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European Union

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PART 2/4

**COMMISSION STAFF WORKING DOCUMENT**

# A Chips Act for Europe

# 3. Global Market Perspectives and where Europe is in the Market

### *3.1 Market Perspectives - World Markets*

The semiconductor market in 2021 was worth **USD 555.9 billion**, according to World Semiconductor Trade Statistics (WSTS), with 1.15 trillion semiconductor components sold. This represents an increase of 26.2% with respect to 2020.

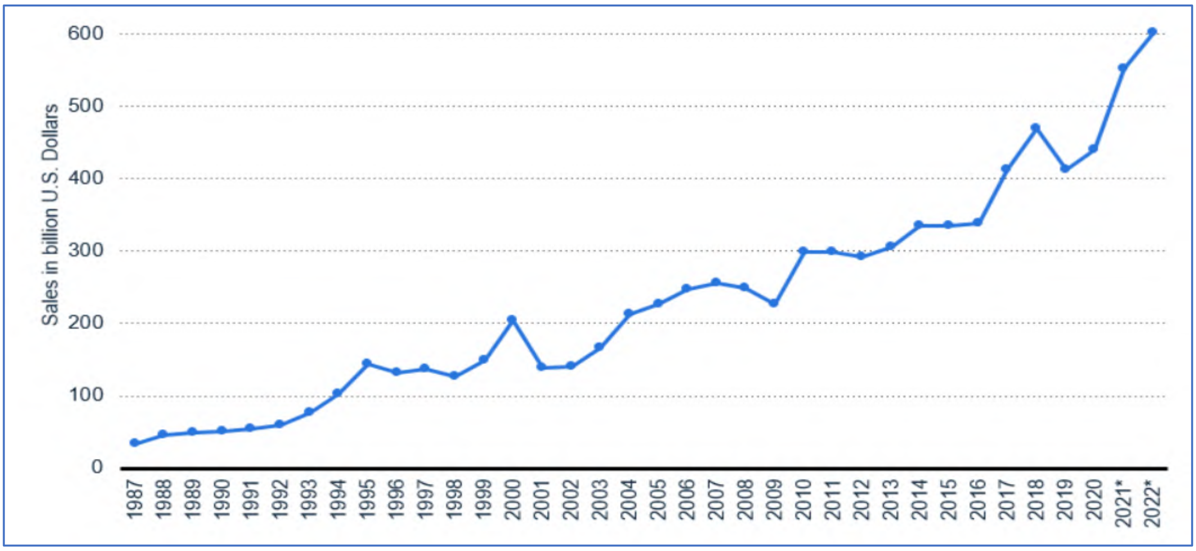
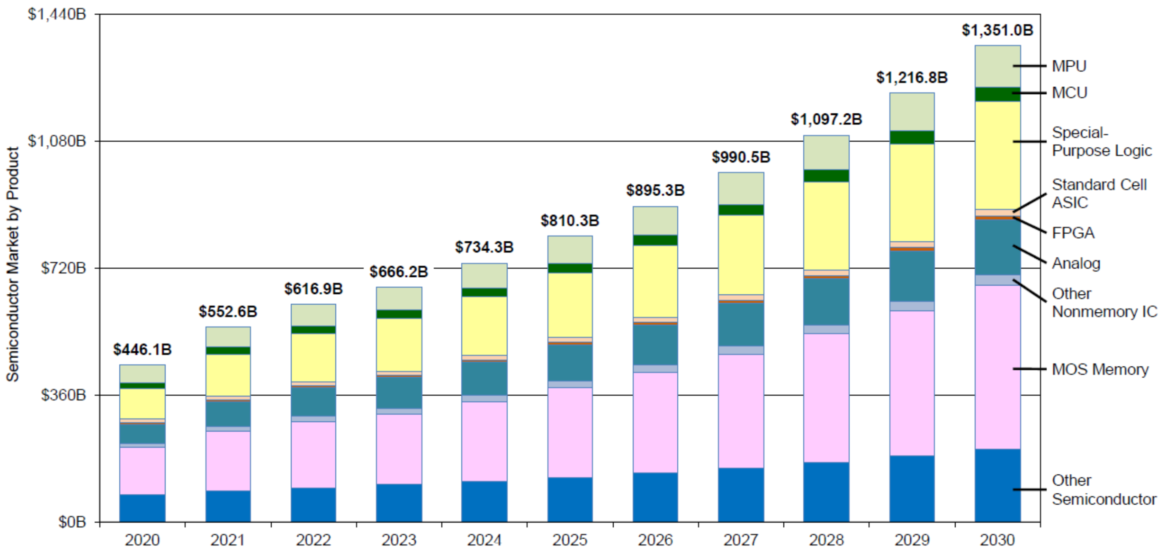



*Figure 10. Semiconductor Industry Sales Worldwide 1987-2022 (Source: WSTS)*

The market has been increasing rapidly as shown in Figure 10 and assuming that the CAGR of 7.1% of the last 20 years continues **until 2030, it is estimated that the market will exceed USD 1 trillion**. According to several sources[1], the total market value is expected to approximately double by 2030; some estimates go even beyond the above (see Figure 11).




[1] SEMI, McKinsey, IBS, SIA and others.

*Figure 11. Semiconductors market forecast by product type (IBS 2022)*

The increasing demand expected in all regions is mostly due to the digital transformation and the constant growth of semiconductor content in electronic systems (see Figure 12).

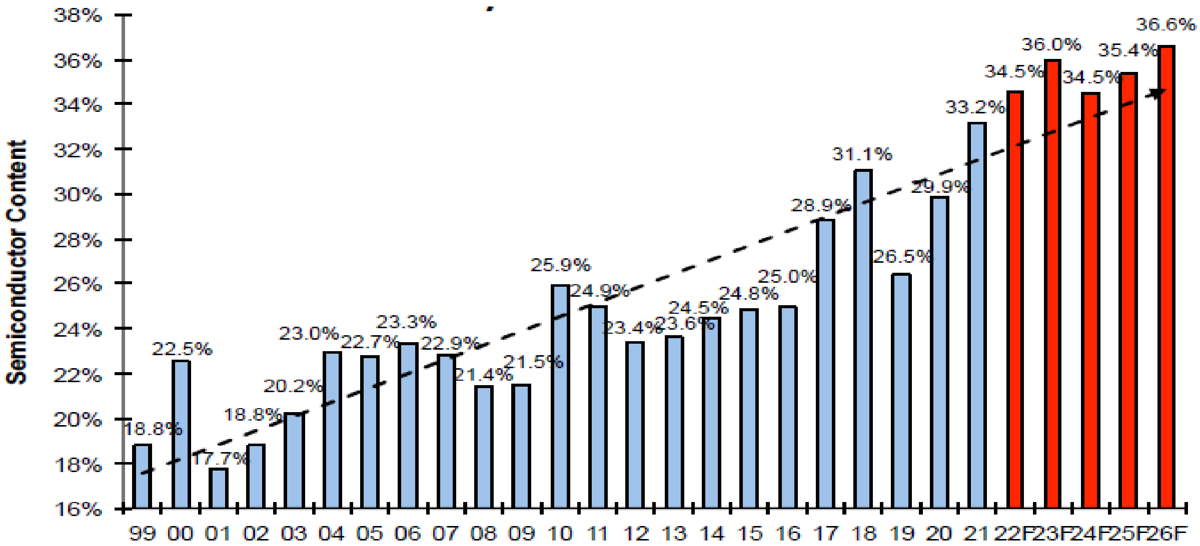



*Figure 12. Semiconductor content in electronic systems (Source: IC Insights, ST, TI)*

Market statistics related to regional shares of global semiconductor sales can be based on different types of data. In the estimation of regional shares and demand, one needs to consider that the value chain is complex, and before reaching its final destination, a semiconductor chip must go through a large number of process steps. The definition of the semiconductor market share therefore depends on which stage of the value chain one refers to, and it can be defined in at least three ways: by the **i) headquarter of the device maker**, ii) the **location of the customer to which the chips are shipped**, or iii) the **location of the end-user**, be it a business or a consumer (see Table 1). Recalling the example presented in Chapter 1: a microchip for a mobile phone can be designed in the US, manufactured in Taiwan, packaged in Malaysia, assembled on a board and in the final product in China, then the final product can be sold in Argentina.

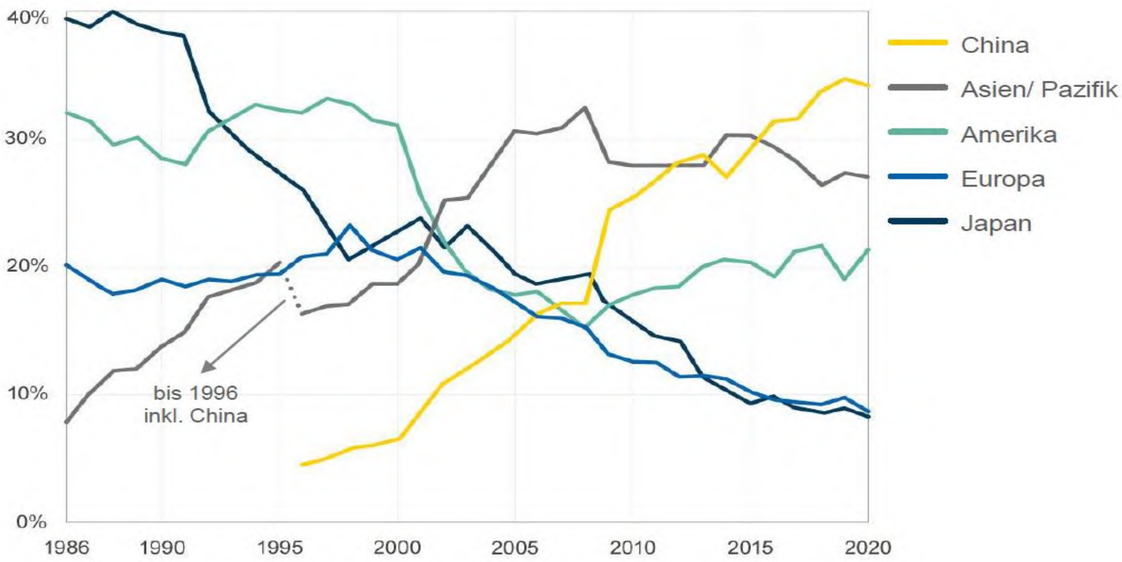



*Figure 13. Global sales by headquarter location (Source: ZVEI)*

i) **Market data related to value of production** of the various regions usually **report sales by headquarter of the device maker**, rather than the physical location of the production facility. In this context, the share of European headquartered companies is currently estimated to be around 9% (Figure 13).

ii) **Regional semiconductor demand usually considers the location to which chips are first shipped**, often for assembly in electronic boards and systems. In this context, the largest market in terms of regional sales is China, in view of the large number of systems assembled in that region. This is followed by Asia-Pacific, Americas and Europe, which represents a share estimated between 8.5% and 10%. (According to WSTS, sales in Europe in 2021 amounted to 8.6% of the global market, while for IBS Europe had over 10% of global demand).

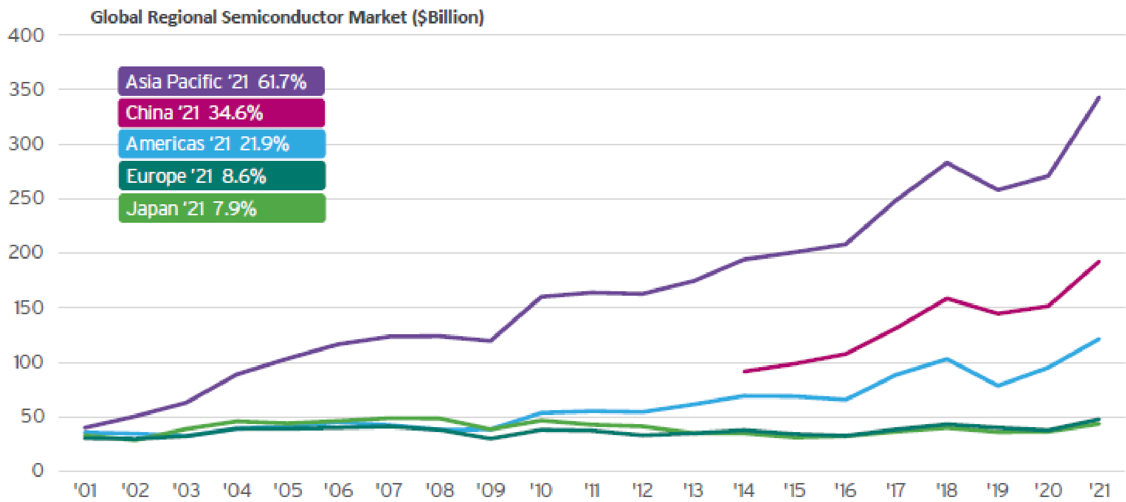



*Figure 14. Regional sales for semiconductors (Source: SIA 2022)*

iii) If we consider the **value of sales of end-user equipment and devices, Europe represents about 20% of the global market**, which is much higher than the regional share of global sales of components by European companies.

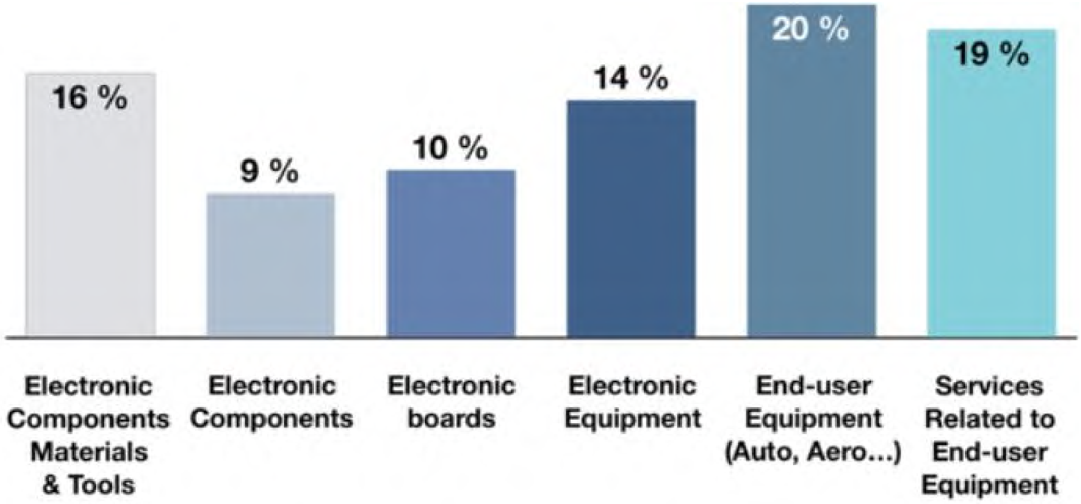



*Figure 15. European share of global sales at the different steps of the value chain (DECISION[2], 2019)*

Summarised in Table 1, Europe's semiconductor market varies between approximately 10%, based on location of system manufacturer or system assembler, and 20% based on location of final end-user.

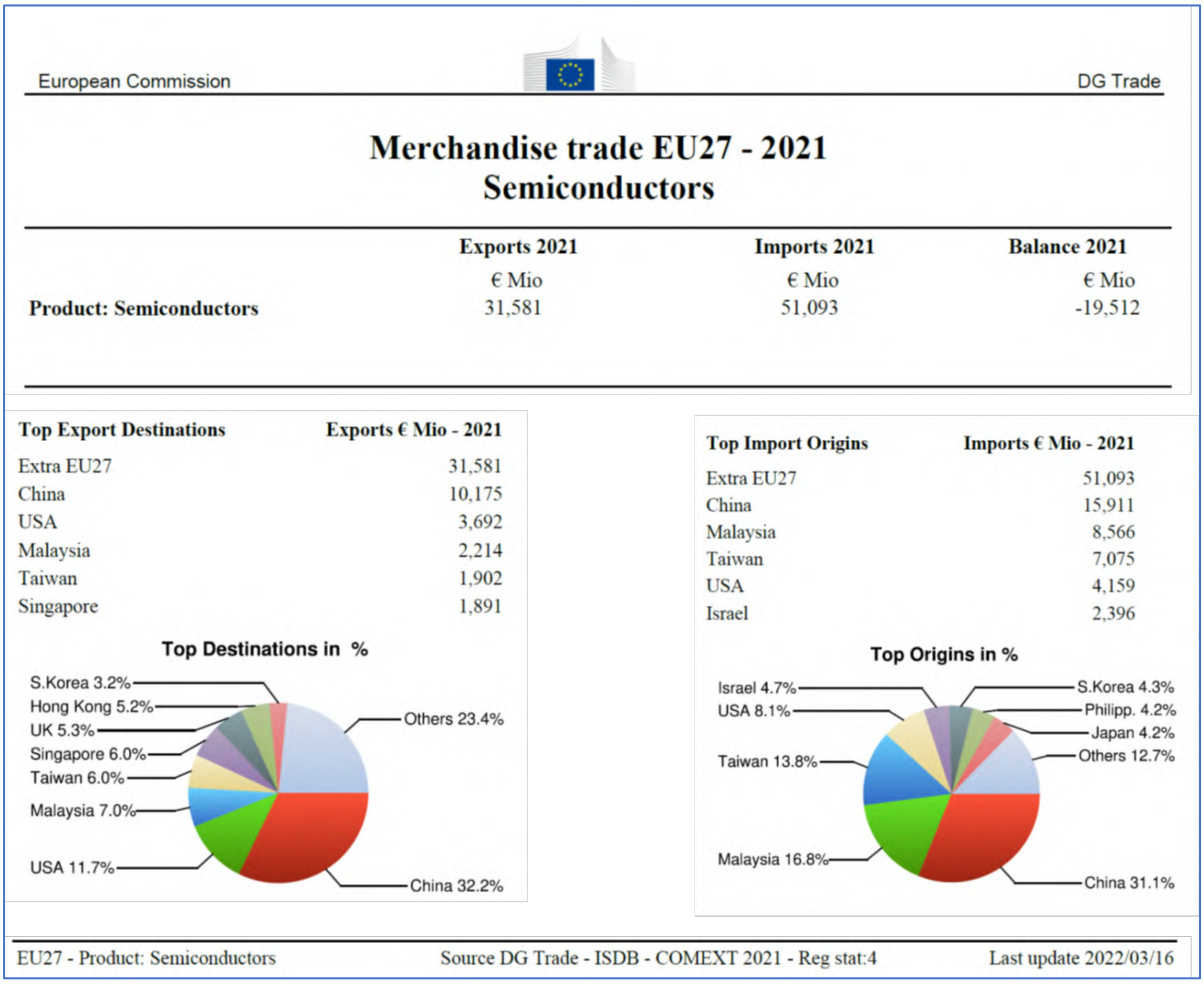
| | By HQ location of the device maker | By location of device assembly | By location of device end-user |
|---|---|---|---|
| US | 33% | 19% | 25% |
| China | 26% | 35% | 24% |
| Europe | 10% | 10% | 20% |
| Japan | 10% | 9% | 6% |
| South Korea | 11% | 12% | 2% |
| Taiwan | 9% | 15% | 1% |
| Other | 1% | <1% | 22% |

*Table 1. Semiconductor sales by region as share of global total (BCG, SIA 2019)*

From the above data it can also be inferred that the value of semiconductors that Europe produces is lower than the one it consumes. Indeed, as shown in Figure 16, in 2021 the EU exported semiconductors for a value of EUR 31.5 billion and imported for EUR 51 billion with a deficit of EUR 19.5 billion. Top export destinations and import origins are countries with major activities in wafer fabrication, and chip packaging, test and assembly: China, Malaysia, Taiwan and the USA.

Although the current level of consumption of semiconductor components in Europe cannot be directly compared to the lower value of components produced by European companies (or the value of components produced in the EU), it provides an indication supporting **Europe's ambition to increase its level of sales or of local production, taking into account that the increase in demand will also lead to an increase in exports.**

[2] Study on the Electronics Ecosystem: Overview, Developments and Europe's Position in the World (EU 2018-19)



European Commission DG Trade

**Merchandise trade EU27 - 2021**
**Semiconductors**

| | Exports 2021 | Imports 2021 | Balance 2021 |
|---|---|---|---|
| | € Mio | € Mio | € Mio |
| **Product: Semiconductors** | 31,581 | 51,093 | -19,512 |

| **Top Export Destinations** | **Exports € Mio - 2021** |
|---|---|
| Extra EU27 | 31,581 |
| China | 10,175 |
| USA | 3,692 |
| Malaysia | 2,214 |
| Taiwan | 1,902 |
| Singapore | 1,891 |

| **Top Import Origins** | **Imports € Mio - 2021** |
|---|---|
| Extra EU27 | 51,093 |
| China | 15,911 |
| Malaysia | 8,566 |
| Taiwan | 7,075 |
| USA | 4,159 |
| Israel | 2,396 |



EU27 - Product: Semiconductors Source DG Trade - ISDB - COMEXT 2021 - Reg stat:4 Last update 2022/03/16

*Figure 16. EU semiconductor import/export in 2021 (source: European Commission, ISDB, Comext)*

As it has been mentioned in previous chapters, the fabrication of semiconductor chips is concentrated in Asia. Figure 17 shows the major foundries and their respective market shares. Taiwan is a major player in the semiconductor industry with 65% of foundry revenues; **TSMC has a 53% share of the global semiconductor foundry market**. The next largest foundry is Korea's Samsung with a market share of 17.1%. Other leading foundries include UMC in Taiwan, SMIC in China and the US-headquartered GlobalFoundries.

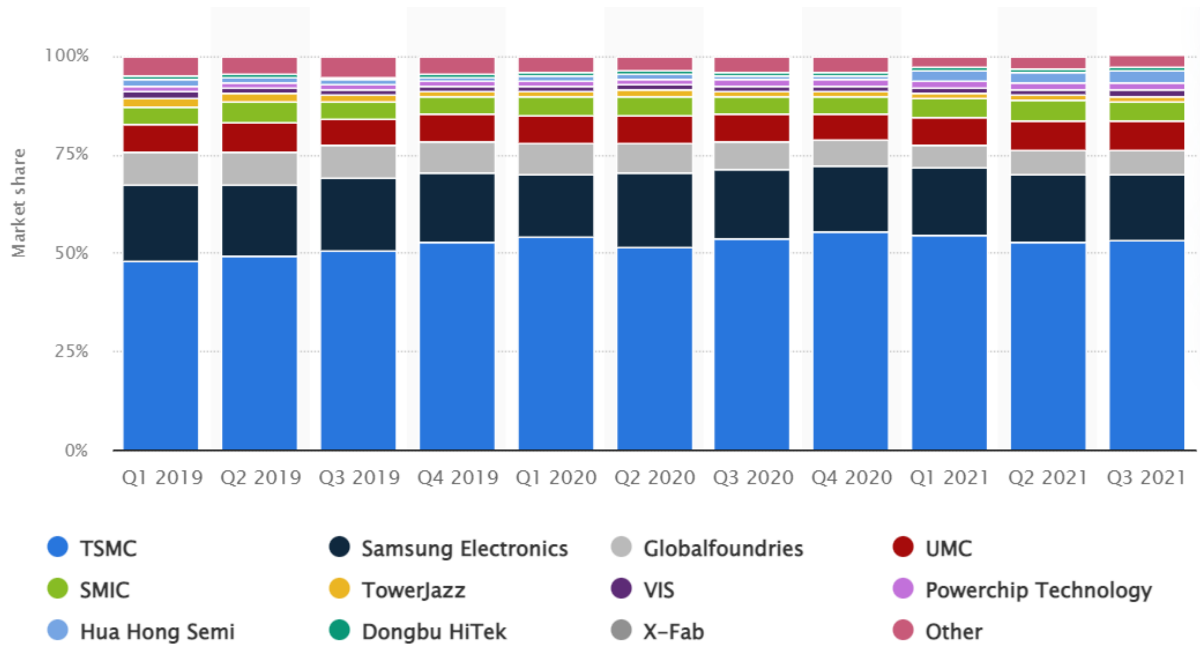



*Figure 17. Global Foundry Market Share of Semiconductor Production 2019-2021 (Source: Statista, Trendforce)*

TSMC and Samsung[3] are the only foundries currently capable of manufacturing chips below 10 nm. Although demand for mature nodes will continue, future growth is expected to be concentrated mostly in the most advanced nodes (see figure 18).

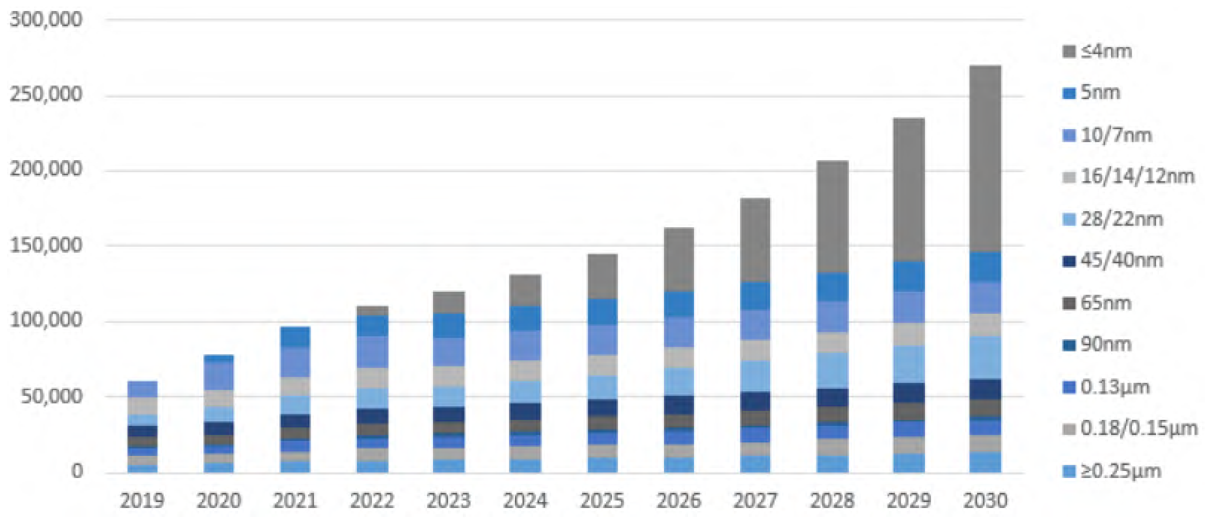



*Figure 18. Foundry Market Growth Areas by node (Source: IBS 2022)*

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Concerning **the level of production of fabs** located in the various regions, usually this is only estimated in terms of number of wafers, not in terms of value as this varies considerably based on different factors. In this respect - see Figure 19 - Europe has observed in the last 20 years a gradually

[3] Intel, which is planning to catch up with TSMC and Samsung in leading-edge nodes, recently announced the intention to start providing foundry services to third parties https://www.intel.com/content/www/us/en/foundry/intel-foundry-services.html

declining share of global capacity to 9.4%, as its investments have remained nearly constant in the past years, versus an overall increase of costs of new production facilities. **The majority of capacity in Europe is still concentrated at 180 nm and above** (see fig 20). The only capacity below 20 nm is at Intel in Ireland (14nm).

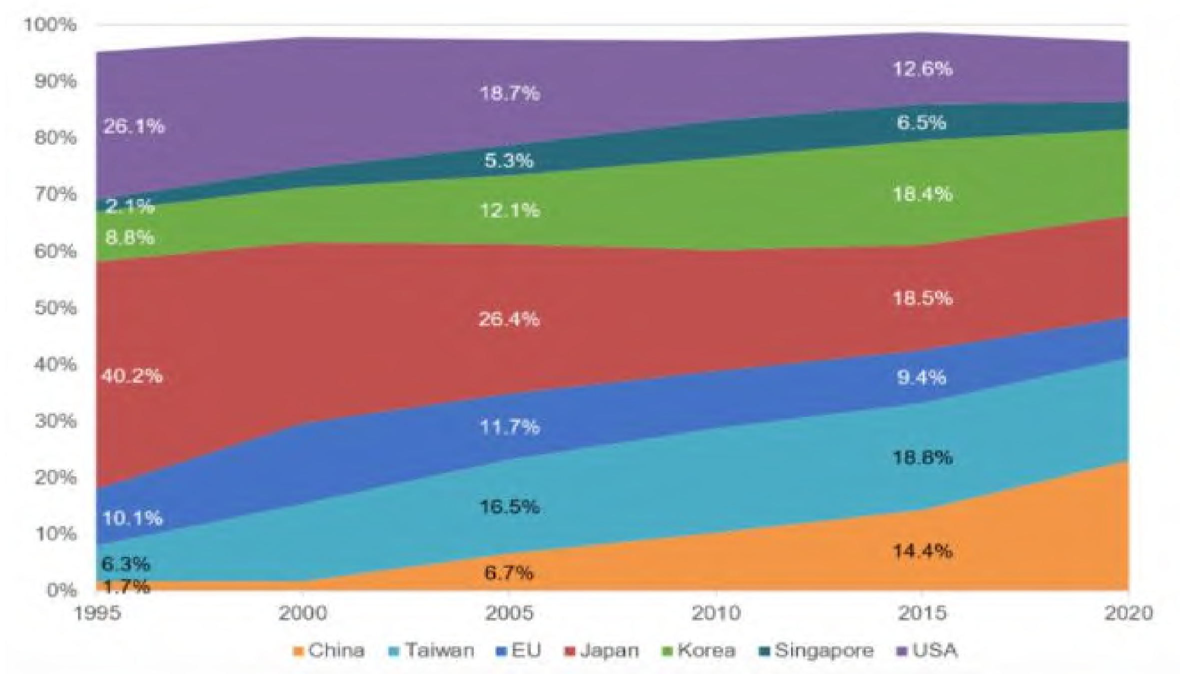



*Figure 19. Wafer capacity by region in 200mm equivalent 1995-2020 (Source: ESIA, SEMI, 2021)*

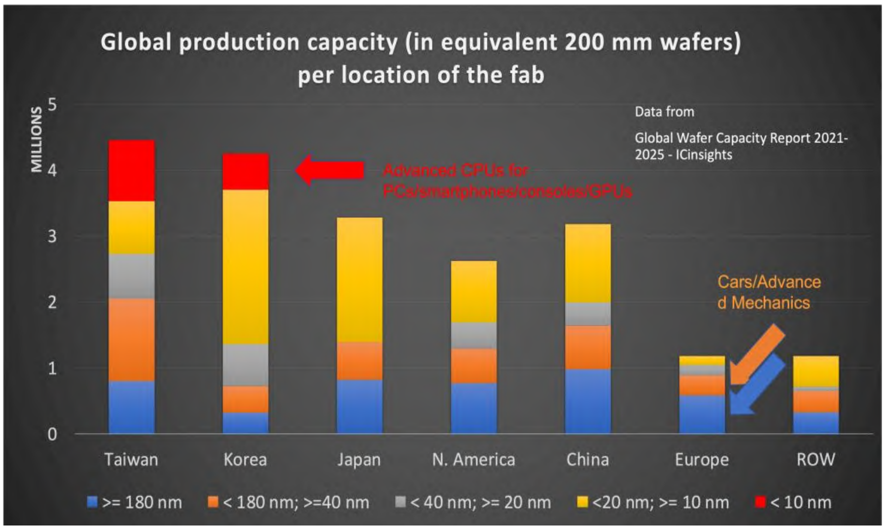



*Figure 20. Wafer capacity by geographic region and node type (Source: IC Insights, 2021)*

The predicted worldwide **market growth for semiconductors in key application markets** over the present decade is shown in Figure 21. Chips for **automotive represents the highest growth market,** forecast to grow by more than three times its current value by 2030. Demand for devices for servers, data centres and storage will also rise significantly as the data economy grows. It is expected that there will be a **doubling of chip demand for both the industrial electronics and consumer electronics markets**. The smartphone market is expected to nearly double by 2030. Personal computing demands will continue to rise, but more slowly, having already grown significantly during the COVID-19 pandemic.

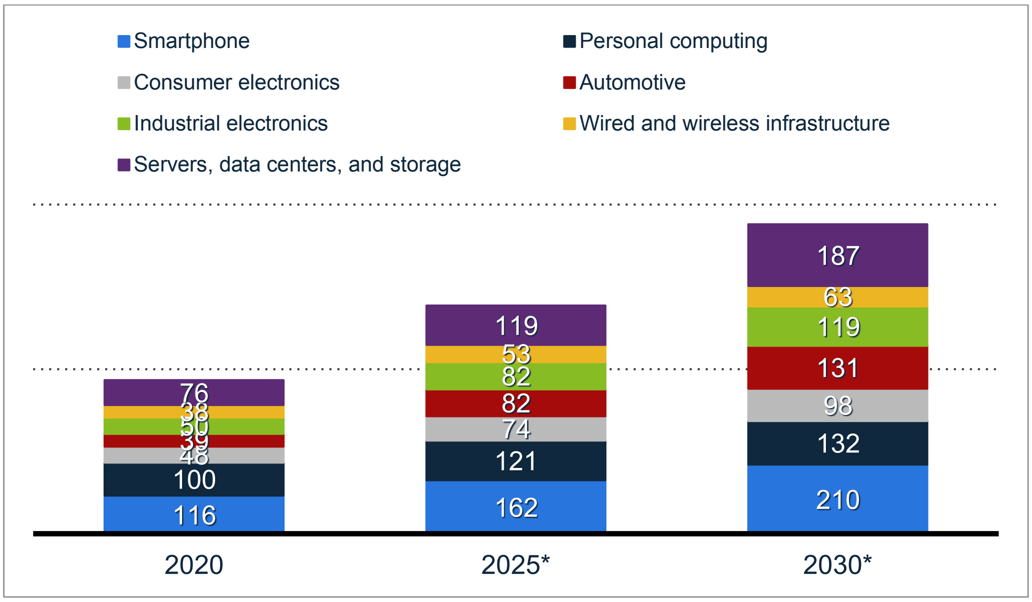



*Figure 21. Semiconductor Market Size forecast by application (in USD billion, Source: Statista, ASML 2021)*

## *3.2 Market Position of Europe*

As shown in Figure 21, the bulk of global demand (close to 70%) comes today from end-use applications in **computing** (including PCs and data centre infrastructure) and **communications** (including smartphones and network infrastructure). In view of their centrality to digital transition, Europe's share of these markets is quite small.

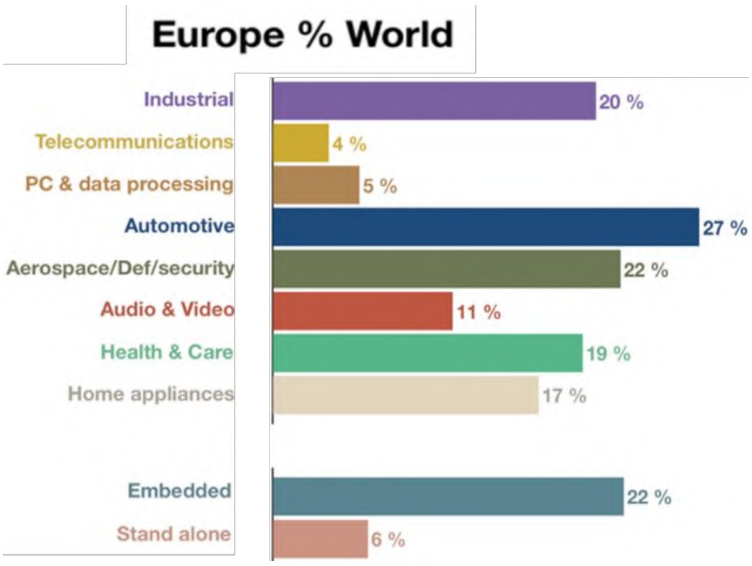



*Figure 22. Production of electronic systems in Europe as share of global sales (Source: Decision, 2019)*

Europe has a strong position in components for embedded and professional systems, which reflects its strengths in the production of electronic systems, as shown in figure 22, whereas little presence is left today in the Union in the area of computers (personal or for data centres) or mobile communication devices. This is reflected also in the European demand for semiconductors from different market segments, which, as shown in figure 23, is particularly high in automotive and industrial automation, segments previously ruled by analogue and mechanical technology. European players such Infineon, NXP, STMicroelectronics and Bosch are indeed among the global leaders in these markets for which the expected growth rate is highest in the coming years (see section 3.3).

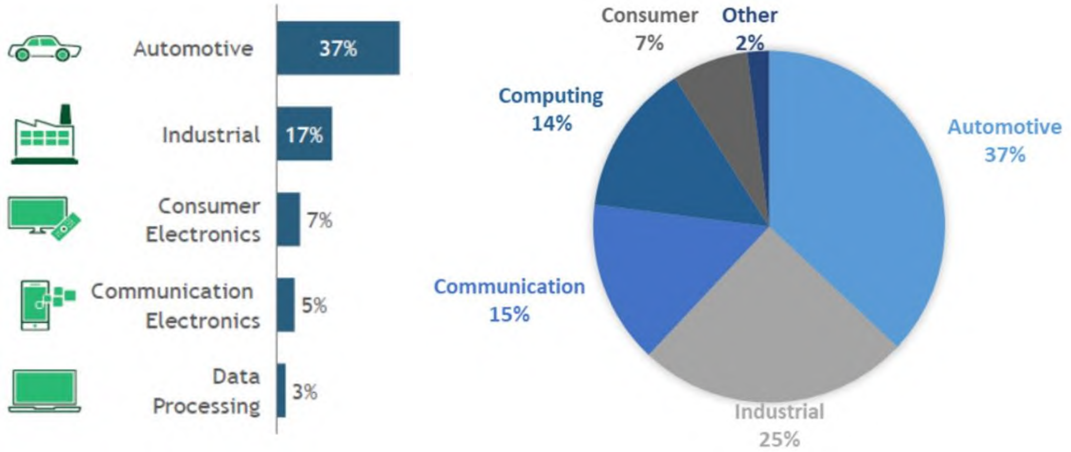



*Figure 23. European share of semiconductor market segments, and demand by end market (Sources: Decision, ZVEI, 2019)*

In addition to these market segments, Europe is relatively strong in the smaller but growing healthcare, wireless (5G/6G) networks, and aerospace and defence segments. These markets are described in Chapter 4.

## *3.3 European Strengths in the Global Market that can be Built Upon*

### 3.3.1 A snapshot of the European supply chain

In terms of role in the various stages of the value chain, Europe has core strengths in R&D as well as in the supply of advanced material and especially of manufacturing equipment. However, in some key stages of the supply chain from design and IP to front-end and back-end manufacturing, the EU needs to address gaps and dependencies from other regions.

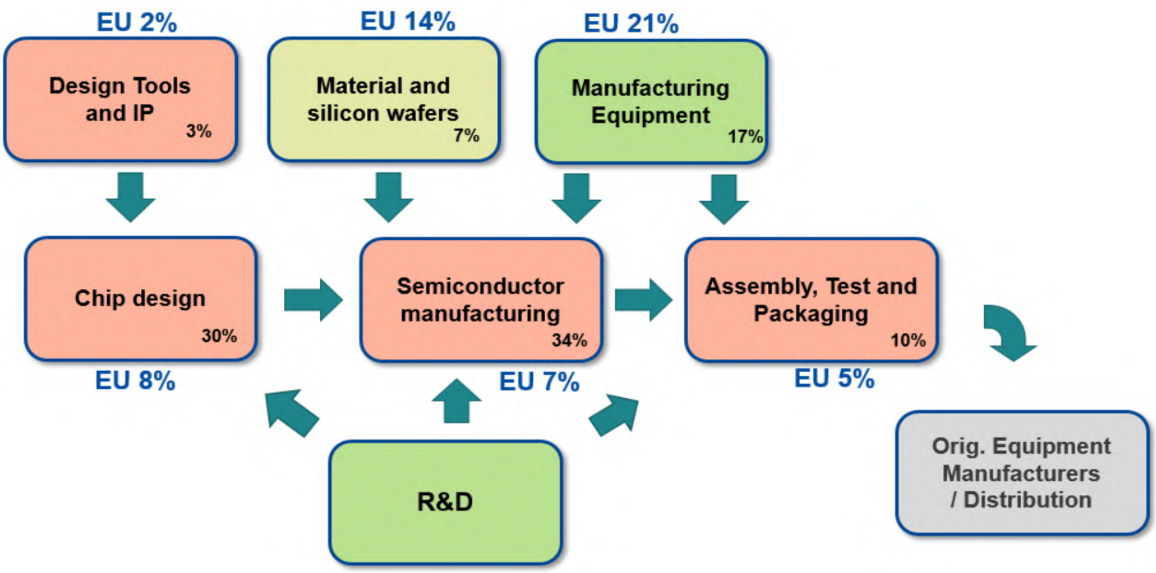
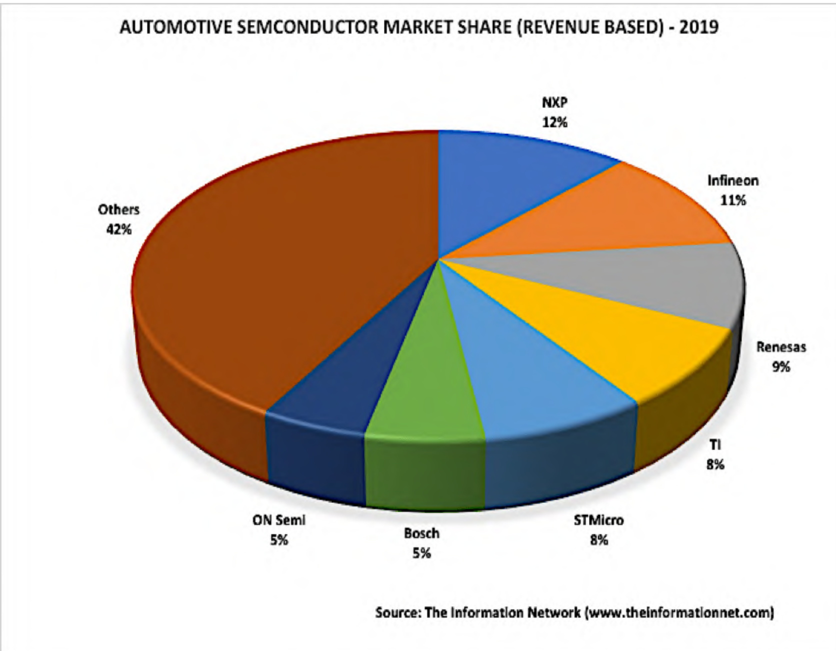


*Figure 24. The main segments of the semiconductor supply chain with relative added value and EU market share (Sources: European Commission, CSET, IC Insights, BCG/SIA, SEMI)*

As set out in Chapter 1, the semiconductor manufacturing value chain is reliant on a wide range of specialist materials, chemicals and sophisticated equipment provided by vendors across the world. Within this global supply chain Europe has world-leading suppliers of **equipment**, e.g. ASML, EV Group, ASM International, and **raw materials providers**, such as Siltronic, SOITEC, BASF, Linde, Merck KGaA and Air Liquide, providing **wafers** and **gases**[4]. In some cases, the global supply chain for advanced chips is totally reliant on European manufacturing equipment such as EUV lithography machines from ASML (see Figure 24).


*Figure 25. Advanced Lithography Machine form ASML Enabling Production of Leading-Edge Chips*

Europe also has leading **chipmakers specialised in the automotive and industrial automation markets**, accounting for about 40% and 20% respectively of the total semiconductor market in those segments (see Figure 25).




[4] Europe is dependent on third countries for certain materials, such as photoresist and silicon metal.

*Figure 26. Automotive Semiconductor Share*

In **automotive,** NXP and Infineon are in the top 2 positions globally; ST and Bosch are also strong players.

European companies dominate the market for embedded **security chips**, the leading actors being NXP, Infineon, ST, Gemalto and Idemia. The concept of trusted chips is regaining traction as cyberattacks grow in number and sophistication, threatening data privacy and security, and the safety of digital systems including cars, trains, planes and physical networks (see Chapter 5.3).

### 3.3.2 Design and Manufacturing in Europe

In Europe there are over 50 semiconductor fabs located in many different Member States, including Germany, France, Ireland, Italy, Austria, Netherlands, Belgium, Hungary, Czech Republic, and Sweden. The majority of these fabs produce at mature nodes on 150 mm and 200 mm wafers; only a limited number of fabs process 300 mm wafers, such as the ones from Intel in Leixlip (IE) (producing at nodes down to 14 nm), GlobalFoundries in Dresden (DE) (down to 22 nm), ST Microelectronics in Crolles (F) (down to 28 nm). New analogue fabs have recently opened, such as the one from Bosch in Dresden (DE), Infineon in Villach (AT) and ST Microelectronics in Agrate (IT).

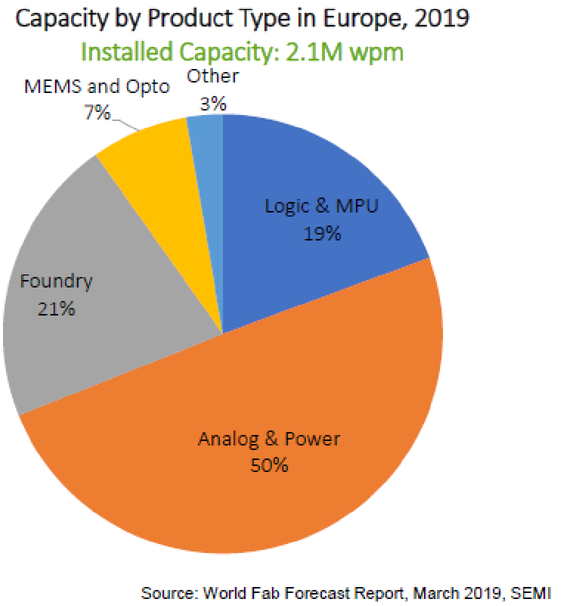



*Figure 27. Global Production Capacity and Product Types in Europe*

Europe's capacity to design chips resides largely with its IDMs and is linked to the markets where they are strong today. However, few chips are designed today without US-origin IP. European chipmakers using US-origin IP have to apply for licences to export to Chinese companies; this can have a negative impact on trade and market share. Europe's share of fabless design has declined from 4% in 2010 to less than 1% today[5]. The fact that there are no EU companies in the top 50 is a matter of concern, not least because among the various segments of the semiconductor value chain, design generates a large share (over 30%) of the value of the final product. Supporting the expansion of design capabilities and the growth of fabless companies in the EU is therefore of critical importance.

[5] Source IC Insights (https://anysilicon.com/fabless-company-sales-by-region-2018/). Note that Dialog (UK) has been acquired by Renesas (JP) in 2021.

Europe has a vibrant ecosystem of SMEs and start-ups spread across many EU Member States. Difficulties in accessing equity however limits their growth prospects. In general companies producing hardware have more difficulty financing through the "Valley of Death" from demonstration-scale to commercialisation than those producing software as they are founded upon engineering innovation and/or scientific advances (which makes them inherently more risky)[6].

### 3.3.3 The Research efforts of Europe

Research activities in semiconductors include:

- **basic research**, which studies materials and processes stimulating innovations in performance and efficiency, and that is carried out mostly by academia and research organisations, sometimes in cooperation with industry;
- **applied research**, studying the effect of the basic principles in specific fields of application, where still research and technology organisations are quite active, but industry plays also key role;
- **development**, which puts the learned principles into practice in terms of devices of manufacturing processes, and is mostly responsibility of the industry itself.

If one considers the average investments that the EU semiconductor industry makes in the 3 steps above, overall they exceed 14% of global sales, which is one of the highest of all industries. At European level, collaborative and individual research efforts in semiconductors are generally supported by the Union's Research and Innovation Framework Programmes, as well as private-public partnerships or joint undertakings (JUs) such as the Key Digital Technologies (KDT) JU (now proposed to become the Chips JU). Further, Member States can support R&D projects by undertakings, up to first industrial deployment, in the framework of an Important Project of Common European Interest (IPCEI), such as the one on Microelectronics and Communication technologies, recently pre-notified to the Commission (see also section 8.1.8).

The strategic alignment between the European Commission, Member States, industry, research and technology organisations (RTOs) and universities, through the ECSEL JU and its predecessors, has encouraged the pooling of European industry-driven R&D efforts. Between 2014 and 2020, under the ECSEL JU, an investment of EUR 2.4 billion (shared equally between the Commission and Member States) was matched by industry, RTOs and universities. This approach has been instrumental in the development of various technologies that have been successful on the market.

Over the years the JUs have supported and developed key innovations in CMOS, mixed-signal, sensor, and power technologies as well as Fully Depleted Silicon on Insulator (FDSOI) semiconductor process technology (see Annex 4), new lithographic techniques such as EUV, and has strengthened the semiconductor equipment and materials ecosystem in Europe.

Underpinning this, there is a large RTO community with world-leading actors, represented among others by IMEC (BE), CEA-LETI (FR), Fraunhofer Group (DE), VTT (FI), TNO (NL), CNR (IT), Tyndall (IE), AIT (AT), RISE (SE), CSIC (ES), INESC (PT), FORTH (GR), CNRS (FR). This is complemented by leading technical Universities, including the ones of Delft (NL), Eindhoven (NL), Grenoble (FR), Dresden (DE), Leuven (BE), Graz (AT), Milano (IT), Tampere (FI), Cork (IE),

[6] Financing Europe's Digital Transformation: Unlocking the value of photonics and micro-electronics, EIB, June 2018

Bratislava (SK), Lund (SE), DTU (DK), Brno (CZ), Gdansk (PL), Thessaloniki (GR), Bucharest (RO), etc. These and many others across Europe contribute to advances in the field, developing European IP, hosting pilot lines and contributing to skills development and training.

Despite the important results in R&D achieved through the above efforts, the EU is much less successful in translating results into industrial benefits. The first Important Project of Common European Interest (IPCEI) on Microelectronics - originally approved in December 2018 with France, Germany, Italy and the UK, with Austria having joined in 2021 -granted aid of up to EUR 1.9 billion to upstream component manufacturers to carry out R&D&I and First Industrial Deployment[7] (FID) in the EU to support applications in downstream industries. It played a role in leveraging industrial investments in Europe of more than EUR 6.5 billion including the first greenfield investment in a fab in Europe in more than a decade (Bosch in Dresden - see Chapter 8), and brought together 32 participants (mostly companies). This has without doubt added value to above-mentioned developments supported by the JUs.

The JUs - being largely bottom-up in nature[8] - have tended to be more closely aligned to the core business interests of the industry. There has been less emphasis on addressing gaps and emerging needs at European level, such as the ones related to the digital transition (including a focus on logic and memory), with end-user companies playing a more active role[9]. The successor JU to ECSEL - the Key Digital Technologies JU – allows also for a top-down approach, whereby part of the funding is allocated in advance to topics selected by the public authorities and the industry partners of the JU. As alluded to in section 3.3.2, an important concern is the lack of venture capital funding in the sector that limits the ability of Europe's most innovative deep-tech start-ups and SMEs in this sector to translate new innovations into products.

The measures proposed to address the above issues are outlined in section 8.1. In the following chapters (4 and 5) the opportunities for innovation in Europe are highlighted.

[7] First industrial deployment means the upscaling of pilot facilities, demonstration plants or of the first-in-kind equipment and facilities covering the steps subsequent to the pilot line including the testing phase and bringing batch production to scale, but not mass production or commercial activities (see Communication C/2021/8481), OJ C 528, 30.12.2021, p. 10–18, paragraph 25).

[8] In particular, the JUs have until 2020 based their workprogrammes on a broad Strategic Research and Innovation Agenda put together and regularly updated by industry associations.

[9] See for example, Study on the impact of ECSEL funded actions, Final Report, Deloitte.VVA, February 2020 or ECSEL Book of Projects volumes 1, 2 and 3. While not providing in-depth analyses, clearly the majority of products are aimed at reinforcing strengths in semiconductor markets or technologies where EU industry is already well-positioned. There is also relatively weak participation by the EU's major end-users of semiconductors. Steps have been taken in the last two years of ECSEL to bring semiconductor suppliers and end-users together in projects in a "full value-chain approach".

# 4. Technology Trends and Evolving User Requirements for Key European Sectors

## *4.1 Industrial Automation*

With 20% of market share in industrial electronics, Europe is ranked second after China, but ahead of the US. The global market for industrial control and factory automation is predicted to grow to almost EUR 140 billion in 2022.[10]

**Wider use of digitalisation and automation** is currently modernising both manufacturing and supply chain management. There is a clear trend for intelligence to migrate closer to machinery and processes in a factory to carry out inspection tasks or for predictive maintenance. This requires a range of processing capabilities at the edge[11] of the network with a wide range of connected devices and systems, the so-called Industrial Internet of Things (I-IoT).

**Industrial robotics** is also evolving, enhanced by edge computing capabilities. There is increasing interest in modular self-reconfiguring robotics to perform different tasks, and in robots able to interact and collaborate with humans to take over the mundane or dangerous tasks (the so-called "cobots").

A key concern is the reliability of these new IoT components. In particular if they are performing control tasks (in addition to computing tasks) they may also cause shutdowns. **This requires technological resilience against cyber threats which is pushing demand for secure edge computing components.** Factory owners are also concerned about sensitive data being sent to remote data centres and the cloud, so local on-premise clouds are often used.

*The Industrial Automation domain is being revolutionised notably by the Internet of Things, requiring powerful secure edge computing devices and high rate, low latency communications such as those provided by 5G.*

Looking to the future, there are drivers towards scalable, reconfigurable and flexible first-time right manufacturing with zero-downtime precision manufacturing, including predictive quality and non-destructive inspection methods. **This is driving advances in the application of Artificial Intelligence not only at the local level, but also for global optimisation.**[12]

The development of Digital Twins allows for the evaluation of industrial assets at all factory levels, and over system or product life cycles. This requires significant processing and also data gathering across the factory from sensors and equipment, possibly enabled by dense 5G interconnectivity.

There will also be increasing interaction with an augmented workforce via wireless and mobile technologies in shopfloor automation and information management to support more flexible, modular and remote operation of manufacturing assets. The integration of 6G wireless tactile networking

[10] Thompson, H., Reimann, M. Et al. (2018). Platforms4CPS. Key Outcomes and Recommendations.
[11] The term "edge computing" refers to computing or data processing close to where the data in question is gathered or generated. It is in contrast to centralised computing where the data is transmitted to a data centre or the cloud for processing. Edge computing has become possible due to the variety of increasingly powerful processor chips (GPUs, TPUs, …) that can be embedded with cameras or sensor devices that capture the data.
[12] Industrial IoT Edge 4.0 Framework: A Gamechanger | ARC Advisory (arcweb.com)

capabilities coupled with advanced embedded computing intelligence platforms will play a central role in the realisation of next generation digital manufacturing workplaces.

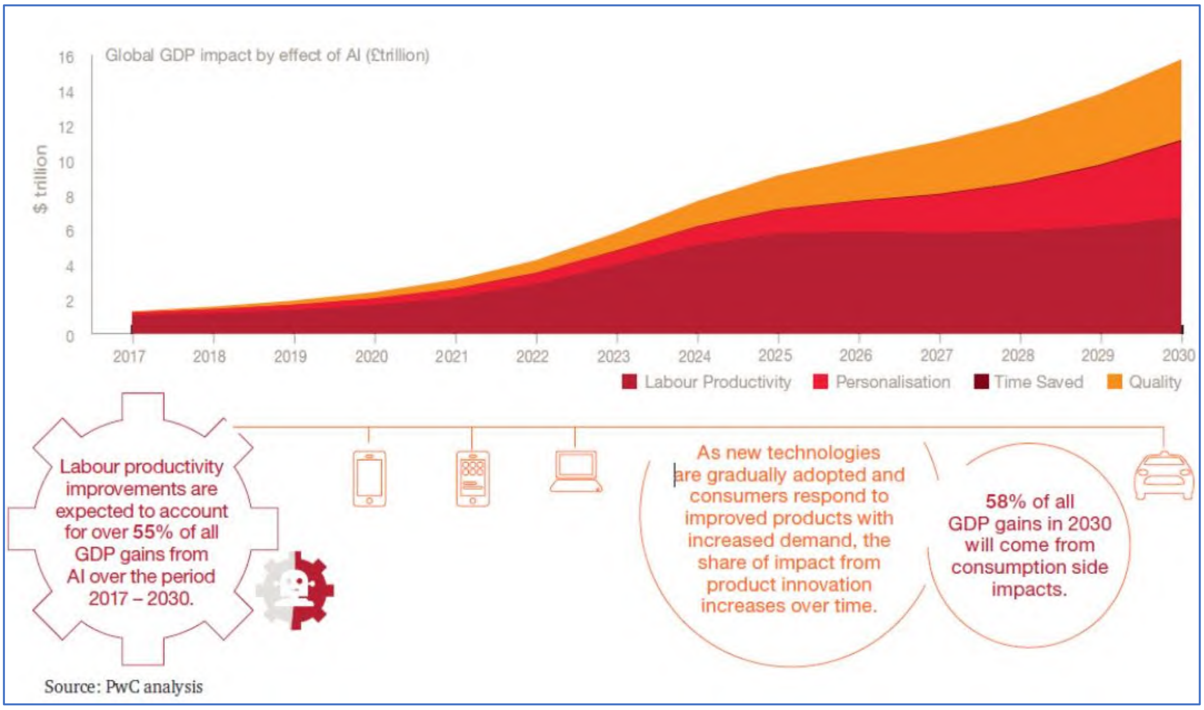



*Figure 28. Growing Use of AI in Manufacturing Optimisation and Products (Source: PwC)*

Sustainable production is also a key driver and companies are striving towards an optimised materials economy to reduce raw materials used, energy and chemical usage, and scrap, as well as a move to circular manufacturing models over the lifetime of products to improve recycling and reuse.

To support the demanding requirements for robotics and automation as well as the increased application of AI at the edge for factory optimisation, there is a need for advanced semiconductor technologies, such as: leading-edge processors (e.g. 10 nm and below), advanced packaging of chiplets and heterogeneous integration to combine sensing, processing, AI acceleration and wireless communication in a single package.

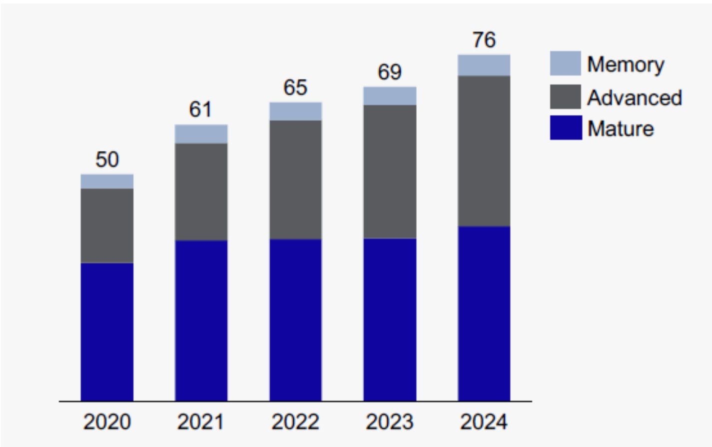



*Figure 29. Semiconductor market evolution for industrial electronics, in USD billion (ASML)*

### *4.2 Automotive Industry*

According to various analysts, the automotive segment is the one with the highest expected growth in the coming years, with a CAGR estimated between 11% and 15%. According to IBS, by 2030, the market may be worth USD 113 billion, with 39% of fully electric vehicles (EV) sold worldwide, and the wide majority featuring a high level of automation (L4 or L5).

In a modern car, there are around 1500 semiconductors with an average value of USD 500 exploiting a range of fabrication processes. By 2030, this number is expected to rise to 3000 semiconductors with an average value of USD 1200.[13] This includes a wide range of components such as microcontrollers, microprocessors, fusion processors, Systems on a Chip (SoCs), ASICs, memory, display drivers, sensors, analogue and power electronics.

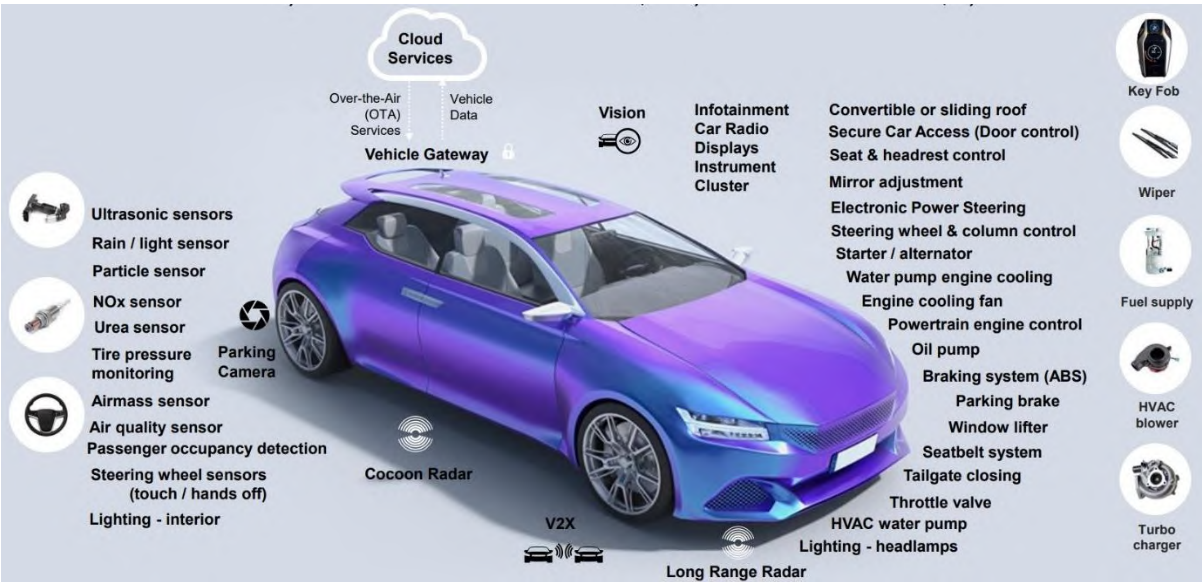



*Figure 30. Components in modern car systems (Source: NXP CMI)*

The range of technologies required currently varies from 16 nm devices for radar processors and for networking, 40nm devices for processors in general, 65-350 nm devices for mixed signal devices, LED, bus and sensors, and 1µm devices for power electronics. In view of the shift towards higher level of automation, with processors for sensor fusion, on-board computing and communication, demand for chips produced at more advanced nodes is expected to grow in the coming years.

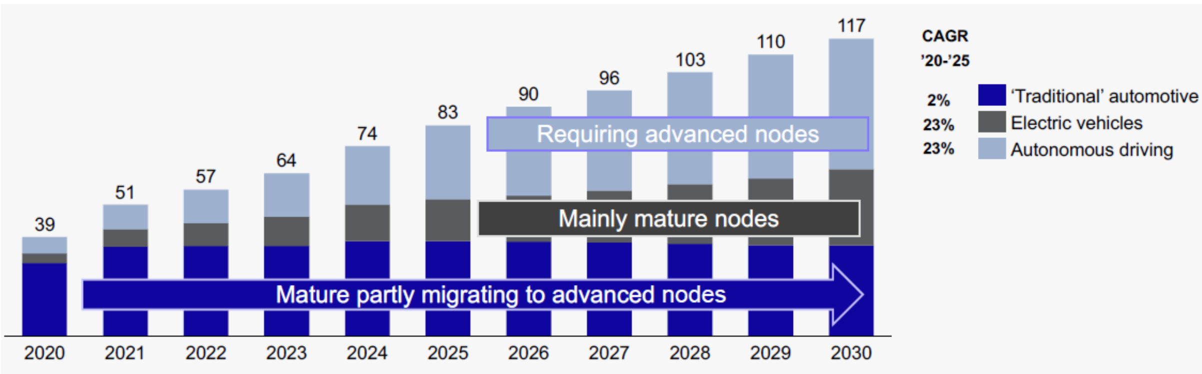



*Figure 31. Semiconductor market evolution for automotive chips, in USD billion (Source: ASML, Gartner 2022)*

[13] IBS, 2021

There are three key drivers in the automotive sector which are increasing the use of semiconductor devices: **connectivity for safety and infotainment systems, increased automation levels and the move towards electric vehicles**.

| Type of Semiconductor | Volume Node(s) today | Design node for new products | Company | # per average vehicle (2019) |
|---|---|---|---|---|
| Auto SoC's | 65nm - 28nm | 16nm (ramp 2021)<br>5nm design (SOP2025) | | 9 |
| | 65nm – 28nm | 16nm ramp 2020 | | |
| | 28nm – 7nm | 5nm design | | |
| | 40nm – 28nm | 7nm design | | |
| Auto Memory | 55nm – 40nm | Not announced | | 13 |
| | 18nm – 15nm | ~10nm | | |
| Auto MCU | 180nm – 55nm | 40nm ramp 2021 | | 34 |
| | 180nm – 40nm | 40nm & 28nm | | |
| Analog (Linear) & Power Semiconductors | 130nm & larger | 90nm | | 253 |
| Discretes / Small Signal Transistors | 130nm & larger | | | 406 |
| Sensors | 130nm & larger | | | 45 |
| All other types | 90nm & larger | | | 213 |
| Total | | | | 960 |

Advanced technology nodes
Higher Volume per Vehicle
###

*Figure 32. Predominant Technology Nodes per Product Type (Source: Strategy Analytics, Jan'2021 for 2019 figures, Company reports)*

Although the number of cars being produced has reduced significantly from 95 million in 2017 to 75 million in 2021 as a result of the current supply crisis, **the number of chips required per car has gone up dramatically driven by new features and the move to hybrid and electric cars**. In order to ease the management of such a large number of components, there is a trend in the industry towards more centralised architectures and the use of System on Chips (SoC), requiring high-performance processors. Further, the increasing penetration of electric mobility will lead to a high growth for power electronics components, especially those adopting compound substrate technologies such as Silicon Carbide (SiC) for fast charging and inverter control[14].

Other areas of device usage are increasing very rapidly. **A concern is in the use of analogue chips as they are key components across a wide range of applications.** This includes SoCs, signal conditioning for sensors, bus transceivers, drives for motors, LEDs, displays and radar transceivers, audio and RF systems. **The lead time for analogue devices is still increasing and this is likely to limit production in the future**[15]. Here there is competing demand for fabrication resources from other sectors such as phones, high-end audio and contactless payment.

[14] According to Yole, the SiC device market is expected to grow at 34% CAGR, from beyond US$1 billion in 2021 to over US$6 billion by 2027 (http://www.yole.fr/Power_SiC_March2022.aspx)
[15] Source IHS Markit™

*In the automotive sector the requirements for connectivity, infotainment, increased automation and electric vehicles are leading to a radical increase in demand for digital and analogue components which is becoming increasingly hard to meet.*

### 4.3 Healthcare

Any medical device used in hospitals and doctor practices that is powered by electricity grid or batteries, depends on semiconductor components to operate. This includes life-saving devices such as defibrillators, pacemakers, insulin pumps, ICU equipment or diagnostic machines such as MRI or CT scanners, ultrasound, ECG stations. As the population ages and the cost of healthcare increases, healthcare is becoming more decentralised, personalised and focused on prevention. **Although there are large differences in healthcare spending across EU Member States, the average figure is approximately 10% of the EU's GDP, or EUR 1.6 trillion**. Solutions for remote monitoring, telemedicine and digital health in general will become imperative, particularly for elder people with chronic diseases allowing them to remain in their own homes and reduce costs of care. These include wearable and implantable devices to provide remote monitoring and alerts for carers, or under-the-skin drug delivery systems, which will drive up the volume for this market segment. The boundaries between medical technologies, medicinal products, digital health technologies and the semiconductor industry are disappearing, resulting in new diagnosis and treatment solutions. This requires digital processing, advanced electronic sensors and photonics, MEMS, and high volume, high-quality, low-cost production capabilities. There is therefore an incredible potential for growth in this segment.

The medical device end-use market is currently estimated being about 1.3% of the total semiconductors market (source Omdia, 2020), around USD 7 billion. Therefore demand may be viewed as limited, but especially very fragmented, which is one of the key obstacles for growth. There are more than 25,000 SMEs in Europe active in the field of medical devices – many spun-out from RTOs and academia. However, only very few breakthrough innovations reach the patient or the clinic. **A key barrier is that these specialised devices are needed in small numbers, which is at odds with foundries' expectation of large volumes to amortise production costs**. There is also a lack of open technology platforms in the medical device industry. Some **European companies (including Philips) are cooperating to develop technology platforms that are open to other parties for bioelectronic medicines** thus giving potential for viable production volumes to be achieved[16].

*Due to the low production volumes and specialised nature of devices required in the health sector, there is a need to develop industry standard platforms that can be used across the community and to introduce measures for the security of supply to the medtech industry.*

### 4.4 5G and 6G Communications

Communication is together with computing the largest segment of the semiconductor market, with revenues in the order of USD 200 billion. Over 90% of the market is wireless communication, mostly due to the 1.5 billion of mobile handsets sold on a yearly basis. This market currently drives the 'More Moore' trend of scaling in chipsets, with smartphone brands having the largest volumes, necessary to justify the costs of new 3 nm and planned 2 nm fabs. 5G, the fifth generation of standard

[16] POSITION-2. The next generation smart catheters and implants.

for mobile communication technology, provides far higher data rates (20Gbps versus 150mbps), with lower latency (1ms vs 60ms on 4G LTE) than previous generation 4G LTE, and the ability to connect more devices in a given volume. Semiconductor consumption of a 5G smartphone is at least 1.4 higher than the previous generation, and the market value of 5G chipset sold is already surpassing the value of chipsets for smartphones up to 4G. 5G has many potential applications, going beyond mobile phones, notably in industrial automation and in automotive.

Another important subpart of this segment is related to chipsets for wireless communication infrastructures, a smaller but highly strategic market, requiring high-performance components. Europe is strong in infrastructure equipment, with two market leaders as Ericsson and Nokia, but companies from US and China have taken the lead in terms of chipsets. Further, the market is evolving towards disaggregation of hardware and software, with open standard interfaces, and virtualised, cloud-based management of the network. This is disrupting the current business models and the established positions, with geopolitics playing also an important role in the adoption of specific technologies.

The next generation communications technology 6G is also being developed for targeted introduction in 2030. In 6G very high frequencies are utilised which will give very high data transmission rates with little or no latency, more heterogeneity and increased sensitivity to the environment. It will support decentralised models with automated management, employing pervasive edge AI, blockchain technologies, virtual reality and augmented reality, which can open up new applications such as the "metaverse"[17]

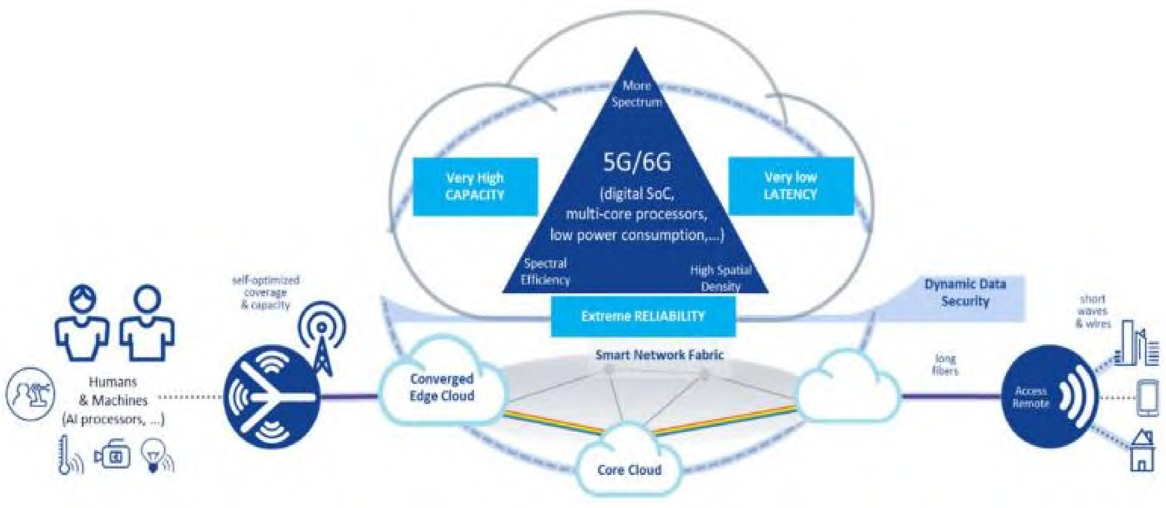



*Figure 33. End-to-End System View (Source COREnect project)*

An end-to-end view of future connectivity systems is depicted in Figure 33. To meet the needs of emerging applications such as industrial automation, future connectivity systems need to offer extremely high capacity, extreme coverage, extremely low latency and high reliability, all at low energy and low cost. In the global competition, we must consider that China is well ahead of US and Europe in 5G deployment and plans to implement 6G starting in 2029.

Europe will need to strengthen its position in 5G and beyond, e.g. for industrial applications, and become a leader in 6G influencing standards, favouring domestic IP, and capturing future business

[17] The metaverse, explained: what it is, and why tech companies love it - Polygon

opportunities. A European ecosystem approach could be developed with intense cooperation between key actors of the semiconductor value chain and the end-users of the equipment industry. European companies can leverage on key strengths in areas such as analogue and RF (radio-frequency) modules, RF-SOI and BiCMOS for high frequency modules, Gallium Nitride and Gallium Arsenide components, low-power embedded computing, power management, silicon photonics, R&D competence in various areas, including heterogeneous integration etc. On the other side there are weaknesses that need to be addressed: digital and baseband processing, manufacturing of leading-edge nodes, industrialisation of II-V materials, industrialisation of advanced packaging, insufficient presence of fabless design, software, IP and EDA companies.

*The expected rapid uptake of 5G and 6G will drive the need for III-V materials, heterogeneous integration of chiplets, edge processing. An ecosystem approach, involving key actors of the EU telecom and semiconductor industries, is needed in the near term to capture opportunities in 6G.*

## 4.5 Aerospace, Defence and Security

Semiconductors for aerospace and defence are subject to demanding requirements in terms of performance, reliability and robustness in harsh environmental conditions. Space semiconductors must resist high levels of mechanical and electrical stress during the launch (vibration, shocks) and during operations in the space (radiation, solar wind, temperature variations). In the defence sector, security is considered more important than the use of last generation products. However, new defence programmes will require more and more the access to chips manufactured on leading-edge nodes.

The importance of security of information in space and defence, but also in critical civilian applications (e.g. end-to-end secured communication), requires the development of 'trusted chips'. This implies the certification and qualification of components suited for space, defence and security applications. Driven by space missions in telecommunication, navigation and Earth observation make use of high-performance semiconductors and, therefore, require access to the most advanced technology nodes. This includes semiconductor technologies based on Silicon, but also advanced technologies making use of compound semiconductors (SiC, GaN, SiGe,…) for the implementation of critical system functions together with dedicated packaging approaches (e.g. radiation hard).

Europe's share of electronics for these markets is (22%) compared with China (24%) and North America (19%). The semiconductor market in the military and aerospace industry is estimated in USD 6.3 billion in 2020 and expected to grow by USD 3.89 billion by 2025[18], driven by factors such as increased upgrading and modernisation of aircraft. This is mainly in cockpit electronics as older systems become obsolete.

## 4.6 Energy

In the energy sector, the efficient production and transmission of electrical power is key to reaching the Green Deal objectives. Europe has particular strengths in this field. On the generation side, Renewable Energy Sources (RES) (such as wind, photovoltaic, etc.) are being deployed to gradually phase out fossil fuel generation. This renewable energy generation needs to be first adapted (inverted, converted) before being connected to the Alternating Current (AC) system. Contextually, Direct

[18] Semiconductor Market Scope in Military and Aerospace Industry. Technavio (Dec. 2021)

Current Technologies (DCT) are being demonstrated as an efficient way to transmit and distribute electrical power in complementarity with the actual AC system. Furthermore, in congested AC grids due to high RES penetration, ad-hoc equipment (STATCOM, FACTS, etc.) are appropriately placed in the grid to control and optimise energy flows.

In all the above applications, power electronics are the key elements for generation, transmission and control of energy by means of inverters, converters and other power conversion equipment and their effectiveness crucially depends on innovative power semiconductors. They represent the key enabling technology for an innovative and very efficient class of power devices suitable for a wide range of power conversion applications, in particular within the High Voltage / High Power types of devices.

New production processes with wide bandgap materials (SiC and GaN) significantly improve switching efficiency, and enable higher voltages, higher temperatures and size reduction. The Offshore Renewable Energy Strategy (60 GW of offshore wind and at least 1 GW of ocean energy by 2030, with a view to reach by 2050 300 GW and 40 GW) will lead to an increased demand for inverters and converters with improved efficiencies and capabilities. The forthcoming EU Solar Strategy stresses, amongst others, the need to accelerate the deployment of Photovoltaic (PV) energy. The grid infrastructure which will dispatch the energy to the consumption centres will grow and evolve to an AC/DC hybrid grid to face the challenges posed by the increasing RES penetration. All this will entail an increase in the number of inverters and converters deployed within the grid, with a massive use of Power Electronics.

# 5. Technology Drivers and Opportunities for the Future

## *5.1 Edge Computing*

Today, 80% of data is processed in the cloud and this market is characterised by few US companies that currently take 80% of the revenue. However, the trend is that the need for computing power at the edge (close to or on the device where data is captured or generated) is growing much faster than the demand for processing in the cloud. It is expected that in 5 years 80% of data processing will take place at the edge reversing today's balance. This represents a huge opportunity for Europe to gain a strong foothold and be at the forefront of leadership in this market.

Already there is a proliferation of so-called edge devices, e.g., smart watches, smart meters, robots, sensors and there are many potential applications, e.g., monitoring the elderly in their homes, optimisation of renewal energy sources, tracking and optimising resource use in factories, optimising pesticide and water use by farm machinery, etc. In all cases, data is collected and analysed locally, close to the device or person in question. By keeping data local, edge computing provides benefits in terms of privacy and reduces energy consumption as less data is sent to the cloud for remote processing. Linkages between application domains, e.g., renewables with EV charging, are also possible to provide further optimisation and generate new business cases.

Edge devices will get smarter and smarter as increasingly higher levels of computational power can be embedded in a device. This will result in a paradigm shift and already there are examples such as autonomous driving happening today with the trialling of ad hoc 5G networks along major highway corridors[19]. In February 2020 the European Commission adopted the Data Strategy[20] and new legislation has been proposed[21]. This naturally puts emphasis on sensors, peripheral equipment and computers used in sectors such as transport, logistics, agriculture, etc.

It is clear that Europe has strengths in systems design for key industrial sectors such as manufacturing, automotive, etc. The key differentiator in future will be in providing trusted hardware/software platforms that can support the non-functional requirements of the application domains. This is an area where Europe is a leader.

## *5.2 Artificial Intelligence*

The advent of AI has been a major disruptive element for the semiconductors industry and it will be one of the main drivers for growth until 2030. This is being driven by the use of AI in data centres, but also increasingly at the edge, e.g. autonomous cars. Beside the semiconductors market leaders such as Nvidia, Intel and Qualcomm, most technology companies such as Google, Amazon, Facebook, Tesla, Huawei, Baidu, have undertaken internal development of AI chips. New players are challenging the incumbents and important investments are being made by venture capital firms in AI chip companies in the US and China. The segment represented by chipsets for AI applications is by

[19] Cross-border corridors | Shaping Europe's digital future (europa.eu)
[20] Strategy for Data | Shaping Europe's digital future (europa.eu)
[21] Commission's Proposal for a Regulation on European data governance (Data Governance Act, COM/2020/767 final); Proposal for a Regulation on harmonised rules on fair access to and use of data (Data Act, COM/2022/68 final).

far the fastest growing in microelectronics, with expected annual growth rates above 40% for the coming years.[31] Deloitte analysts say AI will become the "next kind of superpower" for nations to compete over, and AI chips are the engine to run it. At the same time, however, deep learning models are increasing in size and complexity, requiring ever more computing power.

The quest for AI started in the 1950's, but despite advances in the following decades, computing power remained insufficient until a breakthrough appeared in 2012, when accelerators started being used for deep learning instead of CPUs. The **massive parallelization** of thousands of accelerator cores (instead of typically 4 for CPUs) suddenly provided 100 times higher computing performance, resulting in lower error rates.

**Accelerators** are capable of performing specific operations at a much higher speed than general-purpose processors. The most well-known type of accelerator is a GPU (Graphics Processing Unit), which is generally employed for rendering real-time high-resolution graphics, but now also applied to high-level parallel data processing. Beside GPUs, there is a wide variety of new dedicated architectures (ASICs) for machine and deep learning accelerators (e.g. Google's TPU: Tensor Processing Unit) which keeps expanding at a fast pace (to train neural networks). For inference (the deployment of a neural network), often programmable arrays (FPGAs) are used. Over the past few years, many new hardware solutions have emerged from both start-ups and established chip vendors optimised for deep learning, natural language processing, and other AI workloads. AI accelerators are entering in all types of computing systems from cloud to edge, from low-power devices to HPC servers.

A fundamental issue is that AI is highly demanding in terms of energy. A machine-learning task can require the power of thousands of computers equivalent to the energy produced in one hour by three nuclear plants. As AI penetrates more of our daily life, such **energy needs are not sustainable**; dedicated electronic components can be much more efficient. It is therefore necessary to share intelligence features between hardware and software. In edge AI applications, considering the massive surge of connected devices at the point of use, maximum power efficiency is essential and many AI functions have to be implemented in hardware.

For its AI needs, currently Europe depends fully on electronic components from non-EU suppliers. Industry leaders (such as Intel, Nvidia, Google, Qualcomm, Huawei) are heavily investing in pushing the limits of parallelization and reduced precision. China has a range of initiatives related to AI hardware promoting its early adoption in industry and society. In addition, the end of Moore's law (linear scaling) in semiconductors opens the way to the rise of new processing solutions and technologies (beyond Moore). Specialized accelerators based on innovative approaches are the future of computing in any type of applications from cloud to Edge AI.

Europe has strong R&D competences in novel semiconductor technologies, such as new types of non-volatile memories for In-Memory and Analogue Computing, Neuromorphic Computing, silicon photonics, and more. Europe is also home to a suitable substrate for mixing analogue and digital processing (FDSOI), a clear advantage for the integration in ultra-low power devices for edge AI. This represents an opportunity for Europe in key digital technologies: by investing in research and innovation in these fields, Europe could gain a leading position in this market, with trusted components that respect core European values in terms of privacy, security, AI explainability and environmental sustainability.

## *5.3 Increasing Security and Confidentiality Requirements*

As the world has become more digitalised and interconnected, security has become a key requirement for electronic devices from the point of view of safety, but also from the point of view of confidentiality**. Security has become a major topic across many sectors including automotive, industrial automation, communications, healthcare, aerospace and defence.** For industries such as automotive or healthcare, a security breach can lead to physical injury and/or loss of customer confidence, introducing concerns over liability.

With the introduction of GDPR[22] in Europe personal data needs to be carefully processed. With home working, people are using their own devices which may pose multiple cybersecurity challenges. Devices which are used for both business and personal use may run outdated or pirated software that hackers can exploit to access confidential and valuable business data. It is also easier to gain access to a private network. The average cost of a data breach has increased from USD 3.86 million to USD 4.24 million during 2021[23], due to people working from home. Fewer than 3% of organisations protect their employees' mobile devices.


*Figure 34. ST54J Secure Chip Using SoC for Mobile Devices (Source: STMicroelectronics)*

Cybersecurity challenges come in many forms, including ransomware, phishing attacks, malware attacks, etc. Ransomware attacks target desktops, laptops, mobile phones and smart security devices. The aim is to compromise sensitive user data in the device itself or render it unusable, or alternatively use it as gateway to other devices for other malicious attacks. As cloud services are being increasingly used for personal and professional data, they are subject to increasing attacks. In phishing attacks, user data, such as login credentials and credit card numbers, is stolen. Here the aim is not to block access but to exploit access.

At the chip level there are concerns about third-party IP or unknowns in the global supply chain that may lead to "backdoors" in devices. General approaches currently used to boot securely and to authenticate firmware are not sufficient when considering electronics deployed in cars, robots, drones, servers and medical devices. There is a need for designed-in robust hardware security (see Figure 34) considering different threats.

Designing active security into a device will impact complexity and power consumption - an issue for battery powered devices. The added complexity may also add other vulnerabilities. With complex designs making their way into automotive, medical and industrial applications, where they are expected to be used for up to 25 years, security needs to be well architected and flexible enough to

[22] General Data Protection Regulation (GDPR) – Official Legal Text (gdpr-info.eu)
[23] Alarming cyber security facts to know for 2021 and beyond - CyberTalk

respond to future security holes and more sophisticated attack vectors. **There is a need to continually innovate to guard against future new attacks.**

Designing to reduce the risk of potential hardware breaches requires a solid understanding of a chip's architecture. This includes partitioning and prioritisation of data movement and data storage, as well as obfuscation techniques and activity monitoring. As chipmakers utilise more customisation and heterogeneity, this is becoming more difficult. The drive for scaling is also driving architects to package components together. This presents challenges as not all components may be inherently secure and many customised accelerators and IP blocks are provided as black boxes.

There is thus a need for ensuring that solutions can be fully audited and checked/verified (e.g. possibility to look for back doors in open source IPs). Notably this is not possible for IPs licensed from 3rd parties. Common Criteria security certifications for simple hardware IP such as smart cards[24] exist, however, for more complex processors, security is still in its infancy and it is not possible to buy a Common Criteria certified general purpose multicore processor.

To get around this companies have to make liability limiting statements based on the hardware's documented interface. However, this may be insufficient as highlighted by **the Spectre/Meltdown vulnerabilities which appeared in 2018 which were unexpected for almost all OS vendors.**

EU Member States agreed to "work towards common standards and, where appropriate, certification for trusted electronics, as well as common requirements for procurement of secure chips and embedded systems in applications that rely on or make extensive use of chip technology."[25] **Reference certification procedures for specific critical sectors and technologies with potential high social impact are necessary**[26]. Certification of these chips for trust and security should cover the value chain up to integration in end products and should be reflected in public procurement and promoted in international standardisation activities.

## *5.4 Environmental Sustainability*

The increasing digitalisation of industry can help in saving energy and reducing deployment of resources. For example, the concept of using digital twins in industrial production allows to reduce power consumption and to minimize production of scrap as results can be better anticipated. In electricity grids, the massive deployment of smart meters and IT-based balancing of decentralised supply and demand helps to make large savings. Semiconductor devices are at the basis of these IT systems, and much more will be needed in the future.

As digital systems are increasingly deployed in sectors where they were not common before, such as construction or retail, the power consumption of IT itself is increasing. Today, the Information and Communications Technology (ICT) sector is responsible for 5-9% of the world's total electricity use and more than 2% of GHG emissions. The demand for semiconductor technologies is expected to double over the next decade and will bring energy and resource savings in the applications it controls. It is essential that newer approaches and technologies which are targeted in the proposed Chips Act

[24] https://www.sogis.eu/documents/cc/domains/sc/JIL-Composite-product-evaluation-for-Smart-Cards-and-similar-devices-v1.5.1.pdf

[25] Joint declaration on processors and semiconductor technologies | Shaping Europe's digital future (europa.eu).

[26] Regulation (EU) 2019/881 of the European Parliament and of the Council of 17 April 2019 on ENISA (the European Union Agency for Cybersecurity) and on information and communications technology cybersecurity certification and repealing Regulation (EU) No 526/2013 (Cybersecurity Act)

must be ever more efficient to reach lower overall energy consumption and reduce its impact on the environment.

As we will point out in section 6.1, new generations of microprocessor chips in general consume 30% less power compared to the preceding one. Concretely, Europe is the leader in the Fully Depleted Silicon on Insulator (FDSOI) chip architecture that has major benefits for advanced and future technology nodes, allowing faster switching speeds, reduced power and a simpler manufacturing process. This delivers a greatly improved power/performance/cost trade-off compared to alternatives such as both bulk and FinFET technologies, which has led to its adoption in automotive, smartphones and many other battery-powered devices.

The efficient production and transmission of electrical power is becoming more important. With the green transition, reliance on combustion of fossil fuels (coal, gas, oil etc.) for power generation and heating must go down. This is only possible with the increased use of alternative power sources for electricity generation (photovoltaics, wind turbines) and new uses such as electric cars, heat pumps etc. Power semiconductors and power electronics are indispensable elements to make this happen. The effectiveness of power inverters and converters crucially depends on innovative power semiconductors. New production processes with new materials (SiC and Gallium Nitride) promise to significantly improve switching efficiency.

The production of semiconductors is itself a resource-intense process. High cost of resources together with the need to reduce the environmental impact has driven the semiconductor industry for decades already to consider the total life cycle of chips. Usage of energy, water, raw materials and release of fluorinated greenhouse gases during semiconductor manufacturing are key concerns, and so sophisticated methods have been developed to work in closed cycles as far as possible.

The environmental impacts of semiconductor production in the EU are regulated, inter alia, by Regulation (EU) No 517/2014 on fluorinated greenhouse gases (F-gases). F-gases are human-made chemicals that are very strong greenhouse gases (GHG), often several thousand times stronger than carbon dioxide (CO2). Under the F-gas Regulation, the semiconductor industry sector is covered by a prohibition to intentionally emit F-gases as well as requirements to take technically and economically feasible measures to minimise unintentional ("leakage") of these gases. In its review of the F-gas Regulation (COM(2022) 150 final) the Commission proposes to reinforce provisions on unintended leakage and require also that emissions must be prevented for nitrogen trifluoride (NF3), a compound also used in the semiconductor manufacturing process.

While the production of semiconductors uses some of the F-gases with the highest global warming potential (e.g. trifluoromethane (HFC-23), perfuorocarbons (PFCs), nitrogen trifluoride (NF3), sulphur hexafluoride (SF6) etc.), the quantities are modest amounting to about a few percent of total current F-gas emissions in the EU[27].

Generally, the EU semiconductor industry is taking stricter measures during its manufacturing processes to prevent emitting F-gases compared to other world regions. The sector is claiming to have made substantial investments to implement reduction practices at operations across Europe. The European Semiconductor Industry Association (ESIA) estimated in 2021 that the industry had

[27] See Impact Assessment to: *Regulation (EU) No 517/2014 of the European Parliament and of the Council of 16 April 2014 on fluorinated greenhouse gases and repealing Regulation (EC) No 842/2006 Text with EEA relevance:* https://ec.europa.eu/clima/document/download/9013881e-8d5d-429e-9112-c908f127c833_en?filename=f-gases_impact_assessment_en.pdf

achieved a 42% absolute emission reduction of PFCs between 2010 and 2020[28]. If looked at from a global perspective, an increased and significant production of semiconductors in the EU while minimising where possible emissions, is likely to save emissions from F-gases at global scale.

The semiconductor chips themselves do not pose a serious waste problem, as they consist mainly of silicon (typically 99,5% and more) which is hermetically sealed in an inert package. Yet this is different for the electronics boards on which the chips are mounted, to power smartphones for example. These generate electronic scrap after their lifetime, with diverse toxic substances such as cadmium, lead, lead oxide, antimony, nickel, beryllium, barium, chromium and mercury, which may pollute rivers, lakes and seas, and release gases into the atmosphere that upset ecosystems. The recycling of these electronics components is important and regulation to deal with it is in place[29]. At the chip level, methods to prolong the life of chips and equipment and to investigate ways to recycle key materials in order to reduce electronics waste should be considered already at the design stage.

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28 https://www.electronicspecifier.com/industries/alternative-energy/european-fluorinated-greenhouse-gas-emissions-cut-by-42

29 Directive on **waste electrical and electronic equipment** EUR-Lex - 02012L0019-20180704 - EN - EUR-Lex (europa.eu)