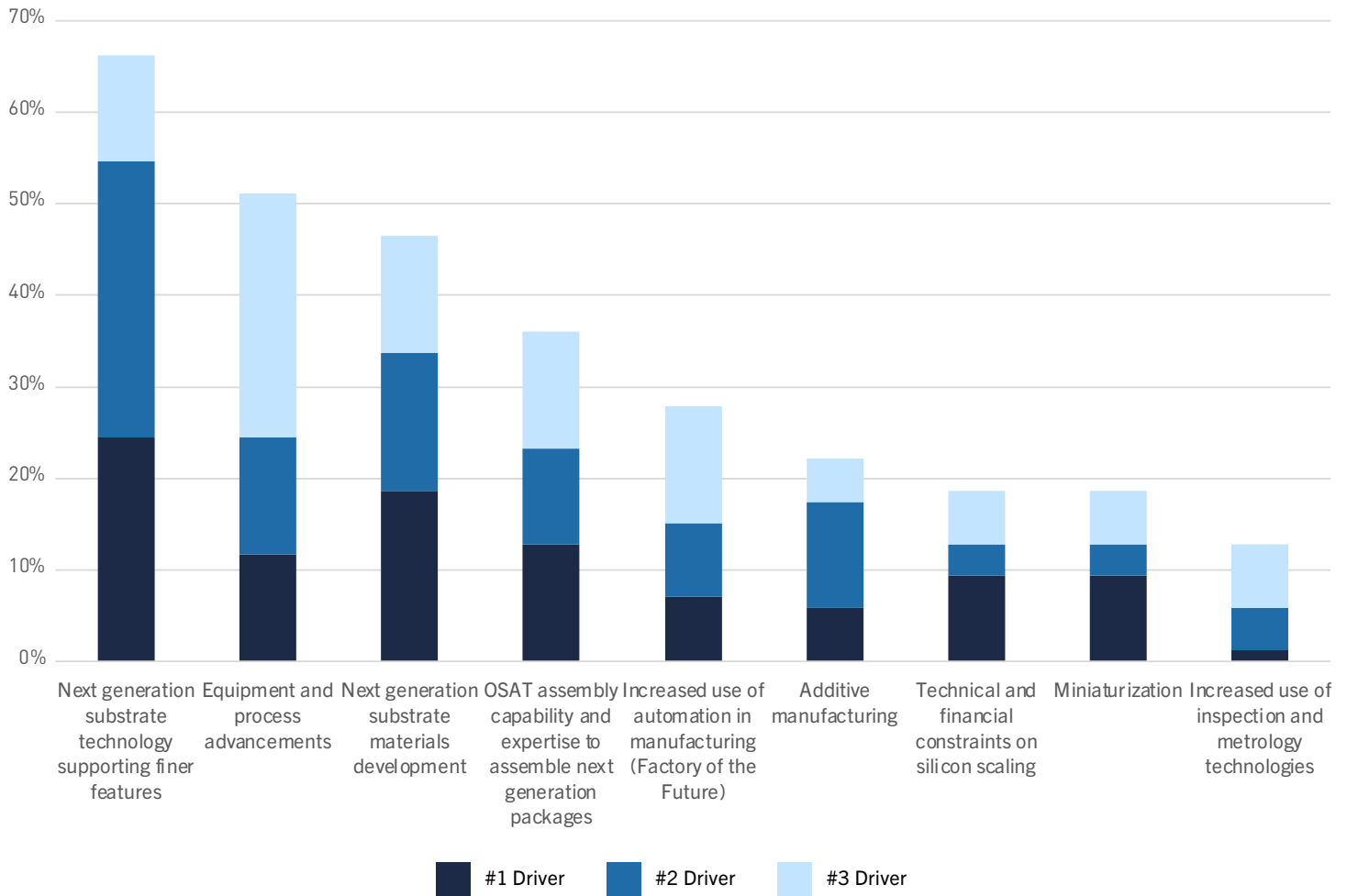
Industry executives see a few general focus areas for investment. Nearly eight in ten (78%) industry leaders believe the advanced packaging community needs to focus on R&D, and roughly three-fourths (76%) of respondents believe the community should also focus on education and workforce development. Over half of leaders believe the advanced packaging community should focus on standards development.

ADVANCED PACKAGING COMMUNITY NEEDS FOR GREATER COLLECTIVE ACTION



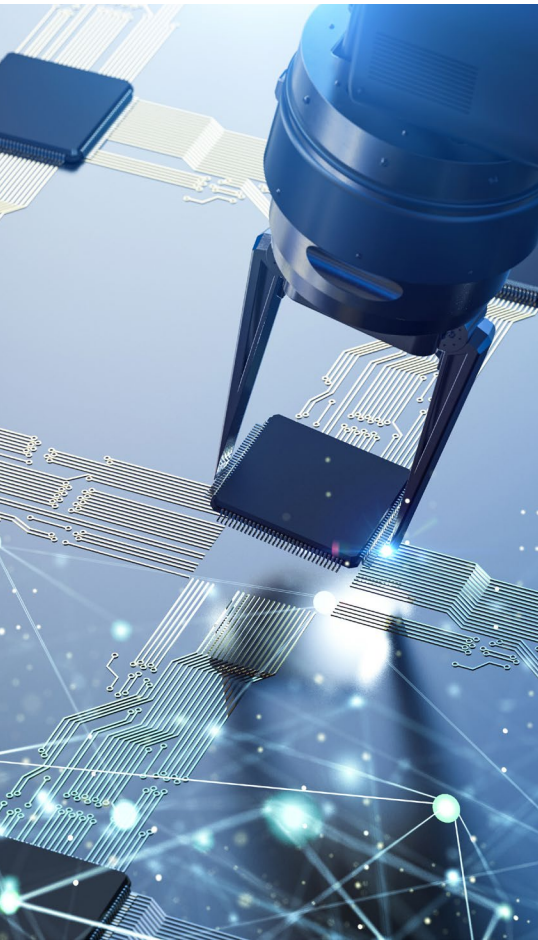
There are a number of specific areas of R&D that industry executives believe should be a central focus of advanced packaging investment. For example, industry experts report the three most important technology drivers for innovation in advanced packaging are: next-generation substrate technology that supports finer features; development of next-generation substrate materials; and equipment and process advancements. These are nascent areas in key geographies like North America, but all of these will require further R&D to bring to fruition.

TOP 3 MOST IMPORTANT TECHNOLOGY DRIVERS FOR INNOVATION IN SEMICONDUCTOR ADVANCED PACKAGING



Next-gen substrates will be needed for the next-gen products. Being able to implement finer features on an IC substrate carries many benefits. It can dramatically reduce the size, weight, and packaging needed, which in turn increases the electronic content within an existing space. Moreover, supporting finer features allows for a reduction in the number of microvia layers required, which reduces cost and improves reliability.

Improving substrate materials is an ongoing effort within the advanced packaging industry. Currently, bismaleimide triazine resin (BT resin) and Ajinomoto build-up film (ABF) are the most commonly used substrate materials. However, further innovation in substrate materials could allow for greater reliability by improving electrical properties.



IPC's Advanced Packaging task force has noted that investment in substrates should focus on substrates of the future that will meet the needs of higher density I/O and advanced nodes. This would include the needs for co-packaged optics, which is combined with assembly capability. Substrates for silicon photonics (co-packaged optics) add to increasing complexity needs..

As noted earlier, advanced packaging is becoming a greater necessity as complexity and cost of the system on a chip (SoC) increases. There is an increased focus on innovations in packaging as a way to increase overall performance and functionality. Sufficient funding and an emphasis on R&D is necessary to make progress in advanced packaging technology since ensuring the packaged chip continues to increase in functionality and performance while integrating new technology is not a straightforward process.

Industry standards will also help improve reliability and quality and 57% of the industry experts surveyed believe the advanced packaging community should focus on standards development. IPC standards are already in use in some aspects of advanced packaging. Industry collaboration is going to be critical to help grow the advanced packaging industry.

THE NEED TO DEVELOP AN ADVANCED PACKAGING WORKFORCE

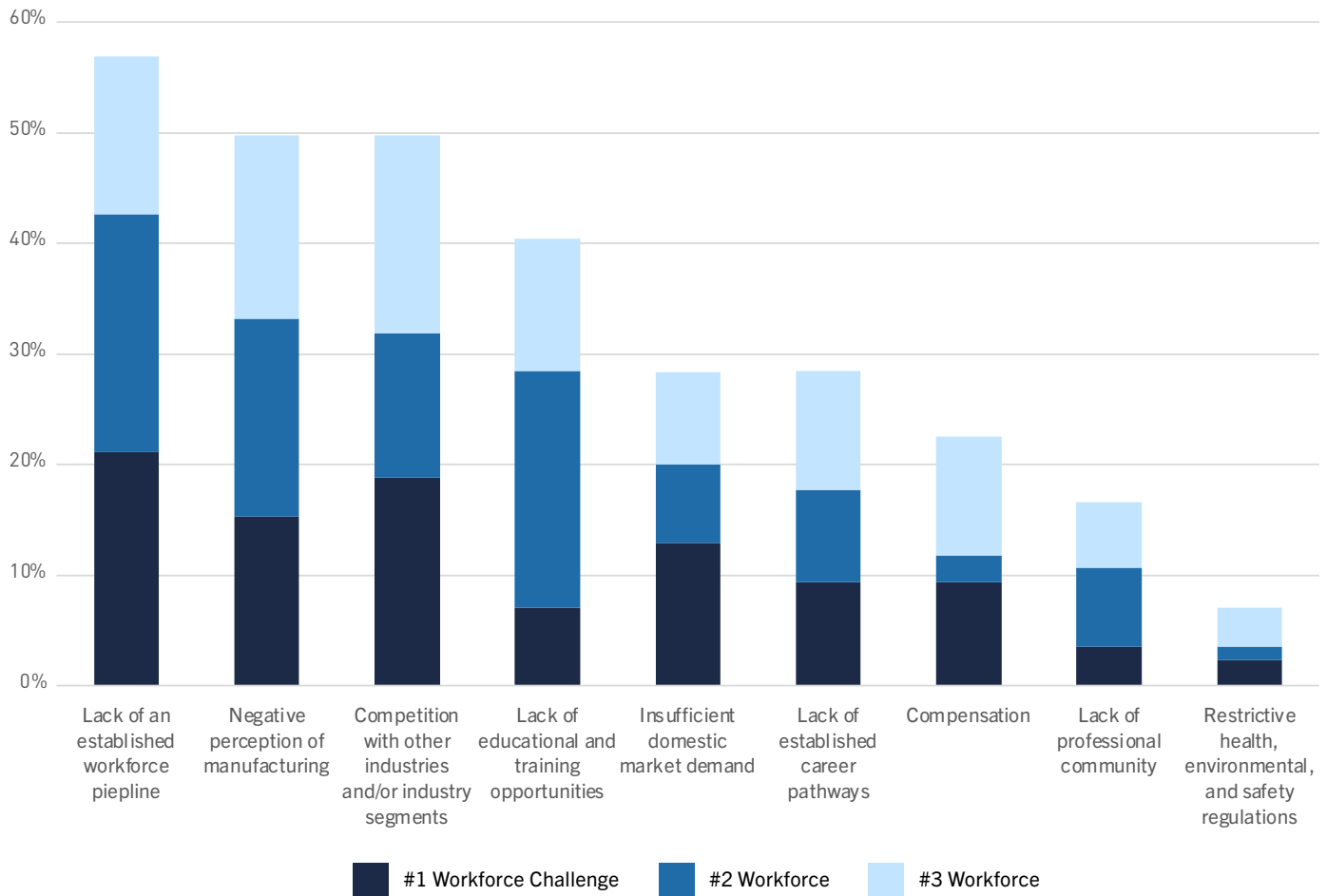
Developing skilled workers is a top concern for the electronics manufacturing sector, and it is clear industry leaders believe it is vital to establish a skilled workforce within the advanced packaging community. Three-fourths (76%) of industry leaders report that education and workforce development are key areas in need of greater collective action within the advanced packaging community.

The three most pressing workforce challenges that are restraining the growth of advanced packaging include the lack of an established workforce pipeline, competition with other industries and other industry segments, and overcoming the negative perception of manufacturing. Roughly 40 percent of industry leaders also report a lack of educational and training opportunities as a top three workforce concern restraining the growth in advanced packaging.

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PERCENTAGE OF INDUSTRY LEADERS REPORT THAT EDUCATION AND WORKFORCE DEVELOPMENT ARE KEY AREAS IN NEED OF GREATER COLLECTIVE ACTION WITHIN THE ADVANCED PACKAGING COMMUNITY

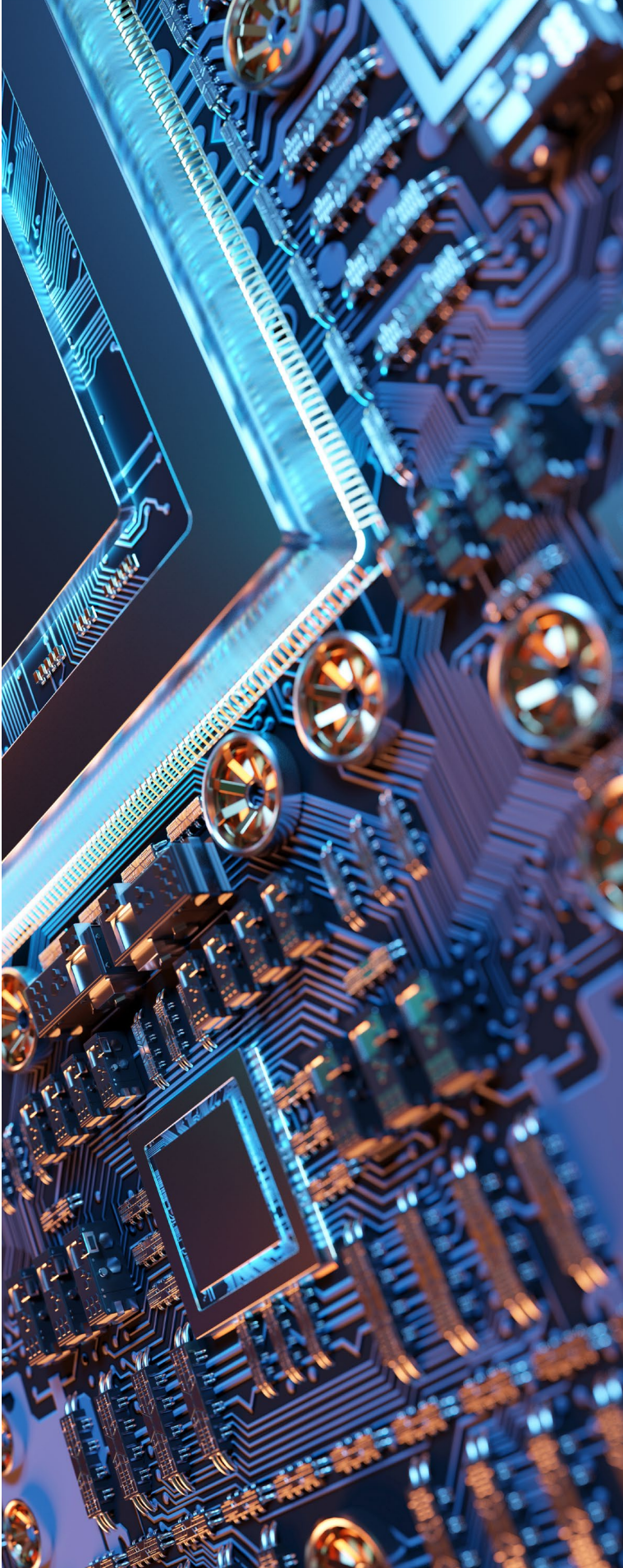
TOP 3 MOST PRESSING WORKFORCE CHALLENGES RESTRAINING THE GROWTH OF THE ADVANCED PACKAGING INDUSTRY



Domestic IC substrate manufacturing capabilities are nascent in the United States and Europe and both regions are seeking to develop capabilities that have never existed domestically. Success will depend on accelerating the development of domestic expertise and leveraging that expertise to introduce innovations into manufacturing processes. This is only possible with a robust, skilled workforce.

Investments aimed at developing the advanced packaging workforce should integrate into and enhance ongoing industry initiatives to develop a robust pipeline for electronics manufacturing. Despite the critical importance of electronics in modern society, a meaningful and sustainable workforce pipeline for electronics manufacturing has never been established in the U.S. or Europe. Initiatives to develop such a pipeline lost traction after 2000 as high-volume electronics manufacturing migrated to Asia. A resurgent industry, however, is collaborating in new, exciting ways to expand and extend workforce training programs and to create career pathways for individuals entering electronics manufacturing.

In the U.S. for example, the National Advanced Packaging Manufacturing Program should support these industry initiatives, as they offer the most effective and expedient means to prepare and upskill workers for opportunities in advanced packaging. The advanced packaging industry is likely to remain



relatively small over the next five to 10 years, meaning that the number of workers needed in advanced packaging will initially be small as well. Trying to establish independent workforce training programs to serve this niche market will be challenging and expensive, not to mention a disservice to workers who today strive for portability in addition to upskilling. By creating a workforce pipeline for the electronics industry, industry and government can also organically create an ongoing, sustainable pool of potential workers for advanced packaging.

Efforts should be made to align advanced packaging workforce training with broader electronics manufacturing workforce development because the lines are blurring between IC substrate and PCB fabrication as well as between first and second level assembly. In fact, it is likely the case that the sophistication of IC substrate manufacturing today characterizes PCB and EMS manufacturing tomorrow. For this reason, governments should view electronics interconnection as a key strategic priority, requiring a skilled workforce. This skilled workforce will naturally pivot to the opportunities that arise as the industry evolves.

Ultimately, establishing an advanced packaging workforce pipeline will be a multifaceted effort, requiring a variety of curricula for use by different stakeholders training workers for different roles. The engineer will have different needs than the technician, which will also differ from the inspector and the operator. It is critical, however, that the curricula are developed through job task analysis to align with industry needs and that industry-recognized credentials are used to validate worker competencies. Governments should seek to better understand the existing mechanisms for workforce training in electronics and to leverage the most effective and scalable of these mechanisms to support the workforce needs of the advanced packaging industry.

ADVANCED PACKAGING & RECENT LEGISLATION IN THE U.S. & EUROPE

Appreciating the role of advanced packaging in driving semiconductor innovation has taken on increased importance as governments globally have sought to strengthen their domestic chip industries. The success of these governmental initiatives will hinge on how well they embrace the opportunities to build advanced packaging capabilities—capabilities that haven't historically existed in North America and Europe.

In the U.S., President Joe Biden signed the CHIPS and Science Act in August 2022, which appropriates more than \$52 billion to implement the previously enacted CHIPS Act. Of this funding, \$2.5 billion was allocated for a National Advanced Packaging Manufacturing Program, and additional funding is likely to be dedicated to advanced packaging through this and other CHIPS Act programs. This is good news, but U.S. policymakers must stay committed to building a robust ecosystem for advanced packaging that doesn't exist domestically today.

In Europe, the situation is less clear. The European Union is taking action on its own regional Chips Act, and while advanced packaging is clearly covered, support for the industry is far too muted. IPC, member companies, and peer associations are pressing the European Parliament to make sensible changes to the proposal to align its policy and funding support with industry needs.

IPC is committed to making sure that every region of the world has access to secure and resilient supply chains for cutting edge electronics.

BUILD IT AND THEY WILL COME

Industry leaders report they would likely purchase advanced IC package substrates and advanced IC packaging assembly from U.S. sources if it were cost-competitive. Only 6% of respondents report they would not buy advanced IC package substrates from cost-competitive U.S. sources, and only 7% report they would not buy advanced IC packaging assembly from cost-competitive U.S. sources.

At the same time, 29% of respondents report they are uncertain if they would use domestically available cost-competitive advanced IC substrate, and 26% of respondents report they are uncertain if they would use domestically available cost-competitive advanced IC packaging assembly. These results highlight the significant switching costs that are involved in changing suppliers. There are many unknowns when it comes to supplier performance, trust, requalification, and expected quality and reliability thresholds. This result highlights the reality that developing a robust ecosystem will take time, likely on the order of three to five years at a minimum. Ultimately, the ecosystem is defined by OEM component makers that need to support domestic sourcing of inputs including semiconductor chips, IC-substrates, and final component assembly and testing. Switching from well established market leading global suppliers to new domestic sources is risky business. New domestic sources must demonstrate required quality and reliability levels while at the same time being able to fulfill production volume orders with high first pass yields.

Approximately 28 percent of industry leaders report insufficient domestic demand is one of the top three challenges constraining workforce growth. This suggests greater domestic capacity will also drive workforce growth. Governments should recognize that infrastructure investment is also labor force investment.

NEXT STEPS

Industry executives are clear that advanced packaging is the new king in the semiconductor industry. They also agree that most governments do not fully understand the importance of advanced packaging in realizing broad technological and innovation goals. As the industry increasingly turns to this technology, it will be crucial for governments to get up to speed on its capabilities and importance. Advanced packaging can provide greater functionality and better performance than traditional packaging, making it ideal for a range of applications.

Industry executives also agree that there are a number of factors restraining growth of the advanced packaging industry. Industry leaders report that a weak domestic and regional electronics manufacturing ecosystem is the number one reason holding back growth for advanced packaging. Industry insiders also note that a lack of technical know-how, R&D, and skilled workers are factors holding back growth.

Industry executives agree that more infrastructure and investment is needed. A healthy, capable assembly ecosystem is needed to bring a wide variety of technologies together to manufacture finished products. Any disruptions, bottlenecks, or capability gaps within this end-to-end ecosystem leads to delays in new products and innovations, limiting the ability to manufacture the most advanced electronic systems. 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. Policymakers will achieve innovation goals and objectives by advancing the larger goal of strengthening the electronics ecosystem.



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.

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