WHITE PAPER

Silicon Carbide Chips: The Auto Sector's Newest Supply Hurdle

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Silicon Carbide Chips: The Auto Sector's Newest Supply Hurdle

Silicon-based semiconductors' long reign as the gold standard for high-power electronics applications is coming to an end. In a groundbreaking shift, advancements in material sciences and manufacturing have led to the emergence of wide bandgap materials that promise significant energy efficiency enhancements over their silicon counterparts. By enabling the transition to renewable sources of electricity and the electrification of transportation and heating systems, these efficiency gains are crucial for achieving sustainability goals.

Silicon carbide (SiC) stands out among these game-changing materials and is well on its way to replacing silicon in high-power applications. By 2025, most major new electric vehicle (EV) platforms are expected to incorporate SiC components, driving a CAGR of more than 30% for the SiC market through 2030. Automotive original equipment manufacturers (OEMs) have acknowledged the indispensable role of SiC in their upcoming EV platforms, while leading semiconductor integrated device manufacturers (IDMs) have recognized this lucrative opportunity.

This study explores the evolving SiC market, aiming to shed light on the outlook for supply-demand imbalances. We find that the market's initial growth will be propelled by the adoption of SiC in EV inverters. However, supply constraints are anticipated in the SiC market for the next five to seven years, giving early investors in SiC capacity a competitive edge. In the long run, SiC demand will be bolstered by applications in the renewable energy sector, including solar and wind inverters, as well as numerous industrial use cases.

SiC's novelty and anticipated supply constraints, coupled with the EV inverter's significance, make securing SiC supply a top priority for automotive OEMs, on par with securing battery supplies. All value chain participants will need to forge new partnerships and plan for significant additional capacity investments to ensure that SiC supply keeps pace with demand beyond 2027.

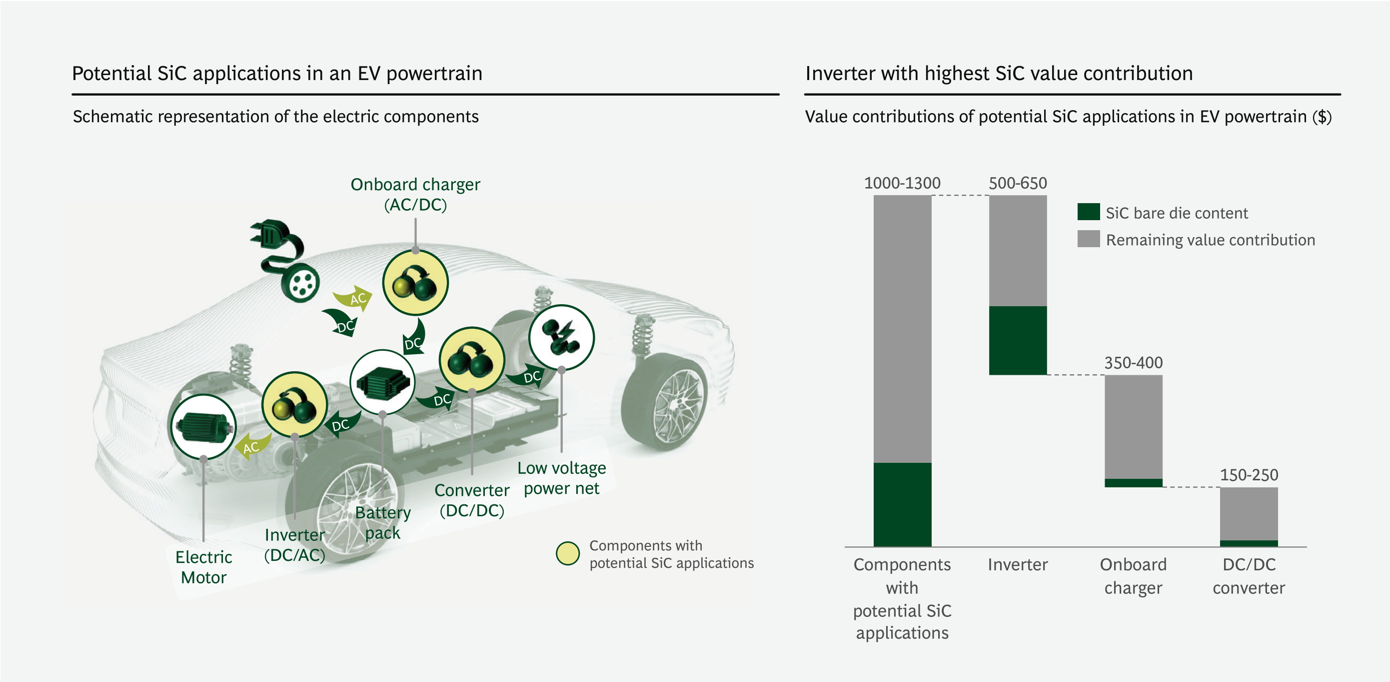
SiC Will Power the Car of the Future

The adoption rate of EVs has consistently surpassed forecasts. It has been further accelerated by recent policy changes, such as the European Union's ban on the sale of new combustion engine vehicles, set to take effect in 2035. By 2030, battery electric vehicles (BEVs) are projected to constitute approximately 40% of global light vehicle production.

In BEVs, power semiconductors regulate the flow of electrical energy from the charger to the high-voltage DC battery, and from the battery to the AC-powered electric motor and low-voltage DC devices. The electric powertrain is one of the primary sources of the increasing semiconductor content per vehicle, along with advanced driver assistance systems (ADAS), autonomous driving (AD) technologies, and digital cabin features.

Within the powertrain, the inverter, which contains the largest amount of semiconductor content, uses power semiconductors to operate and control the AC electric motor with DC from the battery (see Exhibit 1). Most EV platforms launching by the mid-2020s are expected to incorporate SiC in their inverters, promoting significant market growth.

Exhibit 1: SiC Contributes the Most Value in the Inverter



Source: BCG analysis

SiC is set to broadly replace silicon insulated-gate bipolar transistors (Si-IGBTs) in inverters, thanks to its superior electrical properties, such as a larger bandgap and electric breakdown field. These attributes result in an approximately 40% reduction in energy losses during switching, which directly impacts EV range and battery size requirements. Moreover, SiC's greater energy efficiency, enhanced thermal conductivity, and superior stability diminish cooling needs and enable a more compact form factor.

While SiC-based power modules are currently more expensive than their silicon-based counterparts, the overall system benefits, primarily driven by reduced battery costs, already favor SiC. This advantage becomes even more pronounced with the transition from 400-Volt to 800-Volt architectures in BEVs—SiC provides considerably greater benefits in terms of system cost and size for the latter.

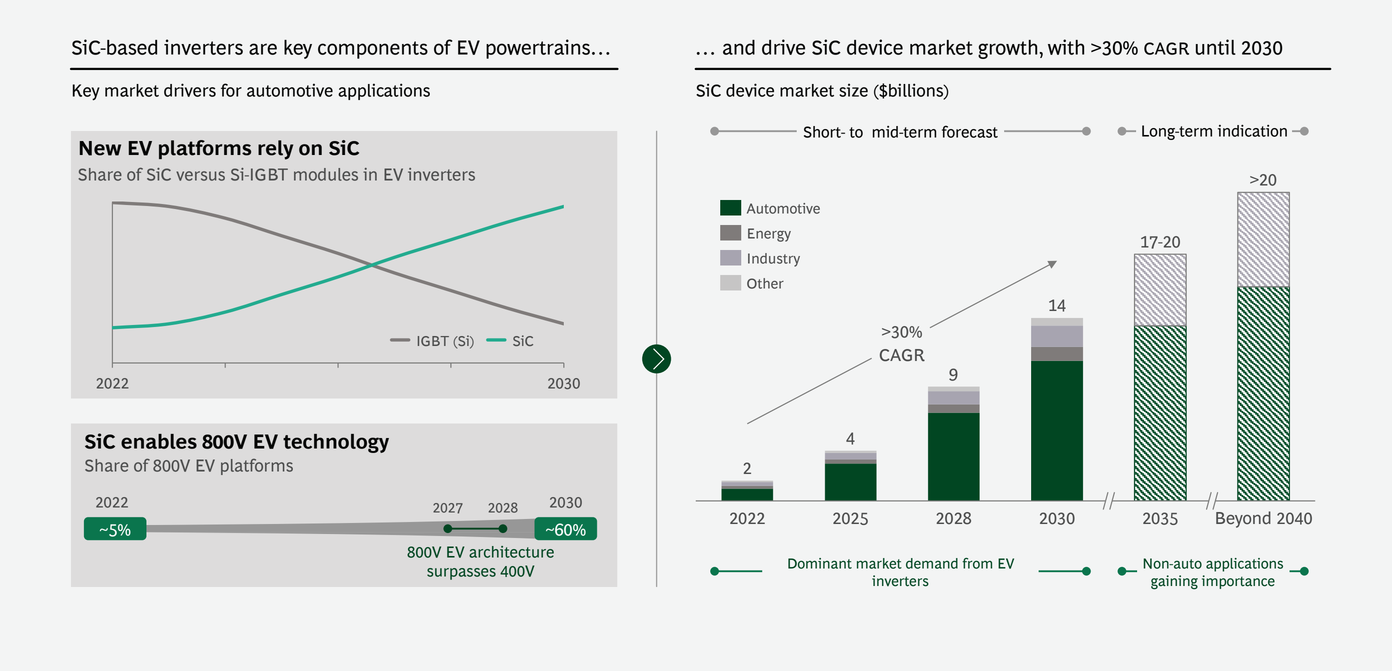
Furthermore, because SiC is a newer technology than Si-IGBT, its price is anticipated to decline faster in the coming years. Smaller chip sizes and growing confidence in SiC's reliability even at higher operating temperatures result in a more competitive cost position that allows for SiC applications in mass-market vehicles with lower inverter power ratings. Recent announcements by Tesla regarding the more efficient use of SiC in its powertrains highlight this trend.

Apart from inverters, onboard chargers and DC-DC converters offer further opportunities for efficiency improvements using SiC. However, these components' lower power ratings mean that they require up to ten times less chip area than inverter power modules. This makes them less-ideal candidates for SiC, especially given the anticipated supply shortages in the coming years. In the long run, the clear winner for powering onboard chargers and DC-DC converters remains to be seen. The options will be mature Si-IGBTs; SiC, which benefits from cost reductions through innovation and scaling; and emerging gallium nitride (GaN) technologies. For the foreseeable future, inverters will be the powertrain's dominant application for SiC, representing approximately one-third of the SiC value contribution, versus about one-tenth for the onboard charger and the DC-DC converter.

GaN, another promising wide bandgap material, is not considered a direct competitor to SiC for high-voltage applications. GaN's cost advantage primarily results from its fabrication on silicon substrates. However, this characteristic also limits GaN's breakdown voltage, which means it is less suitable for high-voltage applications compared to SiC. Additionally, GaN's thermal properties are less favorable, and the thickness of its epitaxial layer poses significant technological challenges. Consequently, GaN's most suitable applications will likely be confined to high-frequency applications, such as fast chargers and radio frequency (RF) devices. Other wide bandgap materials, such as gallium oxide (Ga203), remain far from commercialization and may only play a significant role after 2030.

Taken together, these developments mean that the automotive industry's demand for SiC should not be underestimated. By 2030, SiC adoption in EV inverters is projected to reach around 80%, surpassing silicon-based power modules by 2028, and propelling the SiC market to exceed €14 billion (see Exhibit 2). The automotive sector will account for more than 70% of the market.

Exhibit 2: SiC Adoption in EV Platforms is Driving Market Growth

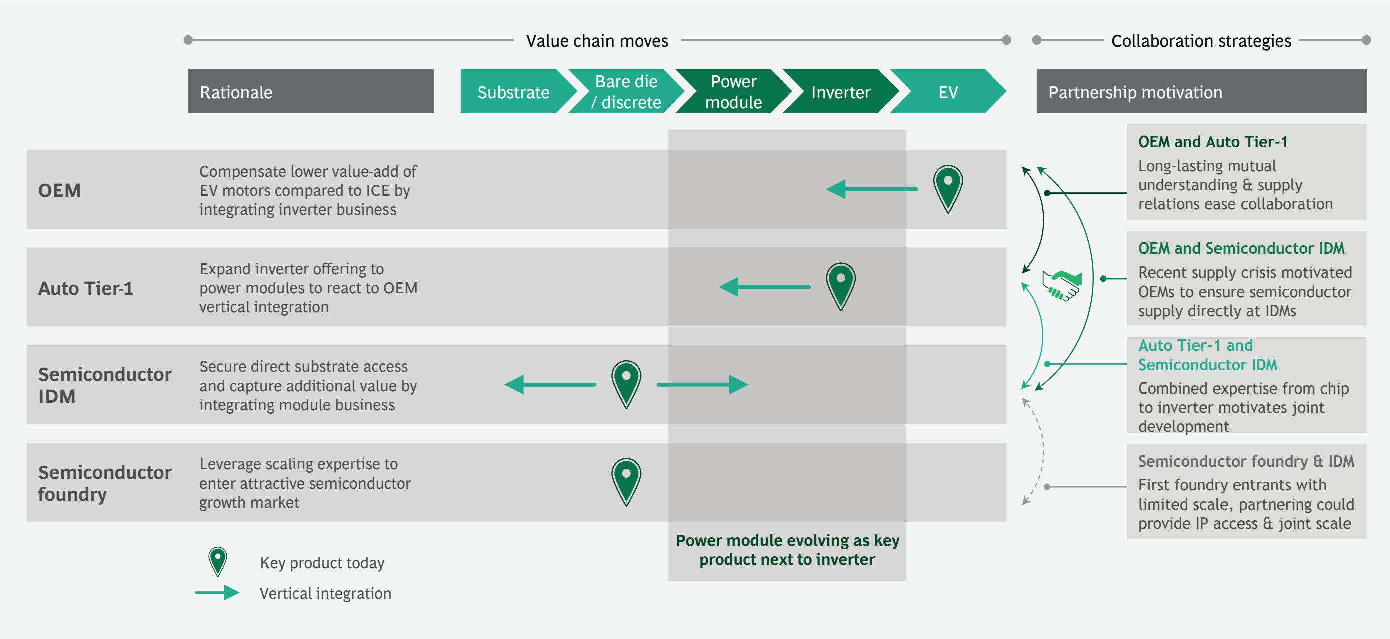


Source: BCG analysis

Vertical Integration is Reshaping the SiC Value Chain

The EV powertrain is considerably less complex than its combustion engine counterpart. To maintain margins and secure jobs despite fewer opportunities to add value, many OEMs have adopted vertical integration strategies, beginning with battery production and moving toward inverter development and production (see Exhibit 3). As a result, power modules are gaining importance as a critical supply component in the market. Applying lessons from the recent semiconductor supply chain crisis, OEMs are using their newly established industry contacts and semiconductor knowledge to secure the SiC supply chain.

Exhibit 3: Vertical Integration Is Changing the SiC Value Chain



Source: BCG analysis

Upstream in the value chain, semiconductor IDMs are also expanding vertically, aiming to integrate power module production. This development increases competitive pressure on tier-1 suppliers. In response, leading tier-1 players are forming close partnerships with semiconductor IDMs to differentiate based on integrated development (from chip to module and inverter) and the expertise to address each OEM's specific requirements. In this context of shifting responsibilities, the semiconductor industry needs to develop standards for power module design.

Few SiC foundry providers have entered the market thus far. Semiconductor IDMs possess extensive intellectual property (IP) and the specialized expertise required to process SiC and design high-performance chips, creating substantial barriers to new entrants. However, foundry players' unparalleled ability to scale semiconductor production may prove valuable in partnerships with smaller IDMs striving to achieve scale benefits.

Further upstream, access to high-quality substrates is crucial for SiC chip manufacturers. SiC substrate and chip production processes are still nascent and have only recently reached maturity for mass production. Boosting substrate quality remains a key hurdle for improving yields in chip production. Moreover, transitioning to 200-millimeter substrates will be essential to achieve the necessary chip quantities and competitive cost positions. A sufficient 150-millimeter substrate supply is expected soon; however, commercial 200-millimeter production is just beginning, and supply shortages are anticipated in the coming years. Consequently, several IDMs have acquired substrate manufacturers to scale their own production, and OEMs have identified substrate access as a critical prerequisite for their SiC power module and inverter suppliers.

Industry and Energy Applications Will Fuel Broader SiC Adoption

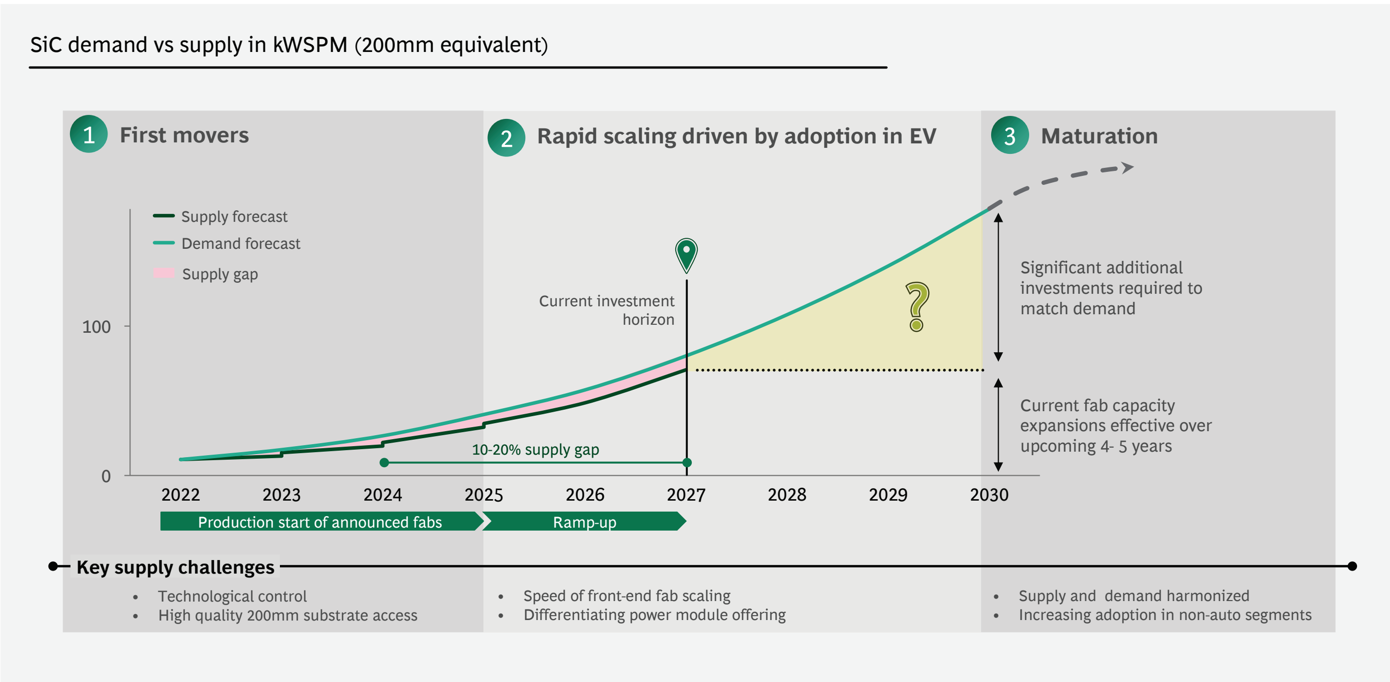
While automotive applications will be the primary drivers of SiC demand, the renewable energy and industrial sectors also stand to benefit from advancements in SiC technology in their quest to raise energy efficiency. SiC's higher costs can be justified in medium- to high-power applications where significant energy savings can be achieved. In the energy sector, photovoltaic inverters and EV charging infrastructure offer the largest growth potential, with additional applications such as grid storage likely to emerge. The industrial segment is dominated by power supplies, with a diverse array of additional applications—including DC-DC converters for trains.

Compared with automotive inverters, adoption in these sectors may be slower because higher voltage ratings are required and standardization levels are lower. Moreover, short-term supply scarcity and large OEM contracts may limit available SiC capacity. However, the ongoing energy transition is set to continue for decades, with energy and industrial applications only now beginning to gain momentum. Once BEV adoption starts to level off, these sectors will likely play an increasingly important role in promoting SiC demand and growth in the long run.

Major New Capacity Investments are Needed as the Market Evolves

Significant investments have already been made in SiC production capacity and IDMs have announced plans for further investments in the coming years. However, there is usually a lag of three to four years before the new front-end SiC capacity is operational. Furthermore, demand will surge from 2025 onwards with the arrival of new EV platforms that rely exclusively on SiC-based semiconductors for inverters. This combination of factors means that supply constraints will persist for the next five to seven years, limiting the market's growth potential (see Exhibit 4). To balance supply and demand by 2030, IDMs will need to make additional investments in capacity expansion within the next few years beyond those already announced.

Exhibit 4: The SiC Market Will See Capacity Constraints



Source: BCG analysis
kWSPM = Thousand Wafer Starts per Month

Considering the constraints, we expect the developing SiC market to transition through three distinct phases:

- The arrival of the first movers and the formation of an ecosystem, which are evident today.
- The rapid scale-up of production capacity, driven by strong demand for SiC adoption in EVs.
- The maturation of the market, characterized by reduced growth rates, consolidation, and broader adoption beyond automotive applications.

Each phase presents unique opportunities, challenges, and strategic imperatives for the players involved, including semiconductor IDMs, automotive tier-1 suppliers, and OEMs.

Phase 1: First Movers

Today's initial phase of SiC development presents a window of opportunity as the ecosystem forms and first movers refine technology, announce capacity investments, and secure market share. With limited SiC production, prices remain high.

For IDMs, priorities during this phase include mastering SiC chip processing technology to increase yield, rapidly scaling through strategic investment and public funding, and differentiating and expanding their power module offerings. Securing access to high-quality SiC substrates is a critical differentiator among IDMs, as the substrate is a major cost driver and heavily influences yield and production capacity.

On the demand side, OEMs have identified SiC as an essential semiconductor component with an uncertain supply landscape. Drawing lessons from the recent semiconductor supply chain crisis, OEMs are capitalizing on their newly established relationships with semiconductor players and their growing understanding of the industry to secure capacity directly from IDMs.

The shifts in the value chain leave tier-1 suppliers in an uncertain position. While they will continue to have some inverter production business, power module sales directly from IDMs to OEMs are becoming increasingly common. The rising trend of direct partnerships between IDMs and OEMs threatens to leave tier-1 suppliers on the sideline. To remain competitive in this landscape, they must establish strong partnerships with both OEMs and IDMs.

Phase 2: Rapid Scaling

From 2025 onward, the primary strategic focus will be on rapid scaling. IDMs will concentrate on quickly ramping up new front-end capacity to capitalize on the potential for high margins. Cost reductions will result from technological advancements, such as the transition to 200-millimeter substrates, advanced wafer splitting, and chip size reductions, as well as scale benefits. Numerous new EV platforms will depend on SiC, prompting OEMs to adopt a multi-sourcing strategy to circumvent potential SiC supply shortages. In the context of rapidly changing geopolitical circumstances, supply to and from China remains uncertain, leading to an expected emphasis on local-for-local sourcing.

Although yield improvements and scale benefits will reduce production costs, decreases in market prices may be delayed by persistent supply constraints. This undersupply could delay the launch of new SiC-based EV platforms, forcing OEMs to substantially redesign platforms to enable the substitution of Si-IGBT. On the other hand, growing public funding opportunities and increasing confidence in market development could stimulate accelerated investments in chip production capacity and technological advancements. This would result in higher chip output and reduced chip area requirements. The balance between supply and demand beyond the current investment horizon, around 2027, will thus be heavily influenced by the decisions and progress made in the coming years.

Phase 3: Market Maturation

In the long term, diversifying the use of SiC in additional applications will gain importance. Increased competition and reduced market growth will lead to price declines. The strategic focus will be influenced by new technological innovations, such as the growing competitiveness of GaN in medium power segments, as well as demand from industrial and energy applications.

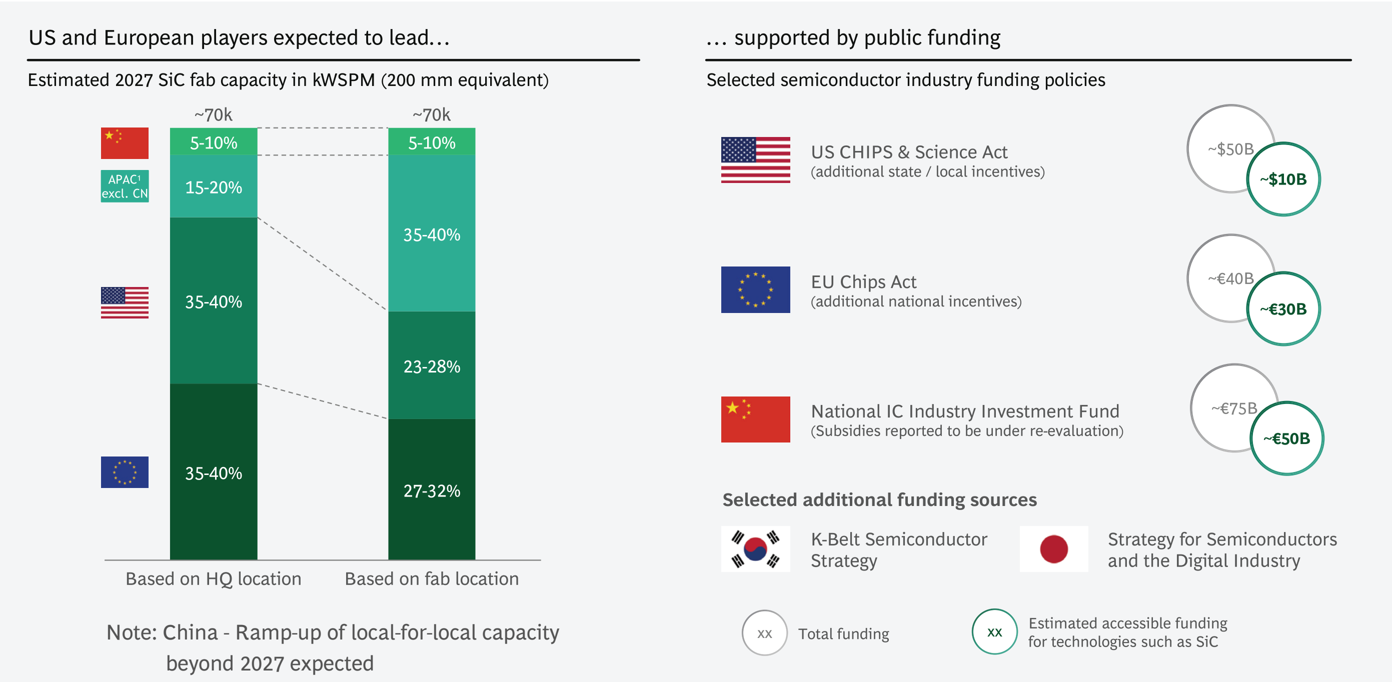
Europe's Strong SiC Players Could Offer a Blueprint for Rebuilding the Chip Industry

To produce high-quality, efficient SiC chips, manufacturers must overcome technological challenges stemming from the material's unique properties, such as its hardness. SiC thus demands a distinct technological approach, process optimization, and dedicated tools. Given the challenges, few manufacturers have scaled up capacity so far. Indeed, in the new race for market leadership, the top five players account for more than 80% of the SiC market revenue.

The leading players have announced significant investments in front-end capacity expansion, demonstrating that SiC technology is mature enough for scaling up mass production. US and European companies are the innovation leaders. Japanese companies, among others, are following close behind. Chinese competitors are also advancing SiC technology. While many players have entered the global substrate market with competitive quality levels, automotive-grade chip production lags and is expected to focus on serving the local market through 2030. More participants are joining the SiC market globally, but the early movers' scale benefits and IP coverage are likely to encourage consolidation in the long run.

Ongoing investments are shaping the global SiC fabrication footprint (see Exhibit 5). Driven by substantial public funding in the US and Europe, along with insights gained from geopolitical shifts and the recent supply chain crisis, a distinctly different landscape is emerging compared to traditional silicon-based chip production. In this landscape, production capacities in the US, Europe, and Asia-Pacific are expected to reach similar levels by 2027.

Exhibit 5: EU and US Players Will Have the Largest Footprint



Source: BCG analysis
Current capacity expansion in Asia-Pacific focused on Japan, South Korea, and Malaysia.
kWSPM = Thousand Wafer Starts per Month

As demand increases, the speed of ramping up new fabrication capacity will be a critical differentiator for growing market share and profiting from the high-margin potential. However, significant challenges remain, especially transitioning to 200-millimeter substrates and controlling and continually improving yield. As a result, investments and developments in chip design and fabrication processes within this newly forming semiconductor segment are crucial for maintaining strong market positions—serving as a blueprint for Europe, in particular, to rebuild its semiconductor industry.

Imperatives Across the Value Chain

Our study's findings point to a set of imperatives for each participant in the value chain:

- **Automotive OEMs** must treat SiC as a critical resource. Its importance is driven by the surging demand for power electronics, particularly as the industry transitions to 800-Volt architectures. However, potential SiC supply shortages could limit its availability for use in new EV platforms. To address the challenges and fully exploit SiC's potential, OEMs should explore partnership opportunities to control major value chain segments. They should also closely monitor the need for local-for-local sourcing in China and prepare to implement such an approach in the medium to long term.

- **Automotive tier-1 suppliers** should prioritize SiC as a key component for power modules. This will be essential to address the increasing competition from OEMs entering the inverter business. In addition, tier-1 suppliers should leverage their close relationships with semiconductor manufacturers to optimally align semiconductor development with automotive specifications and requirements. Such collaborations will add value by differentiating products and securing a market position.

- **Semiconductor IDMs** should scale production capacity rapidly to profit from robust market growth. To maintain competitiveness in the long run, IDMs should drive innovation towards smaller chips on 200-millimeter wafers.

- **Semiconductor foundries** should consider if SiC is an opportunity for them, especially in the context of a partnership with an IDM.

The energy efficiency enhancements made possible by SiC semiconductors will facilitate the transition to EVs and promote the broader adoption of renewable energy sources. However, supply shortages threaten to delay the realization of the opportunities. To reap the full benefits of SiC, value chain participants must act individually and collectively to continue the industry's investment trajectory and allocate the $10 billion to $30 billion investment needed through 2030. Players at the forefront of meeting the challenges will likely secure a significant competitive edge.

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