Photo by Joanna Kosinska
Kearney, Berlin

Europe's urgent need to invest in a leading-edge semiconductor ecosystem

KEARNEY

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Chapter 1: Consumption of leading-edge semiconductors is poised to skyrocket, mainly driven by artificial intelligence and autonomous technologies

Technological advancements in computing power, storage, and connectivity increasingly allow for complex systems that autonomously interact with one another. The resulting demand for leading-edge chips, driven by artificial intelligence, autonomous driving, and 5G/6G, will represent more than 40 percent of European semiconductor consumption by 2030.

Many of us remember the characteristic sound of an analog dial-up modem connecting to the Internet. And soon, we may well be recalling how devices once used to individually perform their tasks while plugged into the power supply alone. Recent technological developments are adding computational power, machine-learning-enabled artificial intelligence (AI), and connectivity into everything from simple household appliances, cars, and medical devices to the most advanced industrial equipment. Enabled by developments such as 5G mobile networks running on energy-efficient leading-edge chips, stationary and mobile devices have become part of an ever-expanding network that combines edge and cloud computing powers. These emerging cyber-physical networks are rapidly becoming an essential part of our daily lives—just like the virtual social networks that we use every day.

This next step in our journey toward digitalization relies on ubiquitous semiconductors and will affect Europe on three levels:

1. **Infrastructure.** Critical infrastructure such as cloud computing, 5G/6G mobile, and satellite-based communication networks are increasingly demanding high-performance computing (HPC) and ubiquitous broadband communication. This infrastructure will continue to develop and expand into an ever more complex, distributed, and seamlessly intertwined world of connected intelligent devices. Cyberattacks on physical infrastructures such as power grids have already given us a glimpse into the extent of our reliance on these cyber-physical infrastructures.

2. **Applications.** Fueled by an empowered, ubiquitous, and pervasive infrastructure of broadband-connected, cost-efficient sense, act, compute, and storage resources, new applications will enable both companies and science to disrupt current business models and to innovate at an increasingly rapid pace.

3. **Society.** As innovation continues to accelerate, society will become more and more reliant upon the complex, interconnected systems that run its most relevant applications. We have all observed how social networks, cloud computing, and remote work transform societies and even the way democracy functions. A secure, nearshore source of chips that provide the building blocks for the digital infrastructure will become increasingly important.

The key enabler to successful digitalization lies with semiconductor components. They power mobile devices and are at the heart of every server executing computational routines as well as communications devices that relay our Internet traffic around the world. And they now expand into areas that were previously ruled by analog and mechanical technology such as cars, industrial equipment, and aerospace and defense applications. In this study, we will focus on non-memory semiconductors that provide the logical brains of these applications.

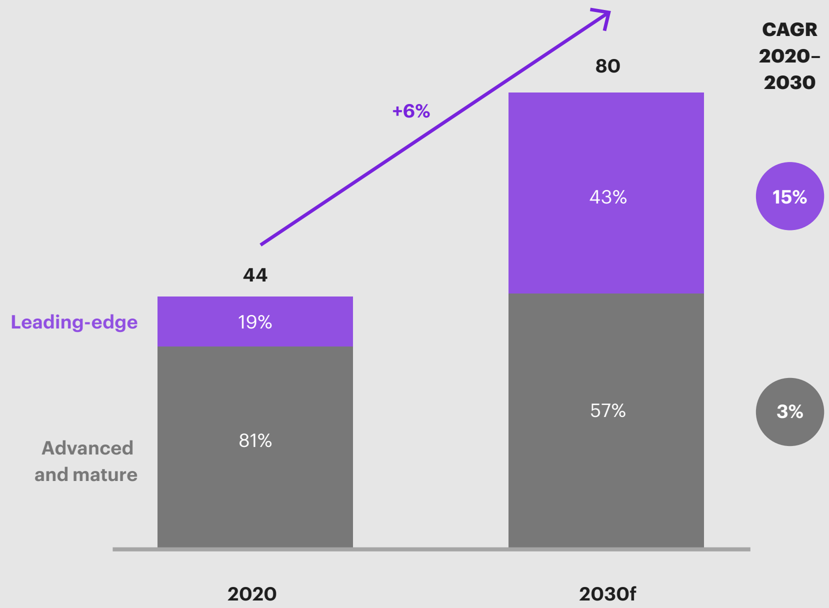
At present, Europe is investing in the infrastructure buildup (for example, 5G mobile networks) necessary to support the applications and products that will become essential parts of our lives and drive the demand for non-memory semiconductor components 5 to 10 years from now. We expect that the value of the EU's consumption—in other words, the value of semiconductors used by European citizens and businesses—will almost double from EUR 44 billion in 2020 to almost EUR 80 billion by 2030, driven by the trends described above. To meet this demand, a complex industry of highly sophisticated and innovative companies has emerged and is constantly evolving (see sidebar: Spotlight: the semiconductor industry landscape today on page 3).

As depicted in figure 1, we differentiate between leading-edge semiconductor demand and other (advanced and mature) semiconductor demand. When referring to "leading-edge" we mean the latest generations of semiconductor process nodes—5nm, 7nm, and 10nm in 2021 (see also figure 4 on page 7)—whereas "advanced" and "mature" nodes refer to older generations.[1] Today, compute electronics and communication electronics jointly account for about 70 percent of the EU's total semiconductor consumption and leading-edge chips account for less than 20 percent of its consumption. This allocation will substantially change over the next decade.

[1] A semiconductor process "node" describes, roughly, the size of the components on the semiconductor—so that a smaller "node" size describes a computationally more powerful semiconductor.

Figure 1
Europe's consumption of leading-edge semiconductors is poised to skyrocket in the next decade

EU27 non-memory integrated circuit consumption by process technology (EUR billion)



	2020	2030f
EU % of global leading-edge consumption[1]	15%	14%
EU % of global consumption	18%	16%

[1] In 2020 leading-edge process includes 10nm and below process technology; in 2030 leading-edge process includes 5nm and below process technology. Non-memory IC includes microcomponents (MPU, MCU), analog, discrete, general-purpose logic, and application-specific semiconductors. fx-rate: US$:EUR = 1.1955

Sources: CSET, Euromonitor, Gartner, IHS, VLSI, expert interviews; Kearney analysis

Spotlight: the semiconductor industry landscape today

Semiconductors are produced by a complex industry that is among the most capital-intensive in the world. At a high level the semiconductor industry stack is built around four levels (see figure a):

— **R&D**: scientific research into material science and physical and chemical processes to improve the next generation of chips in terms of performance, efficiency, or costs.

— **Design**: design of the integrated circuits (ICs) to enable the intended functionality (compute, storage, embedded security, connectivity, and so on) of the chip.

— **Front end**: turning wafers into integrated circuits by transforming IC designs onto the wafer through lithography and other sophisticated chemical processes such as doping and etching.

— **Back end**: testing and packaging of individual wafers into the necessary modules to be mounted onto electronic boards or devices. This involves cutting finished wafers into separate dies, connecting the dies with their periphery using ball grid arrays or wires, and enclosing them with a protective casing. Finally, the chips are tested to ensure their functionality.

The semiconductor industry stack itself is embedded in a wider ecosystem of electronic design automation (EDA) software used by designers to design the chips, material such as wafers and various other consumables (for example, photomasks, chemicals) as inputs into the production process, and tool suppliers that enable the manufacturing of chips.

In response to the exploding costs of designing and manufacturing the next generation of chips, the fabless and foundry business models have emerged to split the capital for R&D and manufacturing expenses.

Different business models have emerged:

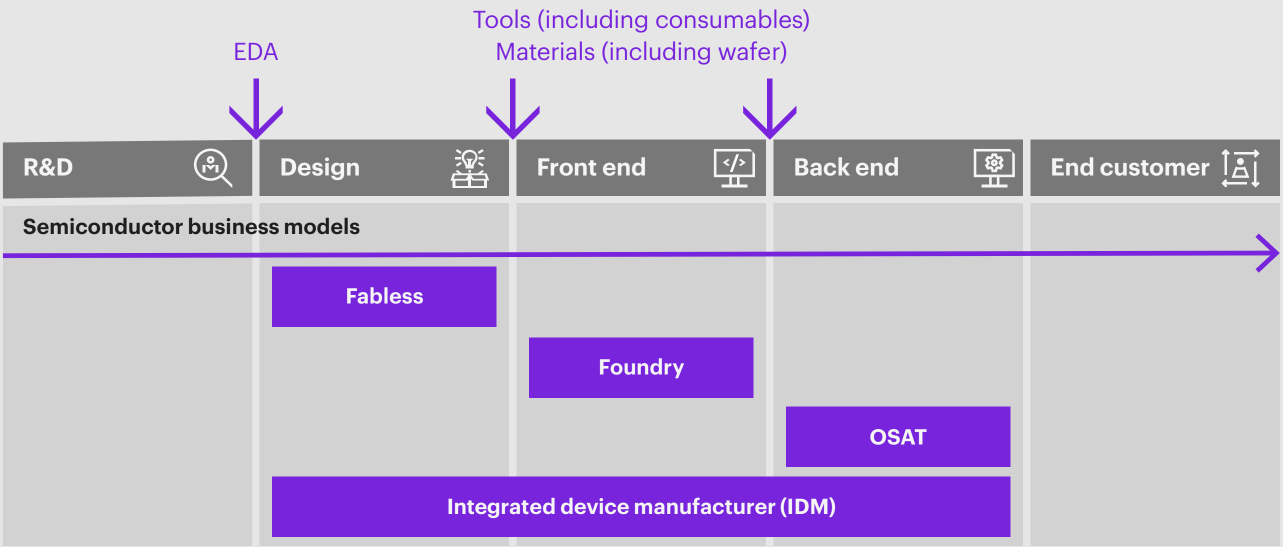
— **Integrated device manufacturer (IDM)**: semiconductor companies that design and produce (front end and back end) their chips in-house and take them to market; these players may also use third parties to handle part of their production capacity or products ("fabless lite" or "fab lite").

— **Fabless**: semiconductor companies that design and market their own chips, but rely on third parties ("foundries") to produce them.

— **Foundry:** semiconductor players that are typically not involved in chip design, but provide front-end manufacturing capacity to other firms, fabricating chips on their behalf.

— **Outsourced semiconductor assembly and test (OSAT):** companies that provide back-end manufacturing capacity to others for the assembly and testing ("packaging") of chips into final packages.

Figure a
The semiconductor industry stack is embedded in a wider ecosystem



Notes: EDA is electronic design automation. OSAT is outsources semiconductor assembly and test.
Source: Kearney analysis

As digitalization transforms more and more aspects of our lives, consumption of leading-edge semiconductors will increase with an annual growth rate of 15 percent and almost double the EU's total consumption by 2030, while demand for mature semiconductor technologies will grow more modestly with a CAGR of 3 percent. The main drivers for this dynamic growth in leading-edge consumption are increasing demand for AI, HPC, edge computing, and wireless communications, which will account for more than 80 percent of leading-edge semiconductor consumption by 2030.

Automotive electronics as well as industrial and other applications (such as medical devices) will be the fastest-growing consumption industries until 2030. The electrification of drivetrains and an increasing level of autonomy—for instance of automobiles—will translate into an annual growth rate of around 10 percent for the semiconductor consumption in these sectors. This shifting consumption pattern is not purely quantitative, but also qualitative. Within automotive, industrial, and other applications, the share of leading-edge chips will grow from about 2 percent today to around 10 percent in 2030. In the automotive industry, for instance, the centralization of previously decentralized controls in extremely powerful central compute units and advanced ADAS and infotainment applications will drive the adoption of HPC chips (non-memory) to increase from 0.5 percent today to more than 40 percent in 2025.

As digitalization transforms more and more aspects of our lives, consumption of leading-edge semiconductors will increase with an annual growth rate of 15 percent.

The latest industry developments indicate that key stakeholders recognize this trend and are shifting up a gear in the race for leading-edge technology. The automotive sector provides a vivid example. In June 2020, NXP presented plans to develop it next-generation, high-performance automotive platform based on a 5nm process that improves its capabilities in areas such as autonomous driving. Tesla went one step further: it was the first carmaker to recognize the strategic importance of chips, paving the way to unprecedented levels of driving assistance. In 2016, Tesla started to design its own ADAS chip, making it the first fabless semiconductor player among pure-play automotive OEMs. Reports suggest that it is now working on a 5nm semiconductor design for its fully self-driving cars. In May 2021, Volkswagen—Europe's largest automotive player—followed suit and announced plans to design its own chips for its cars. And Continental—the world's second-largest automotive supplier—decided to double down on its semiconductor efforts: having collaborated with Nvidia to develop its ADAS capability on 12nm technology, it recently announced a minority investment in Recogni, a Silicon Valley-based AI chip start-up.

While the European automotive industry is charging ahead in switching from mature to leading-edge nodes and upping its game in semiconductor design, other European lighthouse industries such as aerospace and industrial automation have been more conservative. So far, they mostly continue to rely on mature semiconductors. Based on our project experience and expert interviews, we expect that these more traditional industries will eventually follow the lead of the automotive industry and gradually shift from mature to more advanced semiconductor technology. The reasons for this are multifold. The need for greater computing performance, AI-enabled applications, and broadband connectivity—often in applications requiring low power consumption—will increasingly necessitate leading-edge chip technology. Consequently, relying on mature technology alone is not an option for Europe going forward.

Chapter 2: Europe has lost ground in recent decades in global semiconductor production capacity

In the 1990s, Europe was a global leader in semiconductor manufacturing. Since then, the region has been on a steady downward trajectory. Key reasons for this are (1) a general decline of European consumer electronics OEMs, particularly in mobile phones, and (2) the emergence of the foundry and fabless business models, driven by the increasing costs and complexity of leading-edge semiconductor manufacturing and the significant incentives offered by certain Asian governments to offset those costs.

Before 2000, Europe's semiconductor industry was a leader across the value chain and home to more than 20 percent of global chip manufacturing capacity. Since then, its share has dwindled to less than 10 percent, with a focus on mature nodes. For leading-edge nodes, this decline was even more pronounced, with the region's share falling from 19 percent in 2000 to zero in 2020 (see figures 2 and 3 on page 6).

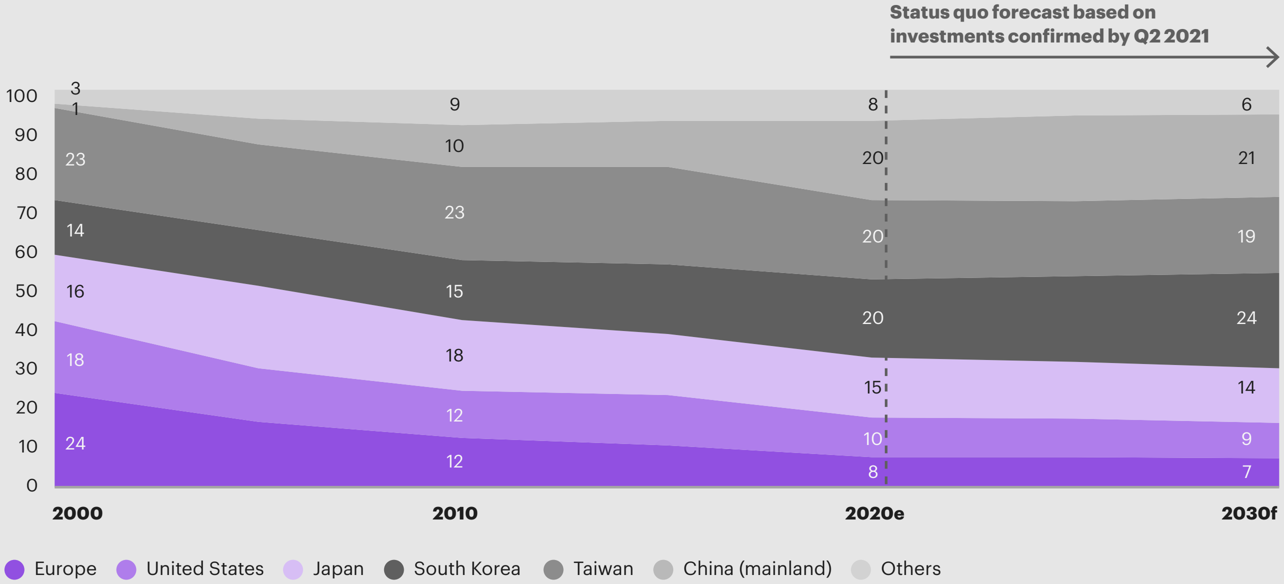
During this period, the industry underwent a radical shift: fewer and fewer players could afford the mounting costs of designing and manufacturing the next generation of chips, which grew almost fivefold, while node sizes shrank from 130nm in 2002 to 22nm in 2012 (see figure 4 on page 7). In response, so-called "fabless" and "foundry" business models emerged, splitting the capital investment between design and manufacturing. This enabled foundry businesses to depreciate their growing upfront investments in manufacturing capacity across a significantly higher volume, which helped to improve margins for both fabless and foundry businesses (for example, the revenue weighted average EBIT margins of foundries increased from 20 percent in the 2000s to 31 percent in the 2010s; for fabless players it grew from 17 percent to 23 percent respectively).[2]

The Taiwanese government's strategy to attract and develop semiconductor manufacturing has been a catalyst for this transition. In 1987, TSMC was established with USD 58 million (EUR 67 million) seed funding from Philips Semiconductors (now NXP) and a USD 100 million (EUR 115 million) stake from the Taiwanese government. In the early 2000s, Taiwanese players such as TSMC—now the foundry market leader—and UMC seized the opportunity to establish themselves as global leaders in the emerging foundry business, while some American players transitioned from integrated device manufacturer (IDM) to fabless business models. The remaining companies in the US, South Korea, and China continued to develop capital-intensive, leading-edge manufacturing capacity. Conversely, Europe started to fall behind—with two exceptions: Intel's fab in Leixlip, Ireland, and STMicroelectronics' (STM) fab in Crolles, France, both capable of manufacturing at the 14nm node.

[2] Sample selection: foundry: TSMC, UMC, SMIC; fabless: AMD, Nvidia, Qualcomm

Figure 2
Europe's share of semiconductor manufacturing capacity has been shrinking

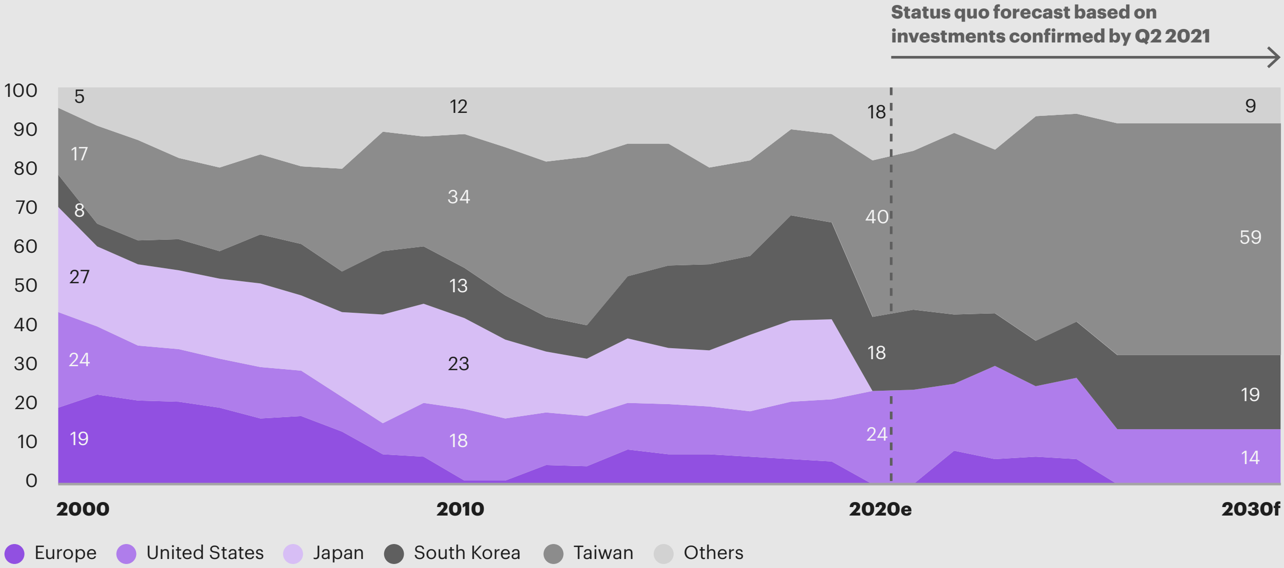
Historical/projected semiconductor manufacturing capacity by location (%)



Notes: All values shown in 200mm equivalents; excludes capacity below 5 kwpm or less than 8 inches; others includes Israel, Singapore, and the rest of the world.
Sources: SEMI second quarter 2020 and second quarter 2021 update; Kearney analysis

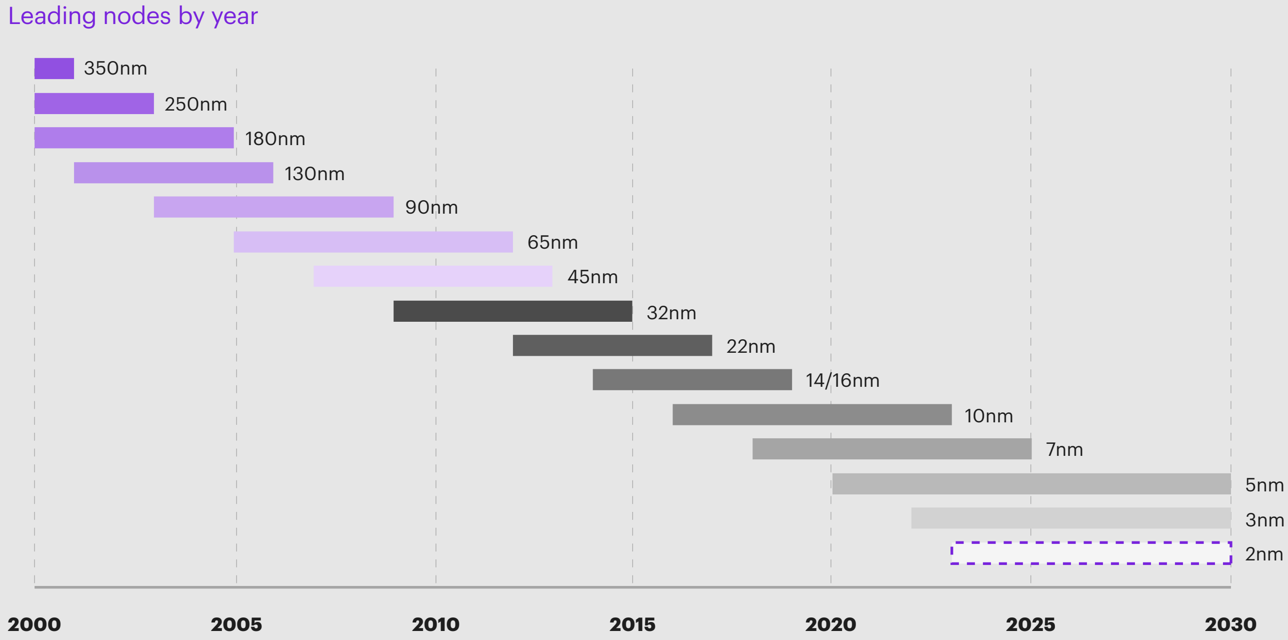
Figure 3
Europe lost ground, particularly in leading-edge manufacturing

Historical/projected leading-edge semiconductor manufacturing capacity by location (%)



Notes: All values shown in 200mm equivalents; excludes capacity below 5 kwpm or less than 8 inches; others includes mainland China, Israel, Singapore, and the rest of the world. The three most recent nodes are considered leading-edge until 2025. 5nm and below considered leading-edge nodes post 2025.
Sources: SEMI, Yole, company data; Kearney analysis

Figure 4
The changing definition of leading semiconductor nodes



Sources: SEMI; Kearney analysis

The emergence of the fabless and foundry model took off in earnest at a time when Europe's Siemens, Ericsson, and Nokia had lost their prime position in mobile phones to US and Asian players. Europe's remaining chip demand was driven by automotive and industrials—applications that, at that time, did not require the same rapid innovation as mobile phones and computing and did not profit that much from rapidly shrinking node sizes. The foundry business proved especially successful in logic semiconductors that benefited most from miniaturization. Consequently, European semiconductor players focused on power electronics remained with the IDM business model given their close ties with automotive and industrial customers and a dwindling European consumer electronics industry. And while European IDMs continued to invest in both design and manufacturing, they soon began to bail out of the race toward smaller node sizes: in Europe, NXP halted further development of manufacturing capabilities at 140nm, Infineon at 90nm, and STM at 14nm nodes, leaving the field of leading-edge manufacturing to Asian and US players.[3]

Today, Europe's small production capacity on 10 to 20nm nodes is almost entirely generated by Intel's fab in Ireland, where the company produces 14nm chips.[4] Taiwan and South Korea currently are the only countries in the world to host leading-edge chip manufacturing at node sizes smaller than 10nm, but even the global 10nm capacity is concentrated at only nine locations (see sidebar: Spotlight: the global footprint of leading-edge semiconductor fabs on page 8).

[3] NXP operates a 90nm fab and Infineon a 55nm fab in Austin, TX.
[4] Intel announced to open this capacity for its foundry business.

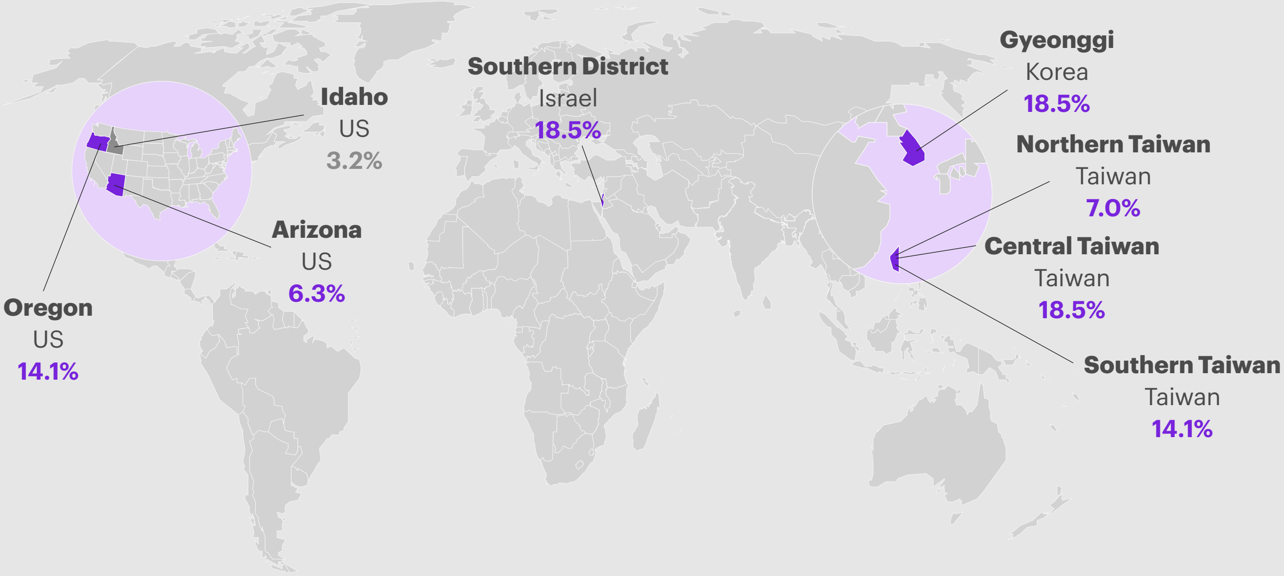
Spotlight: global footprint of leading-edge semiconductor fabs

Since 2000, the global semiconductor supply base has undergone a regional consolidation, especially on the leading-edge nodes. For nodes at and below 10nm the total global capacity is concentrated in nine cities, and 85 percent is located at only six locations (see figure b). This concentration poses a number of risks, including natural hazards (as demonstrated by the Austin, Texas blizzard) and political tensions (as demonstrated by the demise of Huawei).

Figure b

The global semiconductor value chain relies on just a few regions to provide leading-edge fab capacity

Active leading-edge fab manufacturing capacity[1]



[1] Fabs producing on 10nm nodes and below

Notes: Grayed-out capacity represents a leading-edge memory fab. Percentages may not resolve due to rounding

Sources: SEMI 2020 Q2 and 2021 Q2 update; Kearney analysis

Chapter 3: To counter the decline and strengthen technological sovereignty, the EU set a target to achieve 20 percent of global semiconductor manufacturing capacity by 2030

Against the backdrop of current supply shortages, the EU has established a target to more than double its share of global semiconductor manufacturing capacity to 20 percent by 2030. Despite broad agreement on the need to strengthen the EU's semiconductor capacity and capabilities, there is misalignment among industry leaders about the right way to achieve this strategic objective.

The current semiconductor shortage has exposed the vulnerability of supply chains in many industries to disruptions in semiconductor supply caused by structural misalignments between demand and supply as well as other unforeseen events of diverse origin such as natural hazards.

As the demand for semiconductors accelerates across the globe due to increased digitization, capacity is struggling to keep up. That is because building capacity is both costly and time consuming. For example, developing a new leading-edge chip factory capable of producing 35,000 wafers per month is currently estimated to cost north of EUR 18 billion and take approximately five years before it can operate at full potential. Furthermore, certain key equipment markets (including lithography and substrates) are dominated by a small number of highly innovative players and they also are capacity constrained. Consequently, building new capacity takes time and cannot mitigate the current chip shortage in the short term.

Chip shortages have been further amplified by the effects of the COVID-19 pandemic and the counter-measures implemented to slow the spread of the disease. With supply chains being disrupted due to lockdowns, global stocks of available semiconductors diminished quickly. At the same time, more people were required to work from home and schools were conducting remote lessons, thus consumers—spending more time at home—upgraded their home devices. As a result, the demand for electronic products soared, putting further pressure on an already strained semiconductor supply chain.

Natural disasters also contributed to the current chip shortage. In February 2021, a severe blizzard hit Austin, Texas, with heavy snow and a prolonged period of subzero temperatures causing power outages and burst pipes in chip factories not designed for such weather. The resulting manufacturing downtime had a profound impact on the global semiconductor supply chain. While only 2 percent of global capacity was impacted, it cut NXP's output short by 30 percent and Samsung's by 28 percent.

Additionally, the Renesas plant in Hitachinaka, Japan, which provides microcontrollers to automotive clients around the globe, caught fire and it took three months until full capacity could be restored. The effects on automotive supply chains will persist well into 2022. These effects were not as severe as the impacts of previous natural disasters in other hemispheres, for example, the flood that struck Taiwan in 2011 or the lightning bolt that started a fire in NXP's plant in New Mexico in 2000.[5] But they once again highlighted the vulnerability of the global semiconductor supply chains to natural disasters—an effect exacerbated by the relatively high concentration of global semiconductor capacity in just a few regions.

Finally, political tensions and trade disputes across economic blocks have rattled free trade and challenged the fundamental principles that underpin global semiconductor supply chains, leaving some economic blocks with no access to vital semiconductor technology.[6] Hence, local access to semiconductors has become a matter of regional technological sovereignty.

The cumulative impact of these events has been severe in Europe: the chip shortage has already dragged down the eurozone's economy by about 0.1 percent of GDP for 2021—a loss in value creation of approximately EUR 11 billion. Across Europe, automotive manufacturing alone fell 4 million cars short of demand in the first half of 2021. Analysts estimate the global impact on automotive OEMs to add up to a revenue loss of more than EUR 50 billion in 2021. Many believe that these effects will persist well into the present decade.

Driven by accelerating global demand and the recent shortages, semiconductor players and policymakers globally have been motivated to develop investment plans of unprecedented magnitude, which are designed to achieve leadership positions in the global semiconductor industry and increase supply chain resilience. In a bid to tackle this challenge, the EU has set a target to achieve a 20 percent market share in semiconductor manufacturing by 2030. With the announcement of a new European "Chips Act" in September 2021 by Commission President Ursula von der Leyen, the EU seems ready to step into action. However, these strategic ambitions have yet to translate into an actionable agenda for R&D and manufacturing, with appropriate resources and partnerships to back it.

As the EU Commission fleshes out the details of its goal, European stakeholders are at odds over the best way to achieve it. Research institutes, telecommunication players, and digitalization leaders all appreciate the opportunity to bring back leading-edge manufacturing to European soil, but some industrial players are arguing for ramping local capacity of mature nodes used in industrial and automotive applications today. Another source of disagreement regards the discourse between players that want to create regionally independent supply chains, therefore advocating for increased local European manufacturing capacity, and those that are committed advocates of global free trade and therefore advocate against it.[7]

We are convinced of the need for investing in manufacturing capacity in Europe for leading-edge technology for three main reasons. First, demand forecasts suggest that most of the demand growth in the next decade will occur in leading-edge chips, with a 15 percent annual growth rate (see figure 1). Second, as technology advances, leading-edge chips remain at the technological frontier for an average of six years before being replaced by more advanced technology. In other words, today's applications built on mature node semiconductors will over time move to more advanced nodes purely because of the advantages that a more advanced node technology will have on any semiconductor application (for example, reduced power consumption, higher density, and so on). Third, industrial policy creates more benefits when pushing the technological frontier rather than sticking with established, mature technologies. The EU members' individual and joint programs to promote renewable energy, for instance, is a case in point for driving innovation, reducing environmental impacts, and creating up to 900,000 new jobs.

[5] Another famous example of the vulnerability of semiconductor supply chains involves a lightning bolt that struck a high-voltage electricity line close to the Philips Electronics (today NXP) plant in New Mexico in 2000. The fluctuating power caused a small fire. Though extinguished immediately, the impact of the fire was immense: Philips' chips powered 80 percent of phones at that time, and the lightning strike resulted in a shortfall of 7 million phones.
[6] For instance, China's Huawei was considerably constrained in its operations.
[7] Based on 18 interviews conducted with European technology players in September and October 2021.

Chapter 4: Investing in leading-edge chips "made in Europe" will positively impact European prosperity

Close collaboration between chip design and manufacturing is crucial to mastering technological complexity and taking advantage of the benefits of leading-edge node technology. It is beneficial if not existential to Europe to bring leading-edge semiconductor design, development, and production capacity together again locally.

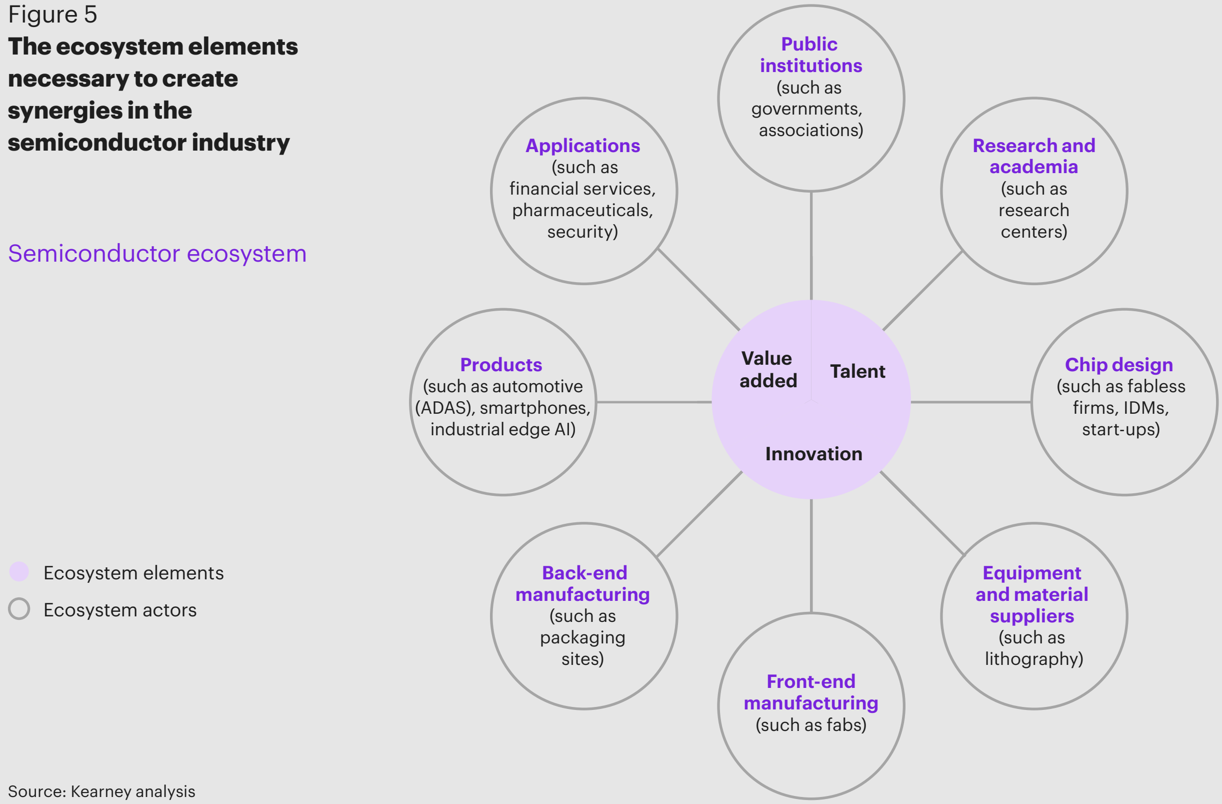
For advanced connected applications to become reality, intense collaboration across the entire technology stack is required. The ecosystems emerging from this collaboration are characterized by networks of individuals and organizations that create synergies far outweighing individual members' contributions (see figure 5 on page 12). Silicon Valley is a prime example of this kind of a synergetic and integrated ecosystem that emerged around the semiconductor industry. Driven by their foundational position (at the very bottom of the technology stack), semiconductor companies—particularly fabs and chip design houses—are and will always remain a center of gravity of technology ecosystems (see sidebar: Spotlight: stronger together than apart—Europe is a winner in industries where it combines advanced engineering and manufacturing on page 13).

Such ecosystems attract and retain capital and talent, and they are key enablers for technology innovations higher up in the technology stack, as much as the need for innovation in applications drives the need for innovation in semiconductors. That impact on the ecosystem is profound, as demonstrated by companies working on novel chip designs: after a period of stagnation in semiconductor design innovation and investment, the US and APAC—regions with vibrant semiconductor ecosystems and leading-edge manufacturing capacity—are now home to 160 and 139 start-ups active in chip design and development, respectively.[8] Conversely, the EU hosts just 33 such firms, of which none is active in leading-edge node designs.

[8] Results based on keyword search in Crunchbase for "chip design," "semiconductor design," "ASIC design," "IC design," and "IC layout." Included companies with less than 1,000 employees.

Figure 5
The ecosystem elements necessary to create synergies in the semiconductor industry

Semiconductor ecosystem



Source: Kearney analysis

Beyond ecosystem-level synergy, leading-edge nodes also require close interaction and collaboration between design, architecture, manufacturing, and packaging, including design for manufacturing (DFM), design for assembly (DFA), and design for reliability (DFR) to manage challenges such as 2D shrink, design 3D architectures (for example, through silicon vias (TSV) and high-bandwidth memory (HBM)), and realize logic-memory integration. Furthermore, close integration of front-end and back-end capabilities enables optimized, chip-level system design (such as chiplets and tiles) and new architectures (such as hybrid bonding). Recognizing the value of this close collaboration, Intel in the US, TSMC in Taiwan, and Samsung in South Korea are taking the lead in co-locating design engineering and manufacturing in their regions. A European leading-edge fab with foundry capacity would support the emerging European fabless semiconductor players in their strategic ambitions. By missing out on such co-location opportunities, Europe will struggle to benefit from future innovation and efficiency gains.

These arguments illustrate a key point: Europe would greatly profit from leading-edge semiconductor manufacturing being brought back to the region. Not only would it benefit from additional regional capacity helping to compensate for the current chip shortages, but it would also fuel a vibrant ecosystem of innovation and build a top-notch, globally competitive European semiconductor industry. A European leading-edge semiconductor ecosystem would spur technological innovation by significantly reducing research costs, for example, by dedicating fab capacity to research projects and pooling prototypes on multi-project wafers.

Spotlight: stronger together than apart—Europe is a winner in industries where it combines advanced engineering and manufacturing

Manufacturing is at the core of Europe's prosperity. Many European manufacturers are world leaders in their respective industries, and much of the region's success is built on its hardware engineering capabilities and overseas demand for its superior products. Access to leading-edge semiconductors will remain a key prerequisite for capturing the global demand for advanced engineered products. About 20 percent of Europe's gross value add depends either directly or indirectly on high-tech inputs such as integrated circuits, and this figure is only expected to grow.

Europe has historically been strong in industries where it combined engineering and manufacturing prowess. The automotive industry is a prime example of how close ties between engineering and leading manufacturing capabilities can create an industry lighthouse. A strong domestic manufacturing backbone enabled European players to build a global reputation for premium products and sell to an increasingly global customer base. European automotive OEMs kept most of their R&D and engineering capacity at home (for example, about 80 percent of the headcounts in Germany for Daimler and France for Renault). This allowed them to continuously introduce new manufacturing technologies combining engineering and production capabilities that remained in Europe, and enabled the introduction of popular prime products, such as Mercedes' EQS.

The development of COVID-19 vaccines is the latest lighthouse for Europe, proving the virtuous circle created by integrated engineering and manufacturing capabilities. While countries around the globe were forced to impose export restrictions on their vaccines, Europe's production sites were able to supply the local campaigns with a vaccine that was largely engineered and produced in the region and distributed globally. European production sites formed the backbone of the region's vaccination campaign that is enabling the reopening of the economy.

On the flip side, focusing exclusively on engineering or specific steps in the value chain will impact the industry as a whole. Photovoltaic (PV) module production provides a compelling example of the downsides of decoupling engineering and manufacturing in Europe. In 2000, about 20 percent of global PV module production originated in Europe, with many small European players serving the market and the European PV industry flourishing. Over the next 20 years, European players outsourced production to Asia. Fueled by favorable domestic conditions and often supported by local subsidies, Chinese manufacturing firms became innovators in the field, while also offering cost-competitive products. The Chinese players dominated the demand uptake, capturing more than 70 percent of the global annual production of PV modules in 2020.

A lesson was learned from the decline of the PV industry and BEV battery production took on another fate. Large parts of the production were outsourced to Asia, while engineering remained in Europe. The recent European expansion of battery production capacities underscores the fact that this industry is not willing to go down the same path.

The recent success of MediaTek, a Taiwanese fabless chip design company, provides a case in point for the benefits of co-location along the semiconductor supply chain. While in 2012 MediaTek lagged Qualcomm and Samsung in chip design by several years, its close local ties with TSMC in Taiwan enabled it to leapfrog its rivals through rapid innovation. It has now become a technology leader, planning to release the first 4nm chip in late 2021. Exhibiting staggering growth, MediaTek overtook Qualcomm in SoC sales in 2021, advancing to become the market leader by sales. Put simply, leading-edge manufacturers pick the winners in the innovation race of fabless players by allocating their scarce capacity and engaging in close design collaboration.

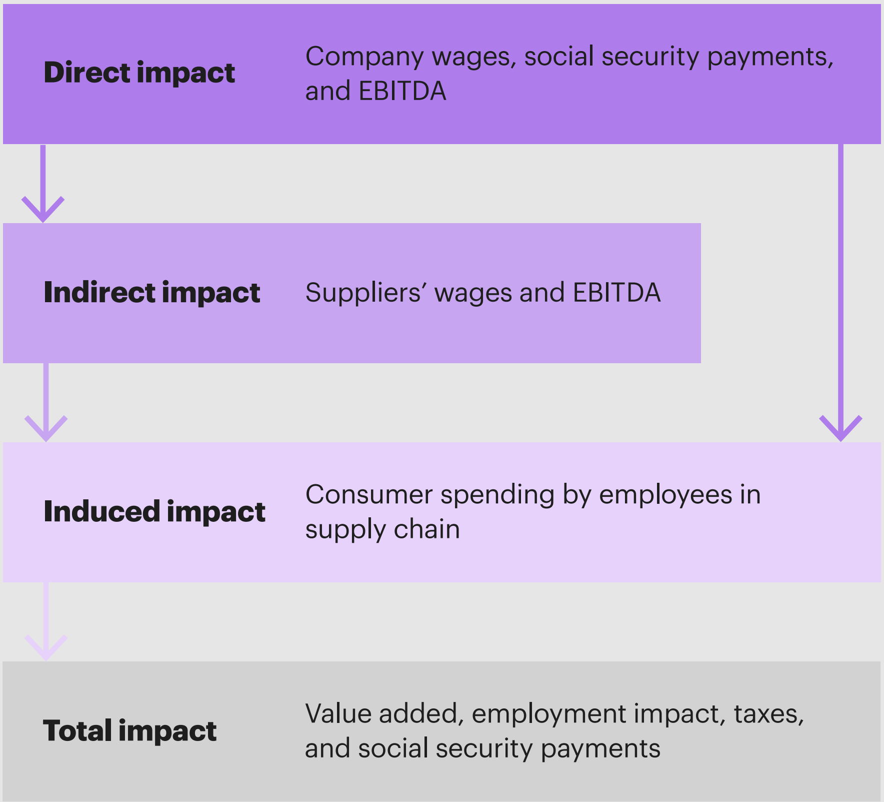
By a similar token, leading-edge manufacturing technology can play a crucial role in developing highly skilled talent and ensuring continuous industry growth as first, more advanced semiconductors are developed and second, an innovation agenda pushes the boundaries of technology itself and boosts R&D across the entire technology ecosystem. To maintain the current momentum of the industry, 18 times more researchers are required to double chip density every two years today than were necessary in the early 1970s. As that highly skilled talent moves around in the broader economy, it is often applied to develop innovations outside of the semiconductor industry.

Furthermore, local European suppliers to the semiconductor industry (for example, ASML, Atlas Copco, AT&S, Besi, IMEC, and Zeiss located across Europe) would profit greatly from a strengthening of the regional semiconductor ecosystem and the added level of strategic autonomy that Europe would gain from reestablishing itself as a relevant player in the manufacturing of leading-edge semiconductors. We see evidence of how suppliers in other regions of the world benefit from ties to semiconductor manufacturing in close proximity—for example, Shin Etsu, the Japan-based global leader in wafer production, and ASE, the Taiwanese global leader in outsourced semiconductor assembly and testing, which profit greatly from local ties to—and collaboration within—their local ecosystems.

While Europe is formulating its strategy to achieve a 20 percent market share in global semiconductor manufacturing capacity, it needs to move fast as global competition for a dominant role in semiconductor technology continues to heat up. In a consolidation wave supported by the enormous capital intensity of the industry, Europe now risks falling even further behind while working on its strategy. It may lose its remaining strongholds in the semiconductor supply chain to more developed, faster-moving peers. Siltronic and ARM provide striking examples of this phenomenon. Siltronic was recently acquired by Taiwanese GlobalWafers, creating a global heavyweight in wafer supply; ARM (owned by Japanese SoftBank, but with its headquarters and operations still in the UK) is mired in a lengthy acquisition process by Nvidia, the fabless US-based graphical processing unit (GPU) giant.

Leading-edge manufacturers pick the winners in the innovation race by allocating their scarce capacity and engaging in close design collaboration.

Figure 6
Model logic



Source: Kearney analysis

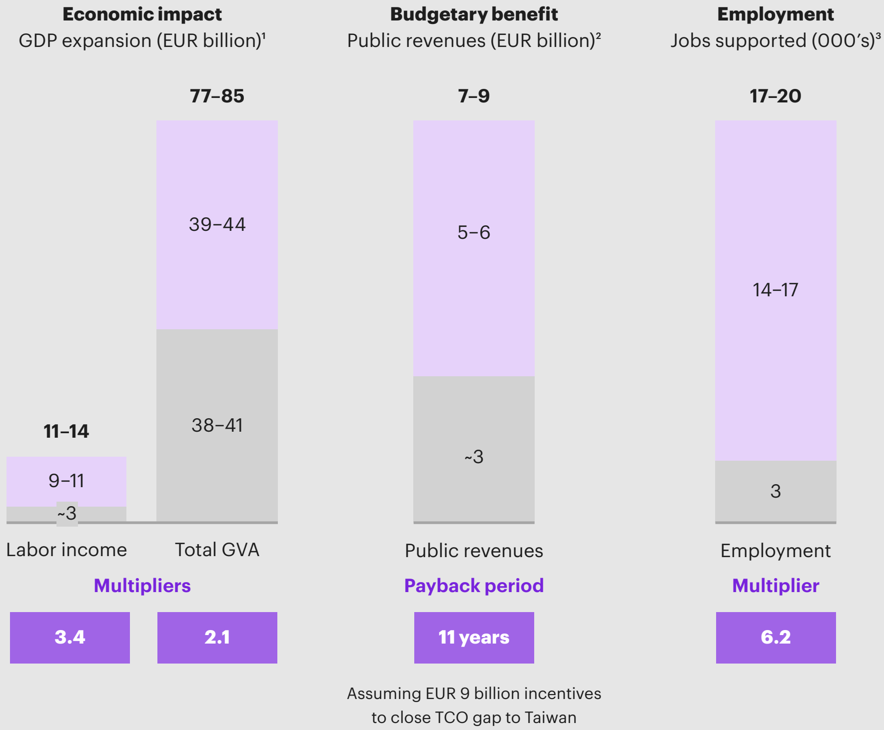
Beyond the direct benefits to the semiconductor ecosystem, the indirect benefits to the wider European economy of establishing additional leading-edge manufacturing capacity are also significant: a mega fab requires an investment of up to EUR 18 billion that creates significant direct economic benefits through high-paying full-time jobs.[9] The corresponding infrastructure enablement would trigger about EUR 2 billion of additional investments, contingent on the exact fab location. However, the positive financial impact on Europe's economies is far greater spanning increased economic activity, inflows into the budgetary systems, and thousands of supported jobs. In figure 6 we outline our model logic that enabled us to estimate a mega fab's direct and indirect benefits by using economic input-output modelling based on data published by European government agencies, intergovernmental organizations, and public data brokers. We estimate a GDP expansion of EUR 77 billion to EUR 85 billion, EUR 7 billion to EUR 9 billion of additional budgetary inflows, and an additional 17,000 to 20,000 jobs.

Economic impact. Driven by spending on local suppliers, wages paid to employees, and the employees' consumption, significant economic activity would be spurred. We estimate that the European economy would experience between EUR 77 billion and EUR 85 billion in additional economic activity (in other words, additional GDP) over a 10-year period (see figure 7 on page 16). The impact directly related to activities around the mega fab—equipment purchases, construction, and infrastructure, plus the costs of operating the fab—would generate EUR 38 billion to EUR 41 billion for the European economy. The indirect effects—those generated as the fab suppliers' economic activities cascade into the wider economy and induced effects from consumer spending—would contribute an additional EUR 39 billion to EUR 44 billion to European GDP, corresponding to an impact multiplier of 2.1.

[9] In our model we assume a mega foundry fab with a capacity of 35,000 300mm wafers per month. In 2021, the largest leading-edge fab in operations is the TSMC giga Fab 18 in Tainan (TW) with a combined capacity of 120,000 300mm wafers per month across three fab modules.

Figure 7
Investment in a foundry fab in Europe would bring substantial economic and budgetary benefits

Economic impact of 5nm mega fab with foundry capacity
(10-year investment horizon, excluding ramp-up)



Direct impact
Indirect + induced impact

[1] Labor income includes income generated by capex investments from non-permanent jobs. Total value added (GDP contribution) is estimated including land preparation expenditure by local public authorities in support of the capital investment. Total economic impact is discounted by average 10-year government bond yield in the euro area. Assuming no ramp-up time.

[2] Estimated tax revenues exclude potential government tax incentives. Assuming no ramp-up time.

[3] Only permanent jobs included.

Notes: GVA is gross value added. TCO is total cost of ownership. fx-rate: US$:EUR = 1.1955

Sources: European Central Bank, European Commission, Eurostat, Goos et. al., 2018, OECD, SIA, S&P CapitalIQ; Kearney analysis

Budgetary impact. These economic activities result in multiple cash flows into the budgetary system. They are fed by corporate income tax from the fab operation and its suppliers, the employees' personal income taxes and social security payments, and the VAT levied on the employees' consumption. As explained later (see figure 10 on page 20), a European leading-edge mega fab would need incentives of about EUR 9 billion (USD 10.4 billion) in order to compete globally for foreign direct investment. These investments will generate a capital flow of EUR 7 billion to EUR 9 billion within 10 years resulting in a midpoint payback period on the original investment of about 11 years. What's more, these estimates do not even factor in the likely spill-over effects into the wider European high-tech ecosystem, increased innovation, and greater availability of crucial semiconductor components for European consumers.

Employment impact. The increased economic activity from a mega fab needs to be backed by the corresponding workforce. A mega fab would itself generate around 3,000 jobs for highly qualified professionals, and it would support 14,000 to 17,000 additional jobs at suppliers providing fab materials and services and in the broader economy, resulting in an employment multiplier of 6.2, while the labor income multiplier is 3.4.

Chapter 5: In the global race for leading-edge semiconductor capacity, Europe has both strengths and shortcomings

While the 20 percent target may seem audacious, the objective is achievable. Europe has the key ingredients to reestablish its competitiveness in leading-edge node manufacturing: it has a strong STEM talent pool, excellent infrastructure, a very high level of political and legal stability, and strongholds in other places of the semiconductor value chain—as well as the financial muscle to compete with other regions for investments in leading-edge capacity.

With a local supply base for input materials and tooling, world-class applied research, and strong educational programs in science, technology, engineering, and math (STEM), Europe has several of the main ingredients to regain a competitive position in leading-edge semiconductor technology.

Semiconductor manufacturing facilities rely on a highly skilled and specialized labor market. As a result, access to graduates with advanced STEM degrees (master's, doctoral, or equivalent) is crucial to designing, manufacturing, and using leading-edge semiconductors. On a global scale, Europe is best positioned to provide these highly trained experts. It is the region that trains the highest number of master's- and PhD-level graduates in STEM disciplines (414,000 European graduates annually vs. 274,000 in China and 201,000 in the US) (see figure 8 on page 18).

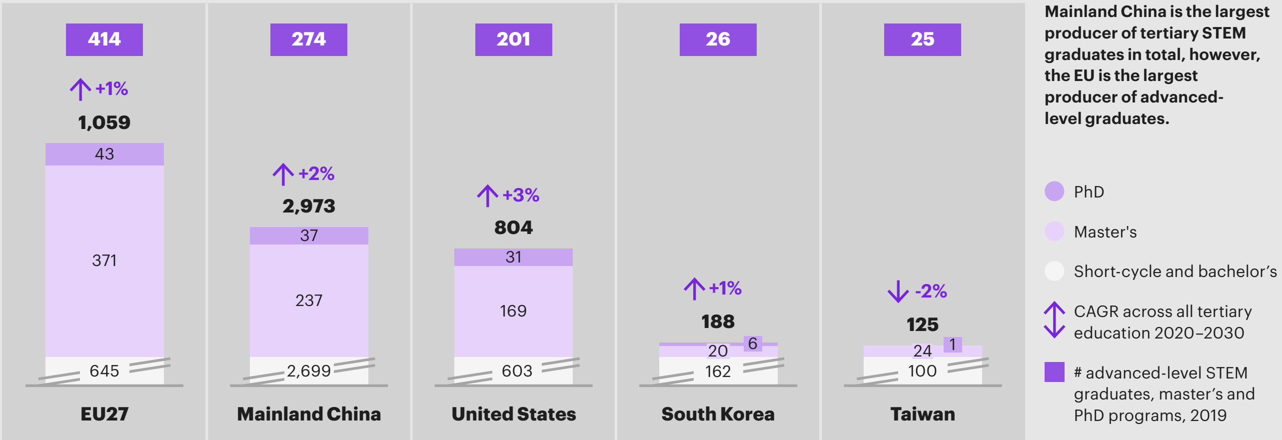
Europe also boasts strong capabilities in innovation and R&D, creating a fertile breeding ground for start-ups.[10] Furthermore, Europe provides the necessary infrastructure (for example, stable power grids), a reliable legal system that protects investors' property rights, and an environment with a relatively low level of natural hazards. Scoring high on these key criteria for site selection makes Europe an attractive location for capital-intensive industries such as semiconductor manufacturing.

[10] In fact, the EU's largest economy—Germany—is rated the global leader in innovation capabilities in the World Economic Forum Competitiveness report 2019, and the second-largest economy in Europe, France, is in the top 10.

Figure 8

Access to advanced STEM talent will be crucial to power the high-tech sector in the next decade; EU is a leading global supplier of advanced talent

Advanced-level STEM graduates forecast by country[1]



[1] STEM graduates in tertiary level 5–8 includes short-cycle tertiary education, bachelor's or equivalent level, master's or equivalent level, and PhD or equivalent level. Includes information and communication technologies (ICT) and engineering, manufacturing, and construction. Forecast estimated by linear trend extrapolation using data 2014–2019 for EU, mainland China, and Taiwan and 2013–2018 for United States and South Korea. Note that statistics from mainland China and Taiwan use "broad" definitions of technology and science, compared to International Standard Classification of Education (ISCED) used by OECD countries.

Note: Totals may not resolve due to rounding.

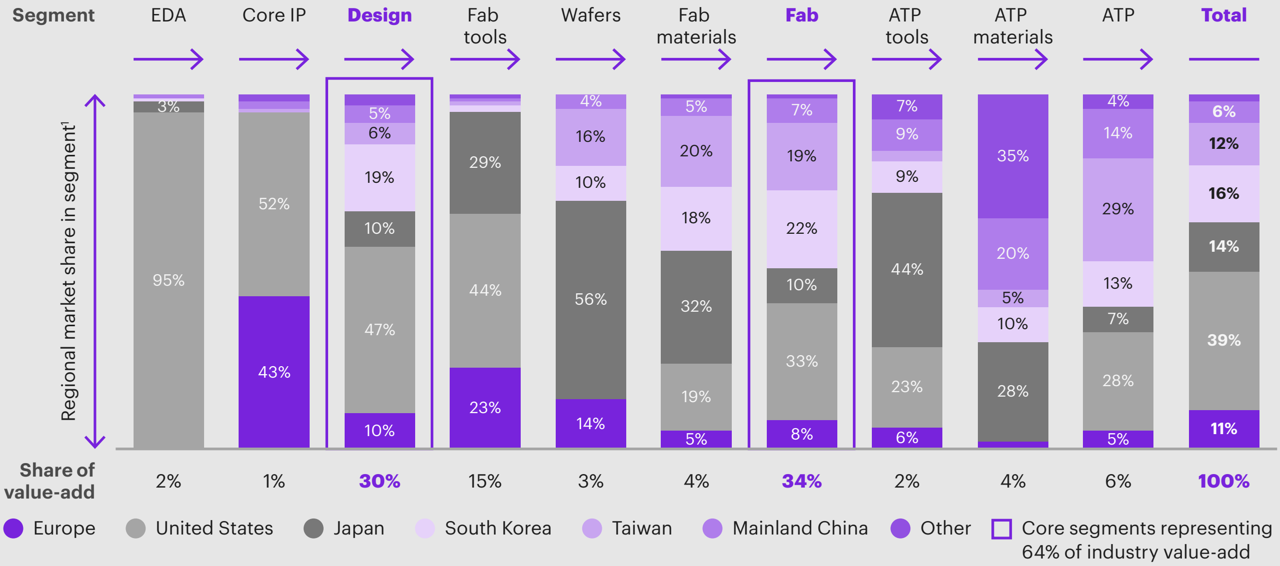
Sources: China Science and Technology Statistical Yearbook, Eurostat, OECD, Taiwan Ministry of Education, UNESCO Institute for Statistics, World Economic Forum; Kearney analysis

Indeed, in some segments of the semiconductor value chain, Europe maintains a position of power and leadership—including for leading-edge technology. The region is at the forefront of R&D for the next generation of chips. Its research institutions such as IMEC, Leti, and Fraunhofer continue to drive fundamental research. In 2020, these organizations and other European universities contributed 25 percent of key research output in leading conferences—up from 12.5 percent in 1995. Other examples of key strongholds are ARM, which is taking the lead in providing the core IP necessary for chip design, and ASML, which is the frontrunner in tool manufacturing of extreme ultraviolet (EUV) lithography and next-generation high-numerical aperture (high-NA) EUV—key enablers for leading-edge manufacturing. Europe is also among the leaders (albeit indirectly) in the supply of highly sophisticated EDA software for chip design (through Mentor Graphics, owned by Siemens). While these strongholds are not enough to dominate any of the segments, the unique nature of the intellectual property (IP) generated by European players such as ASML and ARM gives it a key strategic position in the semiconductor value chain.

However, in the two largest and most value-adding segments of the semiconductor industry—which jointly contribute almost two-thirds of the value add of the entire industry—Europe is a mere bystander: with a share of just 8 percent in fab manufacturing and 10 percent in design, the region is at risk of becoming marginalized in the semiconductor value chain (see figure 9 on page 19). (On the horizontal axis figure 9 shows the segments' value-add contribution to the semiconductor value chain, while the vertical axis shows the regional market share within a specific segment, based on company HQ location.)

Figure 9

Europe's market share is behind in the two most value-adding segments of the semiconductor value chain



Notes: Market shares are from 2019, except ATP market shares, which are from 2018. IDMs perform a large percentage of design, fabrication, and ATP and do not separately report revenues for these activities. Therefore, the market shares for these three segments are based on CSET's estimates. ATP market shares and country- and region-level values add up to more than 100 percent because of rounding. Regional breakdown of fab materials calculated separately using Fuji-Keizai data, not included in CSET calculations.

[1] Regional share is based on company headquarters location.

Sources: CSET calculations, financial statements, Fuji-Keizai, IC insights, SEMI, SIA, VLSI research, WSTS, Yole; Kearney analysis

Bringing leading-edge semiconductor manufacturing to Europe would have upstream and downstream spill-over benefits across the value chain. Leading-edge design services (such as Capgemini in France) could be offered for different industrial verticals such as automotive, industrial automation, and telecom. Prototyping could be carried out by research centers (such as IMEC in Belgium or Fraunhofer in Germany). The presence of a leading-edge mega fab would increase business for European manufacturers of fab tools, such as ASML for EUV (Netherlands), Zeiss for optics (Germany), and Atlas Copco for air compressors (Sweden), as well as for manufacturers of wafer substrates such as SOITEC in France or packaging substrates such as AT&S in Austria. Assembly and testing products and activities would increase for players like Amkor in Portugal or AEM in Finland.

Europe needs significant incentives (tax, regulatory, private and public investments) to make local semiconductor manufacturing cost competitive, as it falls short in comparison with other regions.

Both designing and manufacturing leading-edge chips has become increasingly costly at each node size. For example, the capital expenditures for building and outfitting a leading-edge fab have grown exponentially from about EUR 3 billion just a decade ago to EUR 18 billion today. Additionally, substantial investments into process technology development are necessary to master the processes required to operate a leading-edge fab. (Based on their annual reports, Intel, Samsung, and TSMC have spent more than EUR 100 billion on overall R&D since the arrival of the 10nm process in 2016.) As a result of dramatic increases in manufacturing expenses, less and less manufacturers globally were able to stomach the investments required to develop the latest node sizes (see figure 10). Today, only three leading-edge manufacturers remain: Intel, Samsung, and TSMC.

Figure 10
Semiconductor industry evolution

With each process node the number of leading-edge manufacturers dropped[1]

[1] Only players with leading-edge capabilities in respective period included; later acquisition of manufacturing capabilities did occur
Sources: Yole, Gartner; Kearney analysis

To boost local innovation, Europe needs to support targeted research in chip design that reflects the EU sustainable and secure digital agenda goals. Ideally, such incentives should be rooted in a broad overarching framework such as "Horizon Europe 2021–2027" that funds excellent research to secure European competitiveness in leading-edge technologies. Key items for the future semiconductor research agenda include application-specific chip designs to boost European product and application industries (for example, in automotive, automation, or communication industries). Such research funding will result in an increased pool of specialized talent that in turn will attract international chip design companies to Europe, and the creation of new businesses in this field. In a recent case in point, Apple was attracted by the European talent base and announced its intention to invest more than EUR 1 billion in opening a European Silicon Design Center in Munich.

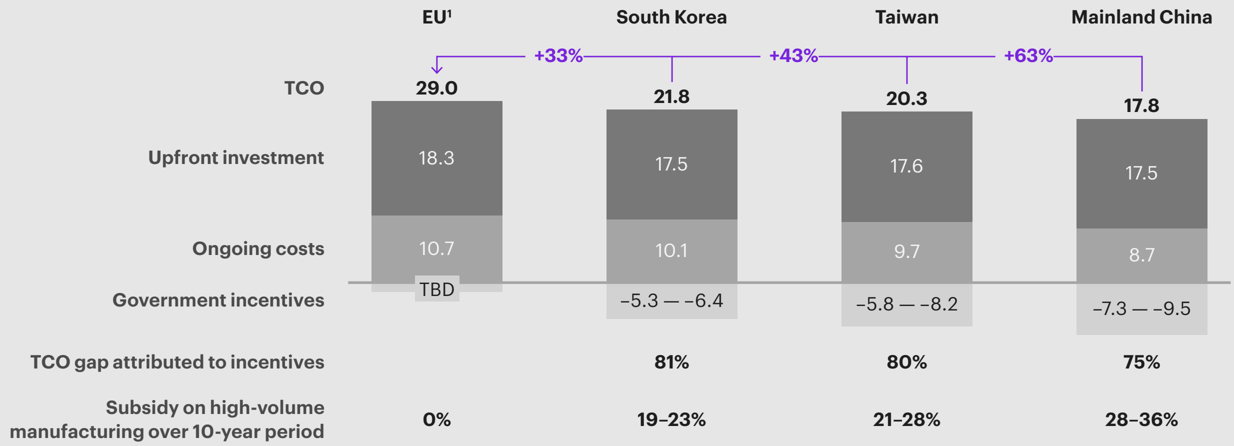
However, lifting design capabilities to a new level would not solve the fundamental need to overcome manufacturing dependency on East Asia and redevelop local sources for mission-critical technologies. Improving design capabilities will also remain substantially harder without co-locating the necessary prototyping and low-volume, pre-series production facilities. In other words, it is vital to close the missing link in the value chain by establishing European leading-edge manufacturing capacity and the corresponding advanced testing and packaging (ATP) sites to finalize the products.

There is another significant hurdle to clear: the deep pockets required by investors who are willing to close this gap in manufacturing. An investor with leading-edge manufacturing technology would spend about EUR 18 billion to set up a greenfield leading-edge mega fab, placing it among the most expensive production sites in history. In comparison, the cost of Tesla's first European Gigafactory, which is set to open near Berlin, is estimated at just EUR 6 billion. The initial investment and ongoing operating expenses vary significantly across regions. Government incentives continue to play a decisive role in attracting and retaining semiconductor manufacturing capacity in a region. Typical government incentives include cash contributions to offset capex, tax holidays or reduced rates, and subsidized land and utility rates that significantly reduce the total cost of ownership (TCO) of building and operating a fab along its entire life cycle.

To compare Europe's competitive position, we have analyzed the 10-year TCO of a 5nm mega fab with foundry capacities across the top semiconductor regions globally. We assume the mega fab to operate at a capacity of 35,000 wafers per month, providing 3,000 full-time jobs. The results are striking: a fab in Europe would be 33 percent more expensive than a comparable facility in South Korea, 43 percent more than in Taiwan, and 63 percent more expensive than in mainland China (see figure 11). The major share of the cost disadvantage (81 percent for South Korea, 80 percent for Taiwan, and 75 percent for mainland China) can be explained by the difference in government incentives granted in the Asian countries, which have defined the semiconductor industry as a core field of industrial policy vs. in Europe. The exact amount of government incentives in the EU depends on an IPCEI framework approval for the leading-edge fab. The comparison of leading-edge fab economics (based on no incentives in the EU) across world regions (as depicted in figure 11) informs about the existing global competition to the IPCEI framework and serves as a guide to alleviate the cost disadvantage of building and operating leading-edge fabs in the EU. To attract semiconductor production investments into the EU, significant incentives are needed to level the playing field.

Figure 11
Strong government incentives in other regions puts Europe at a disadvantage in leading-edge logic semiconductor manufacturing

Simulated 10-year total cost of ownership of 5nm mega fab with foundry capacity (EUR billion)



Key assumptions: 5nm leading-edge logic fab with 35,000 300mm wafers per month capacity. 3,000 direct FTE. No cluster advantages; 10-year total cost of ownership assessment

[1] EU is calculated based on the average price level across Germany, France, and Italy. No incentives applied to the EU TCO as meaningful incentives depend on IPCEI framework approval.

Notes: TCO is total cost of ownership consisting of the sum of the upfront investment plus 10 years of ongoing costs minus government incentives.
fx-rate: US$:EUR = 1.1955

Sources: Model and simulations by Fab Economics (fabeconomics.com); Kearney analysis

Chapter 6: European semiconductor production can regain its position of strength but needs to do so quickly

As the world shifts inexorably into the digital age, Europe depends on a stable supply of semiconductors. Therefore, the region needs a two-pronged approach: first, reduce its dependency on leading-edge production capacity and second, strengthen its technological sovereignty.

Access to leading-edge semiconductors is of existential importance for Europe's prosperity. Currently this access is jeopardized by multiple threats ranging from natural hazards and political risks to technological dependence. Establishing itself as a significant source for leading-edge semiconductors hinges on Europe's ability to restore its own design and manufacturing capabilities—and to accelerate innovation within the local semiconductor ecosystem. Crucially, Europe needs to command a significantly higher share of global leading-edge design, fab, and advanced packaging capacity than today to effectively improve supply chain resilience for its industries relying on semiconductor components as key ingredients to their product offerings.

In response to the skyrocketing demand for leading-edge chips, the three leading-edge players have pledged to expand their capacity in unprecedented investment road maps totaling more than EUR 300 billion until 2030. These investments will transform the manufacturing landscape and redefine the global footprint for decades to come, opening a window of opportunity for Europe to reestablish itself as a relevant player in the semiconductor industry—if it's successful in funneling a significant portion of these investments into the European semiconductor ecosystem. The time to act is now.

Europe needs to follow a two-pronged approach to regain its technological sovereignty. First, it needs to partner up with leading-edge manufacturers to reestablish local semiconductor manufacturing. Second, it needs to reinvigorate the remainder of its local semiconductor ecosystem.

We believe that Europe needs to build global partnerships that enable it to establish local leading-edge manufacturing capacities. Europe alone has neither the capability nor the time to develop what is needed to become a contender in the global market for leading-edge manufacturing. This is primarily because neither of the existing European semiconductor incumbents operates manufacturing facilities at or below 10nm or currently has the in-house capabilities to build and operate a leading-edge fab. It would take more than a decade, tens of billions of Euros, and the hiring of significant expertise and experience for a local semiconductor incumbent to push its capabilities to leading-edge process nodes. TSMC, for instance, almost doubled its R&D expenses vs. the 2015 level and allocated EUR 3.3 billion to R&D in 2020. Its engineers used most of the funds to keep its foundry services' operations on leading-edge. Many other semiconductor manufacturers have not been able to keep up with the innovation race in process technology development. In 2018, for example, Global Foundries announced its exit from leading-edge manufacturing. The stagnant risks associated with developing leading-edge manufacturing capabilities as well as the very high investments in time and money make it prohibitive for any of the European players to develop leading-edge manufacturing capabilities alone.

When looking for a partner to close the technology gap, the focus should be on businesses that can also offer independent foundry services to their clients. Manufacturing businesses with foundry services are inherently better equipped to serve the demands of an open European ecosystem in which both large and small businesses (for example, start-ups) that are developing their own chip designs can access leading-edge manufacturing capacities, and in which design and business innovations can flourish through close collaboration and knowledge exchange up and down the semiconductor value chain.

So, which players could be the right partners for Europe? Only three players can bring the right capabilities to be considered credible partners for Europe in its endeavor to reestablish local leading-edge manufacturing: Intel, Samsung, and TSMC. All of them have the capability, experience, and the financial muscle to build and operate leading-edge manufacturing facilities that provide foundry services that enable chip design innovations in the European ecosystem to flourish. And all of them have expressed an intention to invest in building additional global fab capacity.

All three leading-edge players operate on a global scale and are actively asking for government incentives offered by advanced economies to attract semiconductor investment. Europe needs to actively embrace the challenge arising from this global competition and provide the financial incentives necessary to close the gap with Asia on the TCO for leading-edge manufacturing. We have argued above that tax gains from such additional economic activity would recoup such financial incentives in about 11 years, rendering this investment an attractive business case for long-term competitiveness (please refer to Chapter 4).

In addition to the positive business case provided by such incentives, they also would provide Europe with a lever to ask the manufacturing partner to (1) provide privileged access for European R&D institutions, and (2) ensure active participation to help develop the leading-edge semiconductor ecosystem. This would develop a local supply base and train local semiconductor talent necessary in other areas of a vibrant local semiconductor ecosystem in Europe.

Eventually, an advanced packaging (ATP) facility in Europe would close the last missing link of an end-to-end European semiconductor value chain. Compared to a wafer fab, the capex for an advanced packaging facility is less while relying more on manual labor than a wafer fab. With different wage levels across its 27 member states and the right incentives, the EU would be able to accommodate both business models locally and spur economic activities that contribute to cohesion and regional trade.

2030 is around the corner. The development of local leading-edge manufacturing capacities requires many years (once approvals are given, a fab takes approximately five years before it can operate at full potential). To achieve both key objectives—a 20 percent share of global leading-edge manufacturing capacity and reinvigoration of the local semiconductor ecosystem—the EU needs to act now.

Conclusion: Europe urgently needs to restore its leading-edge semiconductor ecosystem

Leading-edge semiconductor technology has become a keystone technology behind our economy, our society, and our daily lives. Access to leading-edge semiconductors will become of existential importance to every advanced country or region—especially considering the high degree of concentration of the industry and the resulting geopolitical supply risk. Close integration and collaboration between research, design, and manufacturing in the semiconductor industry, as well as close cooperation with the various industries driving its applications, is crucial. Hence, it is imperative for Europe to strengthen its leading-edge semiconductor ecosystem and overcome its current weaknesses.

Having leading-edge semiconductor production located within the region is essential to protect Europe's supply resilience and mitigate operational risks created by the geographic concentration of supply chains and disruption.

The significant cost differentials between leading Asian regions and Europe are largely the result of the support that Asian governments provide. It is therefore crucial that European governments provide the same support, both for the economic value that it will return and for long-term innovation and strategic autonomy in the region.

Strengthening leading-edge semiconductor capabilities will take significant time and investments and needs to start now. Realizing Europe's 20 percent goal by 2030 is unlikely without active government support and without global partnering. The EU should leverage the Semiconductor Alliance to encourage the debate between industry players and policymakers. The announced EU Chips Act is expected to develop the road map for Europe to achieve its goals, and for this reason should be adopted soon. The time is now to align the different views and act.

Realizing Europe's 20 percent goal by 2030 is unlikely without active government support and without global partnering.

Glossary

ADAS—Advanced driving assistance systems

ATP—Advanced testing and packaging

BEV—Battery electric vehicle

DFA—Design for assembly

DFM—Design for manufacturing

DFR—Design for reliability

EDA—Electronic design automation

EUV—Extreme ultraviolet

HBM—High-bandwidth memory

HPC—High-performance computing

IP—Intellectual property

IPCEI—Important project of common European interest

Node—Refers to a specific semiconductor manufacturing process; the smaller the node and the feature size, the more advanced the chip

PV—Photovoltaic

Semiconductor consumption—Value of semiconductors used by citizens and businesses of a region

SOC—System on a chip

STEM—Science, technology, engineering, and math

TSV—Through silicon via

Study background

This study investigates the relevance of leading-edge semiconductors for the EU, addressing the projected demand, the EU's current position in the global supply chain, and strategies for rebuilding Europe as a hub for leading-edge semiconductors. The study is based on public data sources, industry insights, and proprietary data and analyses. As part of this study, we conducted interviews across the European semiconductor ecosystem.

Throughout the study we apply an exchange rate of USD:EUR = 1.1955.

The study was commissioned by Intel Corp. and conducted in summer–fall 2021. Kearney conducted this study independently and is solely responsible for all analyses and conclusions.

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