Discussion Paper

Semiconductor Strategy for Germany and Europe

The current situation, analysis, and goals

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Semiconductor Strategy for Germany and Europe

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Preliminary Remarks

This paper aims to outline further steps towards a comprehensive, longterm, sustainable, and effective strategy to strengthen the semiconductor industry in Germany and Europe. It is intended to highlight the industry's potential to address societal, environmental, and economic challenges. It does not claim to be exhaustive and is deliberately formulated as a basis for discussion and a "work in progress." It is intended to be a starting point for further exchanges, in which all stakeholders interested in the semiconductor industry should participate to unleash its potential in and for Europe. It delivers first ideas for the newly founded Semiconductor Alliance and the announced European Chips Act.

The paper is a contribution to the discussion, but not a coordinated "positioning" of ZVEI or the related industry. In contrast to the current concrete planning of the IPCEI on Microelectronics and Communications Technologies, which is only partially addressed in this paper, this Discussion Paper outlines a longterm version for the microelectronics ecosystem in Europe.

Executive Summary

The existence of an efficient, innovative, resilient, and sustainable semiconductor industry is in the strategic interest of Germany and Europe. The semiconductor industry plays the important role of supplying the downstream industries. Its progressive and targeted expansion contributes indispensably to a high degree of technological sovereignty and to the achievement of social, economic, and ecological goals. Research and development in industry is crucial to create IP, products, and system solutions, and needs an expansion of appropriate policy instruments. In addition, there is a lack of adequate framework conditions to support the improvement of existing production and the expansion of future capacities in Germany and Europe beyond the Important Projects of Common European Interests.

In the global context, close mutual networks have grown from the complex value creation networks of the semiconductor industry over decades. On the one side EU and German policy must avoid the emergence of onesided dependencies, but on the other side we cannot use this as an argument for autarkic structures. Rather, together with a strong semiconductor industry, Europe's interests must be implemented through functioning international trade relations and, at the same time, a high degree of industrial resilience must be realised to ensure independent decisionmaking. To achieve this, the existing technological strengths in Germany and Europe must be expanded and weaknesses must be addressed in a targeted manner.

The guiding principle must be that the strategic course set by the semiconductor industry in the next decade be integrated into the interest of society to progress with digitalisation and sustainability and thus necessarily into an industrial policy strategy. This requires the continuation of the intensive and integrative dialogue between politics and industry at the German and European level, which will lead to the timely implementation of ambitious projects in the field of microelectronics. Microelectronics components necessary for business continuity in current and future key German and EU manufacturing sectors must be placed at the centre of industrial strategies much more strongly than before and not be treated solely in the context of R&D funding structures.

Content

1 The Semiconductor Industry – Myth and Reality

Semiconductors are among the most complex products created by human ingenuity. Semiconductors, or chips, are microelectronic components that come in the most diverse shapes and designs and are used in a wide variety of applications. From 2014 to 2020, the global market grew from 336 to 466.2 billion US dollars[1], representing annual average growth of 4.2 percent. Over the next few years, growth is expected to reach 5.2 percent annually. This growth will be fuelled by greater electrification, connectivity, and digitalization of nearly all areas of human life – electromobility, Industry 4.0, energy efficiency, education and health are just a few examples. Semiconductors create the basis for new technologies and have therefore become the focus of public attention. This attention from society is positive.

To deal with the global and regional framework conditions of the semiconductor industry, a basic understanding of both the manufacturing process and the prevailing global division of labour and increasing capital intensity is necessary. Therefore, the complexities of manufacturing need to be addressed first. Semiconductors are not products that can be manufactured easily and quickly in mass quantities. The following figure (1) illustrates this process, which consists of circuit design/chip design -> production -> test -> assembly -> test -> supplier -> original equipment manufacturer.

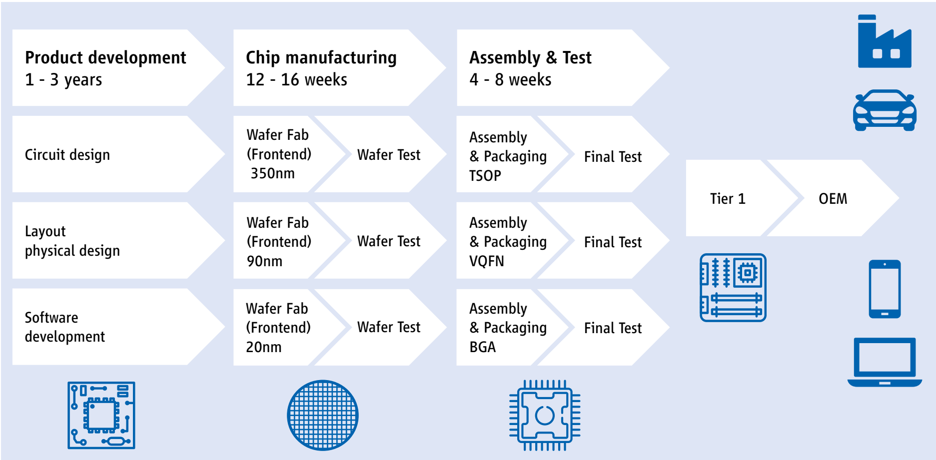


Figure 1: "Process from chip design to original equipment manufacturer" (source: ZVEI)

This illustration already shows that many individual process steps are necessary to design, manufacture, test, and deliver a chip to the respective customer. This process does not take place in a single production facility in one specific region, but usually involves a global supply chain network. This division may involve different companies or be carried out within a single company at different locations around the world. On average, a chip travels around the world several times before the microelectronic component required by the customer can be delivered in the specified quality. The time frame from circuit design to delivery of the final product is as follows:

- Technology development and design: approx. 1 - 3 years
- Production from start to delivery: approx. 4 months

Therefore, the production of semiconductors cannot be ramped up or down on short notice but requires very careful production and logistics planning. Nor are there any "standby" capacities, since semiconductor factories, socalled fabs, can only be operated economically with a capacity utilisation of more than 85 percent, and they regularly reach this level. It is only possible to react spontaneously to shortterm fluctuations in demand to a very limited extent.

It should be noted that the semiconductor industry is characterised by highly complex production chains and dependent on other upstream and downstream value chains. Upstream chains are found in production facilities and materials as well as the necessary chip design infrastructure (EDA, etc.). The downstream chains refer to the user industries.

[1] https://www.gartner.com/en/newsroom/press-releases/2020-04-12-gartner-says-worldwide-semiconductor-revenue-grew-10-4-percent-in-2020

2 Political Framework Conditions of the Semiconductor Industry in Germany and Europe

Due to its strategic importance, the semiconductor industry has received increased political attention worldwide in recent years. In the following subchapters, the existing political instruments of Germany and the European Union (EU) for supporting the industry will be discussed, and new industrial policy concepts examined to see to what extent they could have a direct or indirect influence on the semiconductor industry.

2.1 Technological Sovereignty

The term “technological sovereignty” has become a leitmotif of political action in Germany and Europe in recent years against the backdrop of geopolitical changes. The definition used by the German Federal Ministries (ability to understand, produce and further develop key technologies) is appropriate. Technological sovereignty is not synonymous with autarky. In this context, reference should also be made to the ZVEI paper on the distinction between technological sovereignty and resilience[2]. The existence of an efficient and sustainable semiconductor industry in Germany and Europe is a core component of technological sovereignty.

2.2 The European “Green Deal”

One of the European Union’s priority goals is to be climate neutral by 2050. To this end, the European Commission launched the “European Green Deal” in December 2019. The measures envisioned in the Green Deal Action Plan[3] relate to a large number of legislative and political measures. In particular, the Green Deal foresees the following concrete initiatives:

- Investment in new, environmentally friendly technologies
- Supporting industry to innovate
- Introducing greener, cheaper, and healthier forms of private and public transportation
- Decarbonising the energy sector
- Increasing the energy efficiency of buildings

Only through the ambitious development of technologies, especially in the automotive, energy and industrial sectors, based on innovative semiconductor applications, can the implementation of the Green Deal be successful. All bullet points listed require the development of energyefficient technologies, the intelligent networking of actors and the expansion of a sustainable infrastructure. This is not possible without semiconductors. Therefore, the expansion of research and production capacities in the semiconductor industry in Europe is of key public interest.

2.3 The European Taxonomy Regulation

The EU Regulation (EU) 2020/852[4] [“establishing a framework to facilitate sustainable investments and amending Regulation (EU) 2019/2088”] adopted in 2020 is of fundamental importance for the European manufacturing industry. This regulation is aimed at ensuring that sustainability is made measurable.[5] The regulation is aimed not only at companies but also at their investors. With it, the EU is introducing the world’s first “green list” for sustainable economic activities. This means – as the European Commission proclaims – “a new common classification system with uniform terminology that investors everywhere can use when they want to invest in projects and economic activities with significant positive climate and environmental impacts.”[6] Microelectronics components are necessary for business continuity in current and future key German and EU manufacturing sectors for achieving the goals of the Green Deal and the taxonomy regulation must be seen and evaluated in its context. However, it can already be claimed at this point that the objectives of the Taxonomy Regulation can be an interesting component in the question of future funding structures for microelectronics in Europe.

[2] https://www.zvei.org/en/press-media/publications/technological-sovereignty-industrial-resilience-and-european-competences
[3] https://eur-lex.europa.eu/legal-content/DE/TXT/?qid=1596443911913&uri=CELEX:52019DC0640#document2
[4] https://eur-lex.europa.eu/legal-content/DE/TXT/PDF/?uri=CELEX:32020R0852&from=EN
[5] C.f. https://www.bafin.de/SharedDocs/Veroeffentlichungen/DE/Fachartikel/2020/fa_bj_2008_Taxonomie-VO.html
[6] C.f. https://www.bafin.de/SharedDocs/Veroeffentlichungen/DE/Fachartikel/2020/fa_bj_2008_Taxonomie-VO.html

2.4 Current Funding Structures

Considering the political, socioeconomic, and ecological added value of an innovative semiconductor industry in Germany and Europe that could be created by expanding research and production capacities, a brief analysis of the existing funding structures follows.

2.4.1 IPCEI

Microelectronics was the first industrial sector in which an "Important Project of Common European Interest" according to Article 107 (3)b TFEU (Treaty on the Functioning of the European Union) was applied. This allowed the initially four, now since Austria's accession five, participating EU Member States to allocate direct state aid to projects in the microelectronics sector, which contributed € 1 billion for Germany alone. Preparations are currently underway for a new IPCEI for Microelectronics and Communication Technologies (ME/CT), which, from the point of view of industry and the German Federal Government, should include state aid of € 4.5 billion and total investments of € 15 billion in Germany alone. It is of crucial importance to conclude the negotiations for a new IPCEI ME/CT in a timely manner and to ensure adequate funding as well as a quick start of the project.

Nevertheless, it must be critically noted at this point that even an IPCEI ME/CT will only permit state aid for the expansion of semiconductor production to a very limited extent. On the part of the European Commission, it is becoming apparent that the scope of application of IPCEIs will continue to be handled restrictively and will therefore only be applied in research and development (R&D) and first industrial deployment[7] (FID).

2.4.2 Horizon Europe – Key Digital Technologies Partnership (KDT)

Following the success of the ECSEL Joint Undertaking in the Horizon 2020 research framework programme, the field of electronic components and systems will also be included in the new Horizon Europe framework programme.[8] The strategic importance of microelectronics is underscored by the fact that it is included in the framework programme as one of 10 sectors within the framework of an integrated partnership. It is expected that significant R&D progress will be made in the following areas announced by the Commission during the planned term until 2027:

- Provision of innovative electronic components and systems, software and intelligent integration in digital value chains, provision of secure and trustworthy technologies tailored to the needs of user industries and citizens. This will help to strengthen Europe's innovation power.
- Develop and apply technologies to overcome major global challenges in mobility, health, energy, security, manufacturing, and digital communications. This will contribute to and strengthen Europe's scientific and technological foundations.
- Better focus of R&D and industrial policies on a common approach to mastering these drivers of innovation.

2.4.3 Microelectronics Framework Programme

In addition, the Microelectronics Framework Programme[9], which was launched by the German Federal Ministry of Education and Research last year and primarily emphasises the topic of trustworthiness and sustainability, also deserves to be addressed. This focus is of eminent importance to the current situation – only if electronics are trustworthy, if they are understood and innovatively developed and produced in Europe, cooperation with non-European regions can be continued and expanded on an equal footing. The dimension of trustworthiness is a new concept leading to further requirements in the promotion of microelectronics and is actively supported by industry with great interest and commitment.

[7] C.f. https://ec.europa.eu/competition/consultations/2021_ipcei/index_en.html
[8] https://digital-strategy.ec.europa.eu/en/news/key-digital-technologies-new-partnership-help-speed-transition-green-and-digital-europe
[9] https://www.bmbf.de/files/rahmenprogramm-mikroelektronik-2021-2024.pdf

Furthermore, the EUREKA Clusters Programme (ECP) is a longterm initiative that supports strategically important research, development, and innovation (R&D&I) topics in close cooperation with national authorities to create economic strength and societal benefits for participating countries. We welcome the BMBF's supports for excellent projects that demonstrate a high level of innovation in significant key technologies, especially the support for the Xecs cluster. The strategic goal of the Xecs cluster is to strengthen the position of European industry in (micro)electronics and electronic systems.

2.4.4 Summary

Overall, it can be said that the three funding structures outlined above are appropriate and suitable for strengthening the innovative capacity of microelectronics in Europe in a sustainable and meaningful way. The instruments recognise the strategic role of microelectronics for Europe's technological sovereignty as well as for the implementation of the goals of the Green Deal. Therefore, all three instruments need to be adequately resourced to reflect the political ambition in concrete terms.

However, it is equally obvious that none of these instruments has a focus on the creation of new or the improvement of existing production capacity. Given the expected global growth of the semiconductor sector in the coming decade, this is a serious gap in the European strategy that urgently needs to be closed. The instruments hardly contribute to achieving the EU Commission's recently formulated goal of doubling the production of semiconductors in Europe by 2030 (see "2030 Digital Compass"). This challenge is visualised in the following figure (2):

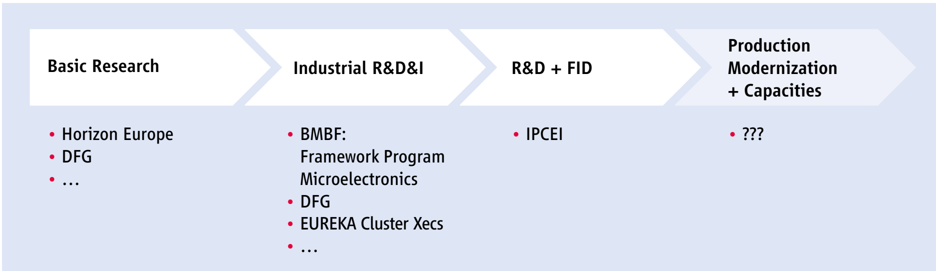


Figure 2: Current funding structure in Germany and Europe (source: ZVEI)

2.5 Europe's Digital Decade – 2030 Digital Compass

Against this backdrop, the Communication "Europe's Digital Decade: Digital Goals for 2030" presented by the European Commission on March 9, 2021,[10] is an interesting basis for the development of new and the innovation of existing production capacity. The Communication sets out the EU Commission's objectives for increasing the production of "avantgarde semiconductors" in Europe. The EU Commission intends to propose measures to increase the global share of semiconductors produced in Europe from the current level of less than 10 percent to 20 percent by the end of the decade. Although this is an ambitious target, this industrial policy goal is constructively supported by the semiconductor industry manufacturing in Europe with the recommendation to secure design and production capabilities and room for innovation. The "Next Generation EU" programme with the Recovery and Resilience Facility (RRF) should provide the necessary funds by 2027 to pave the way for successful implementation beyond this period. A concerted effort of the European Union, the Member States, the semiconductor industry as well as the downstream industries in Europe is needed. This is especially true because the recovery plans of individual Member States to achieve this goal have already made detailed allocations of funds. Since money cannot be spent twice, it seems indispensable to create new funding instruments that are specifically aimed at expanding production capacity and that allow for targeted funding through 2030.

[10] https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_de

It is now important to analyse the initiatives mentioned in the Communication and translate them into an action plan. An initial assessment of the concept suggests the following target:

- Objective: Increase the production of semiconductors in Europe.
- Tool: Flagship "scale up" as far as available using the Recovery and Resilience Facility, or new funding structures to be created, which should be used to close gaps in identified critical capacities in the EU.

To illustrate the scale of such an undertaking, let us look at the recently announced investments by TSMC[11] and SK Hynix[12]:

- TSMC: $100 billion for new semiconductor plants over the next three years.
- Hynix: $106 billion for four new fabs.

IC Insights estimates that, given the large technology and capacity advantage of companies like TSMC and Samsung, the EU, the USA, and China would each need to invest USD 30 billion per year over a five-year period to catch up with the market leaders[13]. This applies to digital Si CMOS (complementary metaloxide semiconductor) processes and does not consider the sum of the semiconductor technologies required for innovative products developed and manufactured in Europe. Analogue radio frequency (RF) technologies such as SiGe hetero-junction bipolar transistors (HBTs) and compound semiconductors are also indispensable. While Europe is well positioned in SiGe HBT technology, there is a technological dominance of the USA in compound semiconductors (GaAs, GAN, InP). In addition, chips made from compound semiconductors such as amplifier MMICs (Monolithic Microwave Integrated Circuits) are often subject to corresponding export restrictions and thus dependencies.

The Digital Compass sees semiconductors, especially processors, as enablers for connected mobility, edge and quantum computing, artificial intelligence, and other applications. The main subject of further and deeper analysis of the objective of increasing production mentioned in the Communication must therefore be on which types of semiconductors are specifically required to achieve the ambitions of the Digital Decade and other initiatives such as the Green Deal, and which are to be designed and produced in Europe. To do this, it is necessary to look at the existing value creation networks and the structure of the downstream industries.

[11] https://www.bloomberg.com/news/articles/2021-04-01/tsmc-to-invest-100-billion-over-three-years-to-grow-capacity

[12] https://www.reuters.com/article/us-sk-hynix-investment/sk-hynix-plans-to-spend-107-billion-building-four-memory-chip-plants-idUKKCN1QA073

[13] https://www.semiconductor-digest.com/2021/03/17/samsung-and-tsmc-seeking-to-spend-their-way-to-worldwide-domination-of-advanced-ic-technology/

3 Economic Framework of the Semiconductor Industry in Europe

3.1 Complex Global Value Creation Networks

As briefly explained above, the semiconductor industry is characterised by complex global production and value networks. Therefore, it would be wrong to assume that the regionalisation of value creation from design and production would represent a sensible alternative to the current global structures.

According to a Boston Consulting Group (BCG) study[14], setting up a closed value chain in a region would require investments of about € 1 trillion and lead to a significant increase in the price of microelectronics in the range of 35 to 65 percent, as well as at least slowing down its use in the identified future technologies. Consequently, topics with great political, ecological, and socioeconomic significance that can to a large extent only be addressed by means of technological innovation could not be translated into concrete initiatives. Microelectronics must not only be efficient, crisisproof, available and sustainable, but also affordable. This applies not only to Europe, but especially to those countries in which digitalisation has not yet made significant progress.

To achieve sustainability goals (e.g., the UN Millennium Development Goals), digitalisation must be accelerated, because the global "digital divide" cannot be allowed to deepen any further. A discussion in the direction of regional isolation and de facto autarky not only fails to recognise the unrealisable economic effort required to create such structures, but also jeopardises all sustainability goals developed through global and European political cooperation, insofar as they are to be achieved through technological innovation.

3.2 Dependencies or Networks?

Global value creation networks are therefore a prerequisite for an innovative, efficient, and marketeconomically successful semiconductor industry in Europe. However, the question arises to what extent these networks need to be adapted to avoid onesided dependencies.

75 percent of the world's semiconductor production capacity is in East Asia. Therefore, we are somewhat dependent on this region. The skills to execute these technologies are limited outside Taiwan and South Korea. For compound semiconductors, there is an analogous dependence on the USA. According to estimates in the BCG study (see above), it would take more than 3 years and an investment of more than € 350 billion to replace the Taiwanese foundries with other foundries.

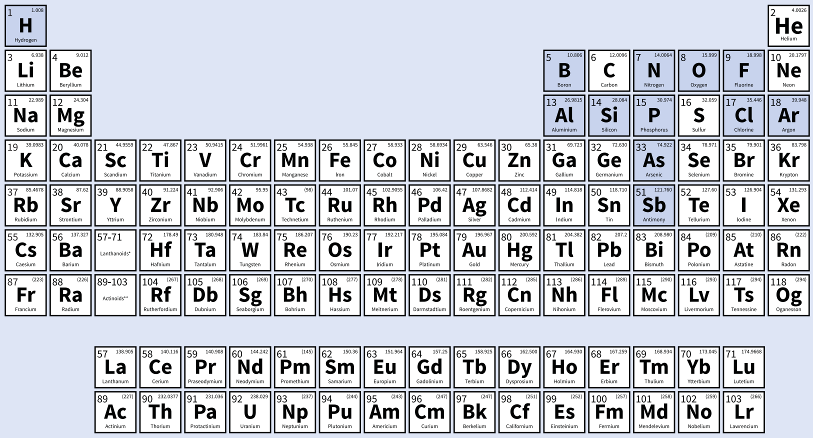
This assessment should give reason to consider further diversifying and more intelligently networking global industrial structures. This must be based on a thorough analysis of the vulnerable points in the value chain, whereby it must be noted that this analysis is primarily the task of the industry including the individual companies along the value chain. The results of this analysis form the basis for possible concrete measures within the framework of a strategic industrial policy. The current structure of the semiconductor industry, and the one that needs to be improved, is one of mutual networking or a high degree of international vertical integration. This is a prerequisite for innovation and a permanently available supply of highperformance microelectronics.

The progress in R&D and its transition into mass production is documented by the broader range of IC materials, i.e., the increase in the number of atomic elements from the periodic system from 12 to 60 within 20 years. This becomes clear in figure (3).

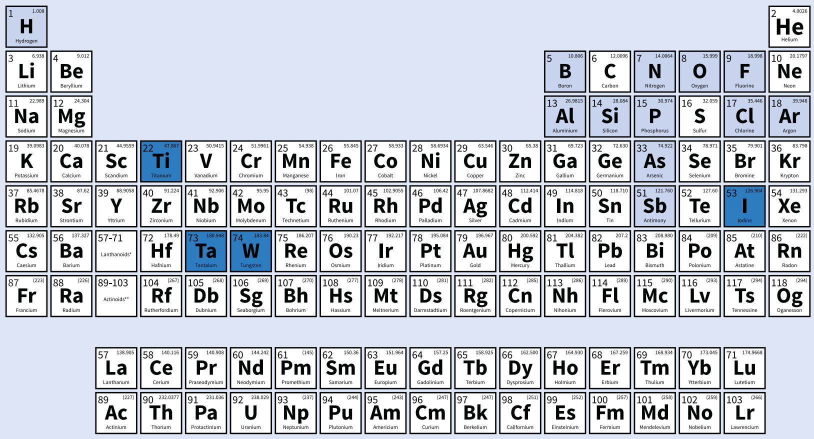
[14] https://www.semiconductors.org/study-identifies-benefits-and-vulnerabilities-of-global-semiconductor-supply-chain-recommends-government-actions-to-strengthen-it/

The number of elements in semiconductors has quadrupled since the 1980s

1980s 12 elements



1990s 16 elements



2000s 60 elements

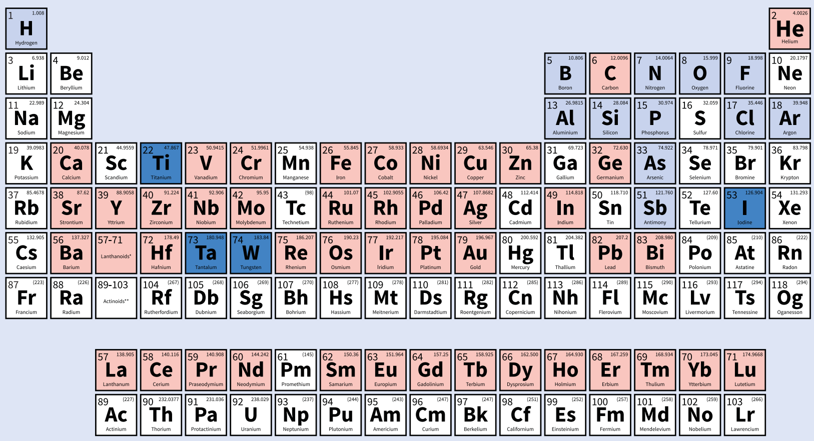


Figure 3: "The number of elements in semiconductors has quadrupled since the 1980s" (source: ZVEI)

Over the last thirty years, the number of elements used in semiconductors, especially in the silicon semiconductor devices shown here, has quadrupled. Thus, there is almost no element occurring in nature that is not used to produce semiconductors, either as a process raw material or as a product material. This can also be seen in figure (4).

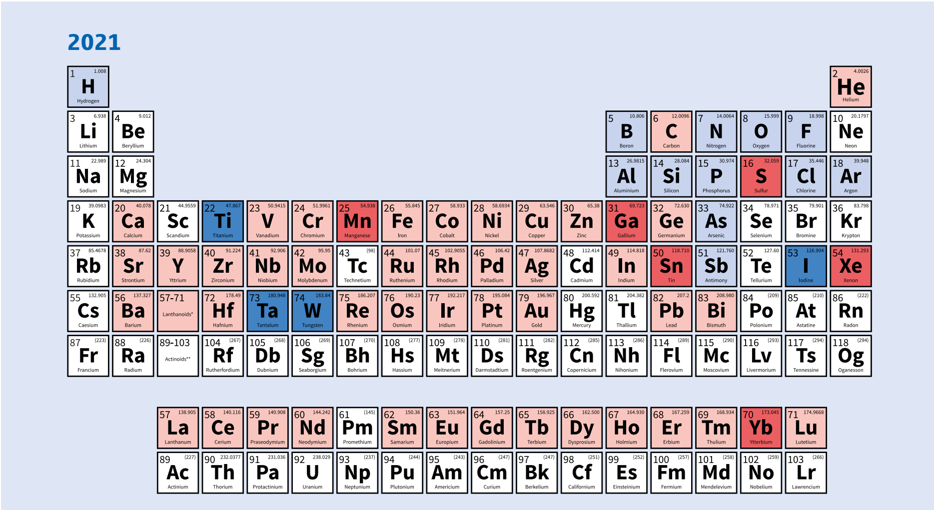


Figure 4: "New elements for semiconductors since 2000 (in red)" (source: ZVEI)

This means that the dependence on the world raw material markets must be accepted as a given and cannot be changed politically, even if there are efforts to achieve more extraction in Europe. A concept of greater autonomy in semiconductor production is thus already limited. Instead, the need for reliable, transparent, and responsible access to these raw materials must be considered through continuing open global value chains. The free availability of raw materials is of great importance not only for the EU semiconductor industry and should be a general objective of European foreign and trade policy.

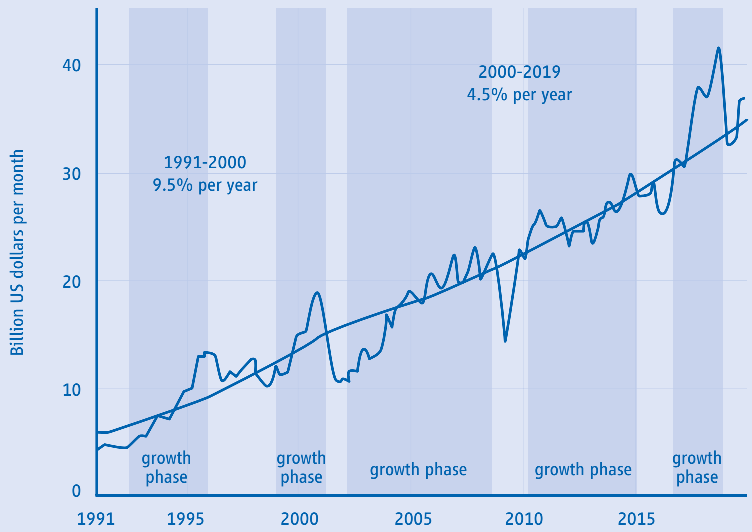
Another issue is the dependence on business strategies in supply industries such as the chemical industry. In the current political discourse, the terminology of dependency is connoted with perceived geostrategic dependencies. However, investment decisions of supplier industries located and manufacturing in Europe could have a direct and noticeable impact on semiconductor production. This regularly becomes clear when, for example, the production of raw chemical materials is relocated from Europe to other regions, thereby putting established supply chains into question. It can be left open whether these decisions by the supplier industry are made because of stricter legal regulations (keyword REACH) or comparatively low demand compared to Asian regions, or perhaps for both reasons. It remains to be said that this topic cannot be disregarded in a comprehensive analysis of the dependencies that apply for the semiconductor industry.

3.3 Different Parameters of Market Share

An important indicator in the public discussion about the semiconductor industry is the respective market share by region. Not all media publications correctly show the market reality of the semiconductor industry. Production locations should not be used as a direct indicator of market share. In this context, reference should be made to the annual trend analysis of the ZVEI. Figure (5) shows the development of the general semiconductor market up to the year 2021 and Figure (6) shows semiconductor production by company location (excluding foundries).

Continuous growth

Monthly trend global market for semiconductors (3-month moving averages)

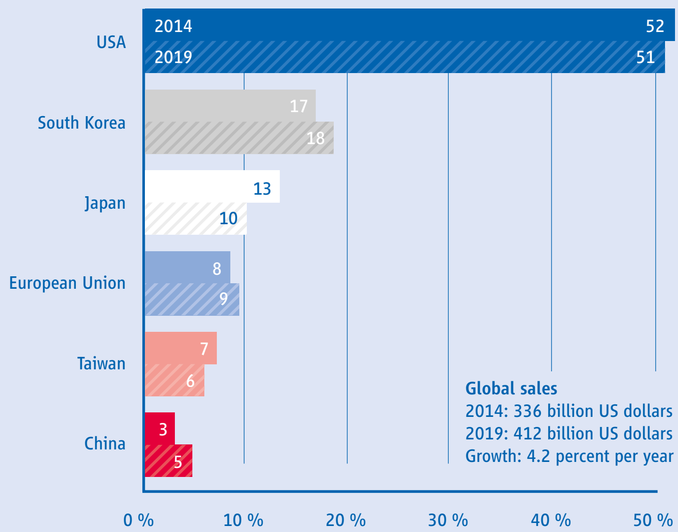


- Biggest slump in the history of the global microelectronics market in February 2009
- Only 13 months later, 3/2010, the peak value from September 2008 was reached again.
- After moderate development, very high growth in 2017 (+21.6 percent) and 2018 (+13.7 percent), largely driven by storage
- Growth excluding storage 9.9 percent in 2017 and 7.8 percent in 2018
- Significant decline in growth since Q4 2018; 2019 -12.1 percent (excluding storage decline -1.7 percent)

Figure 5: "Development of the general semiconductor market up to the year 2021" (source: ZVEI)

Semiconductor manufacturing in 2014/2019

Distribution of production by country based on headquarters
(Sales in US dollars, excluding foundries)



- Semiconductor manufacturers from the US continue to dominate the global market
- Slight increase in South Korea and the European Union
- Share in Japan continues to decline; slight decline in Taiwan as well
- Good growth in China
- With the EU taken as a unit, companies from only six countries are significantly involved in manufacturing. They account for a 99 percent share of global production

Figure 6: Semiconductor production by company location (excluding foundries). (source ZVEI)

This does not mean that more than half of the semiconductors are produced in the USA, but by companies whose headquarters are in the USA. In fact, only 12 percent of all chips produced worldwide still come from the USA, the motherland of the transistor. All US companies produce worldwide, including in Germany and other European countries. Therefore, this chart does not allow any statement about production locations. The following figures (7), (8) and (9) will be used to clarify the situation.

Figures (7) and (8) show, on the one hand, the monthly wafer production capacity in the regions and, on the other hand, relatively the distribution of production capacities among the regions.

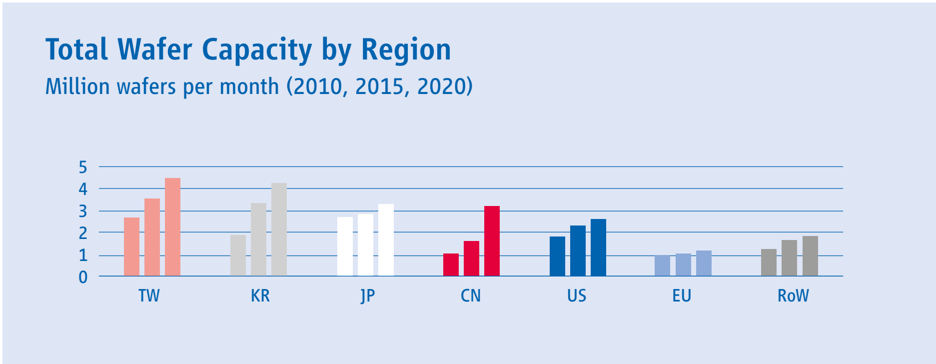


Figure 7: "Total wafer capacity by region (2010, 2015, 2020)" (Source: Stiftung NV: The lack of semiconductor manufacturing in Europe, 2021[15])

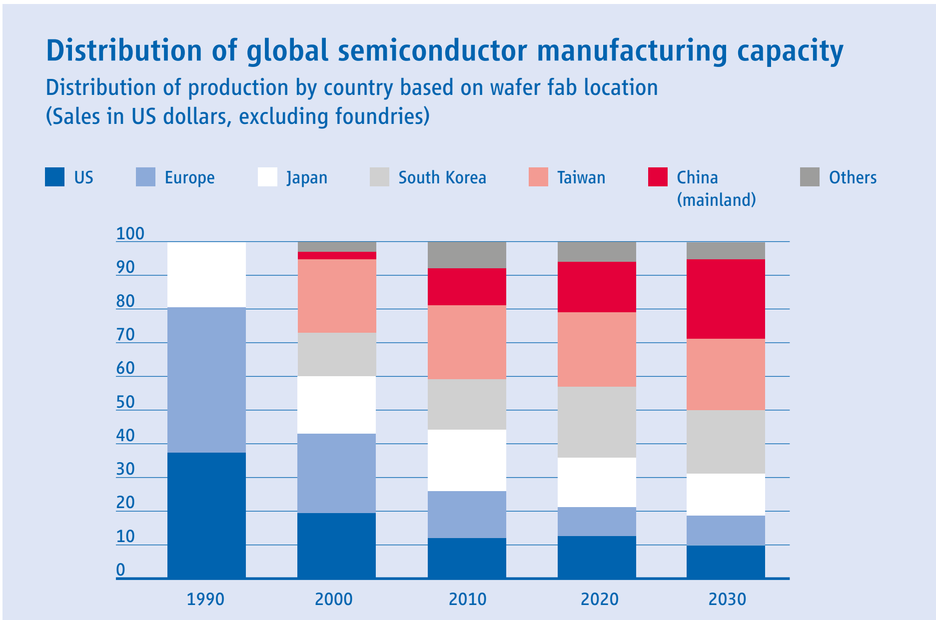


Figure 8: "Relative distribution of global semiconductor manufacturing capacity"
(Source: „Government Incentives and US Competitiveness in Semiconductor Manufacturing" by Boston Consulting Group & Semiconductor Industry Association[16])

[15] C.f. https://www.stiftung-nv.de/de/publikation/lack-semiconductor-manufacturing-europe

[16] C.f. https://www.semiconductors.org/wp-content/uploads/2020/09/Government-Incentives-and-US-Competitiveness-in-Semiconductor-Manufacturing-Sep-2020.pdf

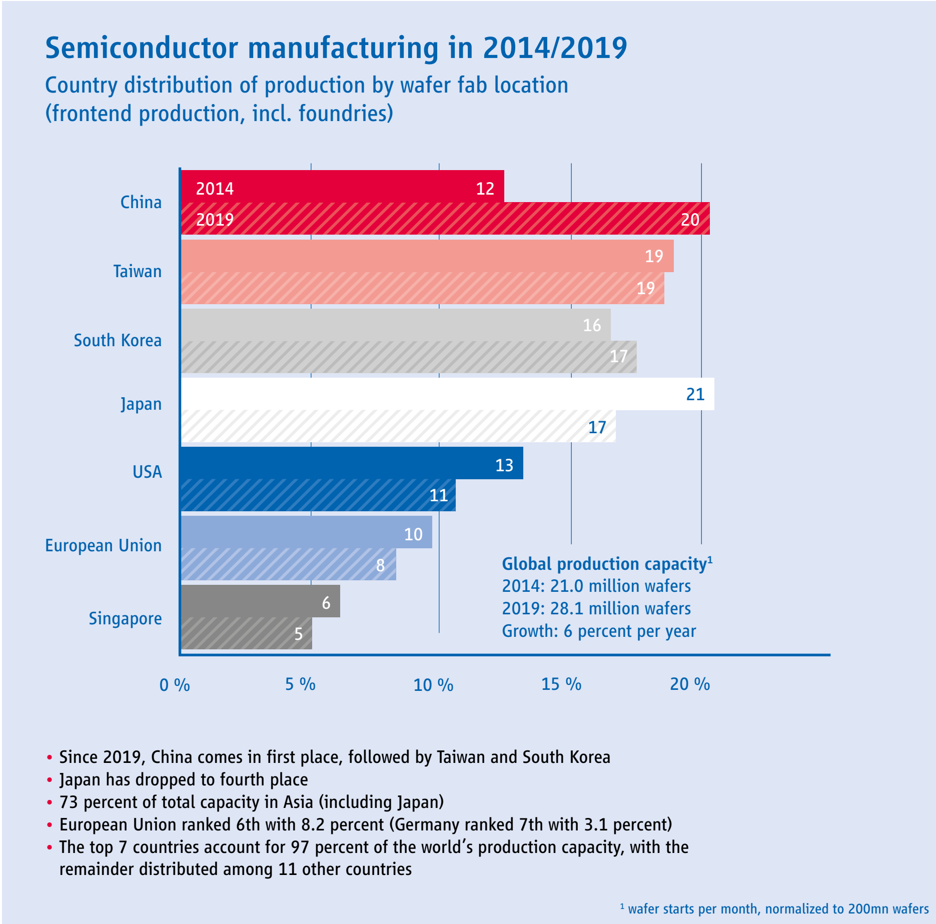


Figure 9: "Production capacity by wafer fab location (including foundries)" (source: ZVEI)

Regarding China, the share of China-based firms (excluding foundries) is 5 percent (C.f. figure 6). The strong increase in production capacity in China is primarily due to foreign direct investment, i.e., production in China is primarily by non-Chinese companies, and the growth of Chinese foundries. These include companies based in Europe, the USA, and other regions. An inference that 20 percent of global semiconductors are manufactured "by China" and that this results in a onesided dependence is inadmissible. Although the current data collection[17] allows statements to be made about the general "Chinese share" in the production facilities of companies from South Korea, Taiwan, the USA, and the EU compared to companies based in Mainland China, no reliable data can be collected regarding the actual distribution of production output. A working group within ZVEI has begun to examine the existing data for corresponding analysis possibilities, since a solid statement about this "split" is of eminent importance in the realistic assessment of China's role in global production.

[17] https://en.wikipedia.org/wiki/List_of_semiconductor_fabrication_plants

3.4 The Concept of "Open Strategic Autonomy" and "Resilience"

At first sight an oxymoron, the concept of "open strategic autonomy" is the leitmotif of the EU's new trade policy[18]. It will be crucial in the coming months and years to develop the concept in a direction that allows for a balance between "openness" and "autonomy." It requires the greatest political sensitivity to place the concept of autonomy in an appropriate perspective and in a historical, political, social, and economic context. The term "autonomy" should not be developed in the direction of isolation and autarky. Current and future geopolitical challenges must be addressed decisively. However, they should only be a reason for any restrictions on global industrial networking as a last resort, especially against the backdrop of the economic reality of the semiconductor industry outlined above.

At the same time, one must prevent too much openness from leading to a lack of "resilience" of European value chains, as can already be observed to some extent today. The concept of "resilience" bridges the gap between the poles of "openness" (and thus our embedding in global production and trade networks) and the necessary "strategic autonomy." In the words of the German Federal Ministry of Economic Affairs and Energy: "Digital sovereignty and digital resilience are indispensable prerequisites for selfdetermined, innovative action by business and government, not only for problemsolving in times of crisis, but also for implementing longterm policy strategies [...][19]."

When it comes to microelectronics in concrete terms, Germany and Europe must be able to ensure their industrial and state actors a high degree of independent capacity to act in conflict and crisis situations. Besides a broad R&D base, this also includes the ability to procure critical microelectronic components in a crisisproof manner – be it from their own production or through supply chains that cannot be manipulated politically or otherwise. Such resilience must be achieved primarily through close cooperation along semiconductor value creation networks and between the semiconductor and downstream industries[20]. Political measures can flank this cooperation.

The focus of political action should therefore be on developing concepts together with industry that sustainably strengthen the entire "semiconductor ecosystem" in Europe and contribute to resilience through targeted investment support.

3.5 Structure and Role of the Downstream Industries

The semiconductor industry cannot be viewed and understood outside the context of its downstream industries. De facto, in the digitalised world, every industry and every manufacturing company is a direct or indirect buyer of semiconductors, regardless of size, activity and location. Therefore, it would go too far here to present the network of supply of semiconductors and the different sales and supply channels, but the following points of relevance to the semiconductor industry in Europe will be discussed.

[18] https://ec.europa.eu/commission/presscorner/detail/de/qanda_21_645

[19] https://www.de.digital/DIGITAL/Redaktion/DE/Digital-Gipfel/Download/2020/digitale-souveraenitaet-und-resilienz.pdf?__blob=publicationFile&v=10

[20] https://www.zvei.org/presse-medien/publikationen/technologische-souveraenitaet-resilienz-der-industrie-und-europaeische-kompetenzen

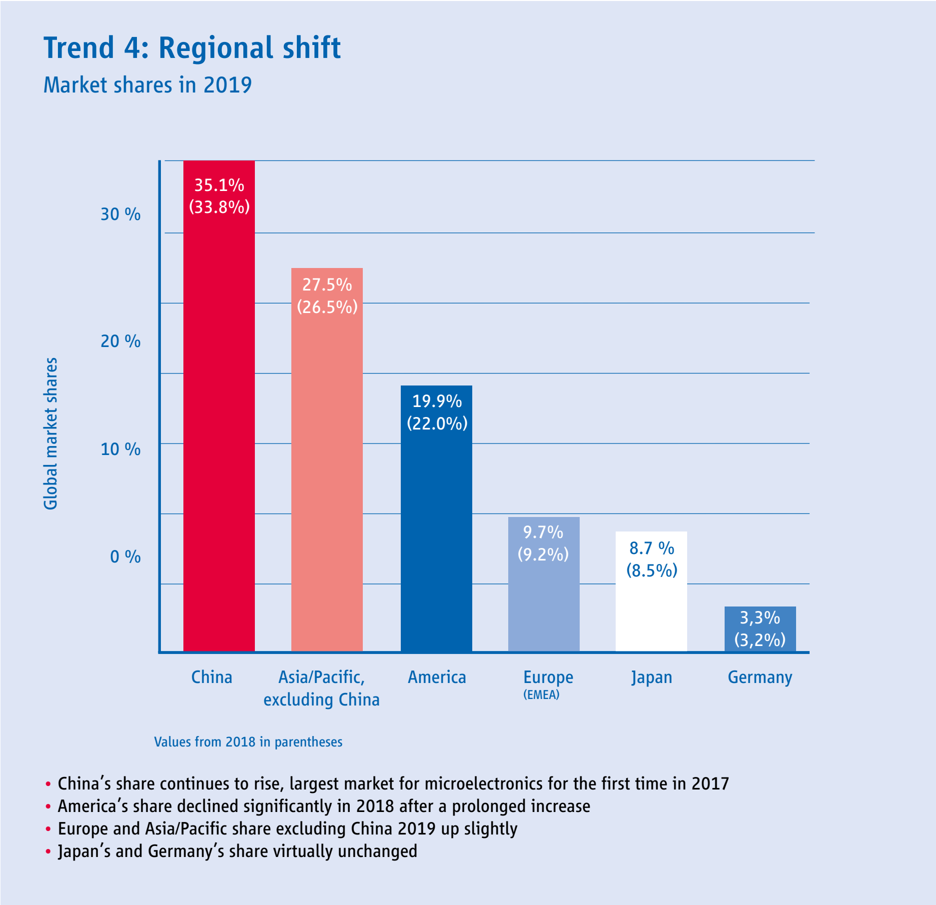


Figure 10: "Important sales markets for the semiconductor industry" (source: ZVEI)

A ZVEI working group is currently reanalysing the data behind the figure (10). The goal is to be able to make statements based on solid data collection about the clientele (domestic Chinese companies or EU- and US-based companies in the electronics industry) from which the semiconductors are installed. This is a crucial prerequisite for assessing the value creation taking place in China and for correctly evaluating China's role. Only on such a solid data basis can political decisions of relevance to the semiconductor industry be made. This is explicitly not intended to suggest that there is no need for action, but rather to underpin the need to act with more concrete data.

The most important ship to markets for the global semiconductor industry are in the Asian region, with a share of more than 60 percent. This follows the long-term trend of a shift of the manufacturing industry for consumer electronics and similar fields to Asia. The area "computing and data storage" (= data centre services, PCs, and notebooks) and the area "wireless communications" (= mobile phones, tablets, communication technology and infrastructure) are the main markets for the semiconductor industry, accounting for more than two-thirds of the market share. The automotive sector is considered to have the highest growth potential, and the industrial sector also has significant growth potential, albeit from a comparatively low level. The importance of absolute market shares is well illustrated by the fact that Apple alone spends more annually on the chips in its iPhones than the automotive industry worldwide.[21]

[21] C.f. https://www.derstandard.de/story/2000124353909/autobauer-rutschen-in-chipkrise-in-der-hackordnung-nach-unten

To further illustrate the global semiconductor market, the following figure (11)[22] appears to be useful, according to which the 10 largest customers account for more than 40 percent of the total global semiconductor market.

2020 Rank	Company	2020 Revenue	2020 Market Share (%)	2019-2020 Growth (%)
1	Apple	53,616	11,9	24,0
2	Samsung Electronics	36,416	8,1	20,4
3	Huawei	19,086	4.2	-23.5
4	Lenovo	18,555	4.1	10.6
5	Dell Technologies	16,581	3.7	6.4
6	BBK Electronics	13,393	3.0	14.9
7	HP Inc.	10,992	2.4	2.4
8	Xiaomi	8,790	2.0	26.0
9	Hon Hai Precision Industry	5,730	1.3	-1.5
10	Hewlett Packard Enterprise	5,570	1.2	0.2
	Others	261,109	58.0	5.4
	Total	449,838	100.0	7.3

Figure 11: "Semiconductor customer ranking in 2020 (Millions of Dollars)" (source: Gartner)

The computing and wireless COM markets are highly interesting from an industry point of view, due to their absolute size and based on their growth forecast. The high level of networking of systems will be a prerequisite for achieving climate protection goals while maintaining prosperity. This networking is largely made possible by innovative communication solutions, which in turn require analogue semiconductors.

However, interesting growth potentials may arise in the European semiconductor market. The European market is known for its strength in the automotive and industrial sectors (figure 12).

Building on the strengths of the European electronics market, significant growth potential can be generated in the automotive and industrial sectors. These downstream industries, in which Europe is the global innovation leader today, need semiconductors to an evergreater extent to maintain this leadership. Furthermore, the entire digital transformation and Industry 4.0 stands behind this Industry segment, making this a decisive issue for the future of Europe as a business location. In addition, the area of communication (5G/6G/Open RAN) in Europe should be given much stronger emphasis. Existing and increasing weaknesses in this area should be countered with a strategic, innovationoriented funding policy aimed at expanding production capacity.

[22] C.f. https://www.gartner.com/en/newsroom/press-releases/2021-02-09-gartner-says-apple-and-samsung-extended-their-lead-as

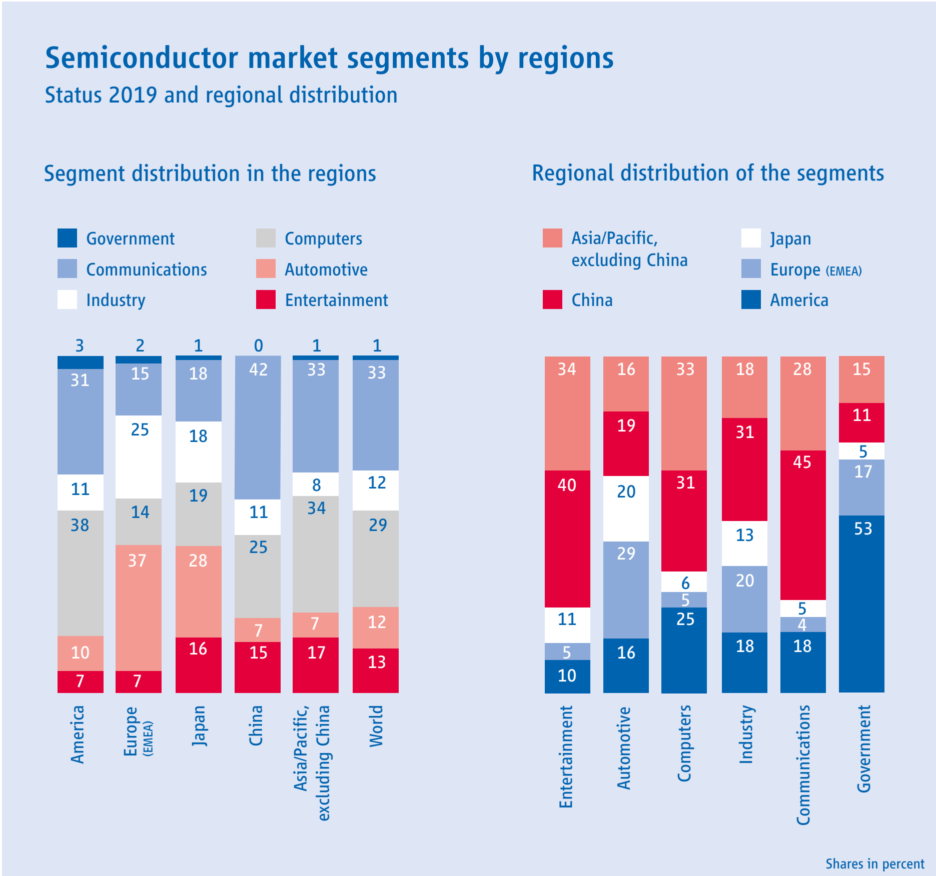


Figure 12: "Semiconductor market segments by regions" (source: own ZVEI)

This area can only be sensibly improved through close cooperation between the semiconductor industry and the downstream industries. The distribution of risks cannot be at the expense of the semiconductor industry alone. The downstream industry must play its part in developing and implementing sustainable value chains and rethink its approach to warehousing instead of just-in-time production.

Concrete and quick steps towards better cooperation between semiconductor manufacturers and the downstream industry at the German and European level are necessary. ZVEI has already taken this need into account and organised virtual exchanges between manufacturers and downstream industries represented in the ZVEI and other German industry associations on April 21, 2021, and July 13, 2021.[23] These initiatives must now be continued on a broader scale – for example in the newly founded Semiconductor Alliance. This will require the involvement of the associations of the downstream industries in Europe and Germany, the chambers of industry and commerce and the logistics sector. The objective must be to obtain a reliable assessment of the downstream industries manufacturing in Germany and Europe within a reasonable period as to which applications and technologies are needed in the short and medium term. It goes without saying that German and European antitrust regulations set the framework for such an initiative. Restrictions due to export control requirements are likewise to be considered. Besides the limited production capacity, administrative restrictions, e.g., due to export control, must also be considered for the security of supply of the domestic industry.

[23] Co-organized together with the BDI – the Federation of German Industries.

4 Technological Framework of the Semiconductor Industry

It is beyond the scope of this paper to go into detail about the production steps and global division of labour. However, the following links illustrate this topic and provide important information for a better understanding of semiconductor production:

https://www.youtube.com/watch?v=whQmCJF_JB0

https://www.youtube.com/watch?v=kuANgMCRnqY

4.1 Which Technologies Are Necessary for Which Products?

4.1.1 "Computer Chips" and High-Performance Processors ⟶ Smaller than 10nm

The future communication standard 6G will be used in many new applications, such as autonomous driving, medical science, or machine learning in industrial manufacturing. These fields will create huge demand for data processing at the edge and drive demand for highperformance processors in the technology nodes <10nm.

Radar sensor systems for autonomous driving, AI accelerators for Industry 4.0, 6G base station processors for signal processing and conditioning, but also edge processing are very specific examples of the "<10 nm" area. German and European semiconductor companies are – also thanks to the strong industrial, "vertical" ecosystem – in a very good starting position to develop the IP for the necessary computing platforms and enable future topics such as autonomous/sustainable mobility, digital factories "Industry 4.0" and 6G.

4.1.2 Embedded, IoT, Automotive, ⟶ ≥ 16 nm

Microcontrollers (MCU) and microprocessors (MPU) in the 16-40 nm technology nodes make up a significant share of global chip demand – as of today. And market analysts are forecasting steady demand for these products over the next 10-15 years (at least). In a recently presented paper, Acatech, the German Academy of Science and Engineering, puts it this way: "However, high-end chips optimised for pure performance are not necessary for many projects in future fields of industrial value creation in Germany such as IoT and edge computing, stationary mobile radio stations and sectors such as automotive engineering and the pharmaceutical industry[24]."

Processors and microcontrollers with these "good enough" (Acatech) computing powers are used in a wide range of applications: Industry 4.0, health (e.g., hearing aids), WiFi/BL/BLE, power management (for automotive applications, among other areas), radar, mobile communications. They are also used in very large quantities for socalled "consumer IoT" products such as fitness wristbands, smart home solutions (e.g., intelligent speakers such as "Alexa"), game consoles, and household appliances of all kinds. In addition, depending on the application, these chip solutions fulfil the necessary requirements for functional and cyber security. Further integration could be made here (e.g., power management). These are old processes for microcontrollers and processors, but if they are further developed, highly integrated systemonchip (SoC: integration of all or a large share of the functions of a programmable electronic system on a chip) is possible, which goes beyond what is feasible today.

[24] https://www.acatech.de/publikation/digitale-souveraenitaet-status-quo-und-handlungsfelder/

4.1.3 Sensors, Actuators, Controllers ⟶ Greater than 90nm

Many microelectronic components, especially for automotive and industrial use, must function reliably in demanding environmental conditions. These components "sense," "think," "act" and "communicate" in a wide variety of applications and represent the link between the real and the digital world. These components must operate at higher voltages (> 3V - 600V) and control higher currents (mA-A). The smallest digital technology nodes are not suitable for this, as they can neither cope with high voltages nor switch higher currents. Instead, socalled high-voltage analogue mixed-signal CMOS technologies with structure sizes between 65 nm and 1.2 µm are used, which are also considered leading edge technologies in their respective applications. Applications in the vehicle include e.g.

- Motor control of air conditioning flaps, pumps, servomotors (window lifters, seats, mirrors), fans, brakes, steering, etc.
- ICs for lighting (LED, xenon, halogen, etc.)
- Voltage regulators to supply microcontrollers (12 V down to 1 V)
- Current sensors, charge control and monitoring of the battery
- ICs for airbag deployment
- Optical sensors (e.g., SPAD) for LiDAR
- 6G analogue

4.1.4 Power Semiconductors

The conversion of electrical energy into various AC and DC voltage levels has undergone several fundamental paradigm shifts throughout its history. Perhaps the most significant has been the development of switching power supplies, which enable far greater efficiency than before and provide functions that were previously impossible, isolated DC conversion without motor-generator sets. Today, switching power converters enable complex functions in areas such as wireless charging, cellular, renewable energy, and smart motors in everything from industrial to electric vehicles to small household appliances.

In recent years, electronics have made massive inroads into machinery and equipment by producing many innovative solutions. In view of the efforts to save energy, special attention should be paid to the crosssectional product "frequency converter," which is installed in many machines driven by an electric motor (e.g., pump, fan, etc.). Intelligent motor control with a frequency converter constantly reduces energy losses in industrial processes in machines and systems. There are many synonyms for the frequency inverter, e.g., drive controller, inverter, variable speed drive.

The key components for functionality are power semiconductors as important part of power electronics. Semiconductor switches are crucial for the function of a power converter or frequency converter. Besides siliconbased technologies such as MOSFETs and IGBTs, SiC and GaN power semiconductor devices are now available for particularly demanding applications. These semiconductor devices are designed for controlling and switching high electrical currents and voltages (more than 1 ampere and voltages of more than about 24 volts). The upper limit is several thousand amperes and volts in each case.

4.1.5 MEMS

MEMS stands for Micro-Electro-Mechanical-Systems. As a rule, these are mechanically movable silicon structures that are manufactured on silicon wafers using advanced methods of semiconductor technology. Areas of application include sensors for measuring acceleration and rotation, pressure, sound, and gas composition, but increasingly also actuators, e.g., for optical micromirrors. The areas of application are correspondingly broad and range from automotive applications (airbags, ESP, automated driving) to IoT (motion detection, proximity detection in smartphones, microphones, smart glasses), medicine (pacemakers) to industrial applications (function monitoring, laser systems), to name but a few.

Leading edge in this field is defined by the individual processes of process technology (e.g., vertical etching with the highest dimensional control), the codesign of electrical and mechanical function (simulation), also the reduction of structures (shrink) as well as the continuous higher integration of electronics and mechanics by way of wafer bonding or monolithic integration. Progress is measured in functional parameters such as accuracy, offset stability, and robustness. The progress in these parameters is often very high, in some cases a factor of 10 can be observed every 2 years in the last decade.

4.1.6 Smart LEDs and Non-VIS Light Sources

Light emitting devices (LEDs) have been evolved towards classical "more-than-Moore" and "Beyond-Moore" representants. Todays and future applications are based on the integration with electronic components such as ICs, ASICs, CMOS etc. not only for conventional driverfunctionality, but also to meet the requirements of future displays (high resolution, contrast, dynamic and efficiency) and Non-VIS radiation sources (SWIR, UV).

These components are essential for the human machine interface and represent the link between the real and the digital world, in both directions. Therefore, they contribute to exterior and interior sensing and lighting in autonomous driven electrical vehicles, to industrial automatization (industry 4.0), to sensing and treatment for health and wellbeing applications as well as consumer products ubiquitously used in daily life. Furthermore, they also enable e.g., mercuryfree curing of compound materials and disinfection of surfaces and air.

Key components are miniaturized LEDs, socalled micro-LEDs with lateral dimensions down to below 1µm, where fundamental physics laws come into play limiting the performance and lifetime of such devices. NIR and IR emitting devices are eyesafe and well suited for sensing and distance measurements. Here, wavelength stability, absorption by air and water, reliability and lifetime of the devices are the discriminating criteria. The same holds e.g., for novel semiconductorbased UV-C emitter and sensors.

4.1.7 Packaging

Packaging, as a field of microelectronics and microsystems technology, encompasses the entirety of technologies and design tools required for the assembly of microelectronic components in the smallest of spaces. It enables the linking of microelectronic and nonelectronic micro components to form a complete system. Originally developed as a technique for the electrical contacting of microconnections (bonding) of microchips (die) and for their encapsulation/enclosure from several disciplines (electrical engineering, microjoining technology, materials science), packaging has developed into an independent discipline in the field of microsystems technology. A purely process engineering approach is no longer sufficient for the increasing complexity of electronic microsystems. Designanalytical expertise is becoming increasingly important.

Packaging for:

- Power semiconductors: In the power electronics segment, the convergence of new semiconductor technologies and the associated packaging technologies is becoming increasingly important. Today, packaging technologies no longer have simple protective functions, but must decisively support thermal, mechanical, and electrical performance. Examples here include special designs for heat dissipation or inductances in the enclosure. This is the only way to make innovations possible, in the systems of the electrical, automation or automotive industries, for example.

- Wafer level technologies for combining silicon technologies: Where system integration with the highest performance is required, chip embedding technologies based on wafer level packaging offer great advantages in terms of high-frequency capability and thus speed and data rate due to their extremely short interconnection lengths.

- Sensors, Smart LEDs, and Non-VIS Light Sources: Packaging for sensors is aimed at continuous downsizing of the products with greatly improved functionality. Numerous assembly and interconnection technologies have been and are being developed for sensors and smart LEDs for the first time or made possible with technologies from sensor and LED production, for example silicon glass bonds, eutectic bonding, direct bonding, chip stacking or throughsilicon vias. Special attention is paid to the mechanical interaction (stress, pressure, temperature) of the structure with the electrical and sensing function of the sensor, as well as the supply of media (liquid, gas, light, sound) required for some sensors.

- Technology for micro- and millimetrewave applications. Only with these capabilities will future communication and radar systems up to and above 100 GHz be possible. Analogue and mixed signal semiconductor technologies for communication and radar applications (the latter can also be a “sensor application”) especially needed for micro- and millimetrewave applications include the following:

  - SiGe HBT < 130 nm
  - GaAs pHEMT < 100 nm
  - GAN HEMT < 100 nm
  - INP HBT < 250 nm
  - INP HEMT < 100 nm

Without these technologies, there is no interface between the digital or switching semiconductors described in this paper or our analogue world. Transistors made from III-V semiconductor technologies are ideal for energy-efficient power amplifiers for future base stations in micro and millimetre applications due to their open-circuit voltage combined with high speed. This will not be possible with CMOS. In mobile end devices, the power amplifier is also based on In-GaP HBT technologies in Sub 6GHz networks today. In higher frequency ranges, 28/50 GHz for 5G FR2 (Frequency range 2) or up to 170 GHz in 6G, these technologies are essential. Dependence on US technologies is not in support of the European resilience strategy. SiGe HBTs, in turn, are required to convert digital signals to analogue signals with high linearity and dynamic range.

4.2 Technological Strengths and Weaknesses

A SWOT analysis is used to answer the important question of the current strengths and weaknesses of the semiconductor industry in Europe.

Strengths	**Weaknesses**
Building on the strengths and market shares of the EU microelectronics industry: • Power electronics • MEMS • optoelectronics • Application know-how (automotive, industry) • Energyefficient drive and automation solutions for modern machines and plants • More-than-Moore technologies incl. FD-SOI	• Enable EU to develop own IPs in sub-20 nm technology nodes (e.g., microprocessors, AI,). • Thus, reduce dependencies. • Expand negotiation power by building on EU strengths (e.g., lithography, application know-how,) • Nearly no advanced logic chip design capabilities in Europe: With Nordic Semiconductors, there is one fabless company in Europe. • Compound Semiconductor production capacity incl. Microwave Monolithic Integrated Circuit (MMICs) component design capabilities. • Technology for micro- and millimetrewave applications.
Threats	**Opportunities**
• The importance of the above technologies and the necessary application know-how is also recognised, promoted, and expanded by other regions (China, Asia, Japan). The EU lead is being caught up to by Asia. • The customer industries relevant to the above technologies could grow more strongly in other regions and thus there is a certain risk that know-how and innovation will also lag behind the corresponding semiconductor production. • Higher speed in other regions and more attractive for investments through sufficient public funding. • In compound semiconductor technologies, the USA has a great technological edge and China invests heavily (e.g., SANAN IC or acquisition or investments in Western know-how carriers (Global Communications Semiconductors (USA), Ommic (France). • Acquisition of central know-how by non-EU Investment.	• Develop technologies, methods, and IPs to ensure the trustworthiness of e.g., processors, even if they are developed and produced outside the EU. • In parallel, establish own capabilities and expand capacities. • Establish robust supply chains. • Seize opportunities to play a leading role in emerging markets: Power electronics, inmemory computing, AI accelerators, quantum sensors, quantum computing. • Continuous innovation as a key to digital sovereignty. • The EU has always been strong in defining and standardizing new mobile communications standards. This is again apparent in 6G (6G flagship Initiative), but EU companies play only a minor role in exploiting the technology. With the introduction of semiconductor processes for 6G micro- and millimetrewave applications, Europe will also be able to participate more in their commercial exploitation.

The following strategic objectives can be derived based on this analysis:

- In correlation strengths and opportunities:
  Pursuing new opportunities that fit well with the company's strengths (matching strategy).
- In the correlation weaknesses and opportunities:
  Eliminate weaknesses to exploit new opportunities, i.e., convert risks into opportunities (transformation strategy).
- In the correlation strengths and threats:
  Use strengths to ward off risks or threats (neutralization strategy).
- In the correlation of weaknesses and threats:
  Develop defence strategies to prevent current weaknesses from becoming the target of threats.

4.3 Where Does Value Creation / Innovation Take Place?

Due to the technological complexity of semiconductor production, it is not always immediately obvious at which production steps innovation takes place and thus value creation is generated and optimised.

Basically, innovation / design / application development are those production steps in which the greatest value creation takes place, and the most intellectual property is generated. These innovations that are realised through the new design of integrated circuits still take place to a large extent in Germany and Europe.

If the business model of a manufacturer is a socalled "fabless company" (e.g., Qualcomm, AMD, NVidia etc.), the production of semiconductors is completely outsourced to a foundry, a contract manufacturer. Companies like IFX, NXP, TI etc., which are predominately Integrated Device Manufacturers with design and production in their own facilities, also follow a socalled „fablight" business model, allowing for production outsourcing. As the business model of the traditional semiconductor manufacturers (Integrated Device Manufacturers (IDM) like Intel, Micron, Samsung, etc.) has declined over the last 20 years, the foundry market is now growing much faster than the semiconductor market[25].

The foundries can only enable the rise of fabless companies and the steady decline of IDM production if they continuously invest in their technology development. Even though the focus of foundries is on Taiwan, Korea and increasingly Mainland China, the foundry sector in Europe has gained in importance over the last decade.

The innovative capacity achieved in Germany and Europe would be inconceivable without a closeknit network of research institutions. Fraunhofer Gesellschaft, IMEC and CEA-Leti are world class research institutions, as is the Leibniz Institute IHP Frankfurt/Oder based on its know-how on SiGe HBT. Their innovation leadership and collaboration with industry forms the basis for the value creation of the semiconductor industry, which can still be realised in Europe.

[25] From 2019 to 2024, analysts forecast the pure-play foundry market to grow at a compound annual growth rate (CAGR) of 9.8 percent. This would be significantly higher than the projected CAGR of the semiconductor market between 2019 and 2024.

5 The Semiconductor Industry in an International Context

It follows from the political, economic, and technological considerations highlighted above that the presence of an efficient and sustainable semiconductor industry is in the strategic interest of Europe and Germany. A further argument that is often cited is the global systemic competition between the EU, the USA and China.

The 14th Five-Year Plan[26] of the People's Republic of China states that China wants to focus on research and development in the field of semiconductor technology. This should be seen in the context of the trade policy disputes between the USA and China, which continue to cut China off from the supply of complex semiconductor technology. It remains to be seen what concrete investments will be made in the semiconductor sector within the plan and what technologies they will be made in. Nevertheless, one can also see that the Chinese government is increasingly using regulatory frameworks and certification schemes as a strategic tool to control market access to make it more difficult for foreign players to enter. From a European perspective, it is thus increasingly important to find a common position on market foreclosure practices in China.

The US initiatives to strengthen its manufacturing share in the semiconductor industry must be seen in the same context. The new US administration considers semiconductors to be of overriding strategic importance, especially for US security. The following individual policy announcements or legislative initiatives are significant in this regard:

- CHIPS for America Act[27]
- Executive Order on America's Supply Chains[28]
- The American Jobs Plan[29]

The US government is actively pursuing the goal of locating semiconductor production in the USA. This is also evident in the significant investments planned by companies in the USA[30].

Via the export control tool, the US administration actively "manages" know-how and component access. This is particularly true for compound semiconductor technologies, as from the point of view of the USA, the current technological lead is to be maintained or expanded as far as possible.

An appropriate and futureproof response to the international situation will be for Europe to not only systematically build on its strengths but also to systematically eliminate weaknesses in the research and production industries here, so that the industrial, ecological, demographic, and socioeconomic challenges can be met with the help of innovative technologies. This could lead to a global leadership role for Europe. International cooperation should also and especially be included and expanded in semiconductor technology. The CHIPS for America Act already contains a corresponding passage in the form of the "Multilateral Microelectronics Security Fund," which should make this collaboration possible. The area of intellectual property protection could be a concrete area for future cooperation in this context. Here, close cooperation between the USA and Europe would be of mutual interest.

India is a relatively new player in this area. The announcement of the Indian government to support investments in the development of production capacity with one billion USD cannot be overlooked[31].

[26] C.f. https://www.bundestag.de/resource/blob/815806/715fc6323a399f045ef33c19a0896899/WD-5-127-20-pdf-data.pdf
[27] https://www.congress.gov/bill/116th-congress/house-bill/7178
[28] https://www.whitehouse.gov/briefing-room/presidential-actions/2021/02/24/executive-order-on-americas-supply-chains/
[29] https://www.whitehouse.gov/briefing-room/statements-releases/2021/03/31/fact-sheet-the-american-jobs-plan/
[30] https://www.electronicsweekly.com/news/business/tsmc-reported-planning-a35bn-gigafab-arizona-2021-03/
[31] C.f. https://www.indiatimes.com/technology/news/india-govt-1-billion-dollar-chip-manufacturer-reward-make-in-india-537419.html

6 Recommendations to Develop an Efficient Semiconductor Industry in Germany and Europe

For the decade up to 2030, concrete action steps are needed to expand an efficient semiconductor industry in Europe. The analysis shows that Europe has a very good basis in R&D, which is a solid scientific foundation for the success of the industry researching and manufacturing in Europe. The challenges therefore lie more in production capacity and attracting young talent.

6.1 Competitiveness Through Innovation

It is clear from the EU Commission's communications that Europe has recognised the need to expand production capacity and is willing to address this. The approach of establishing the production of chips < 5 nm mentioned in the EU Commission's communication on the "Digital Decade" is a longterm lighthouse project that could give significant impulses to the innovative capacity of the semiconductor industry in Europe. However, the strategic development of the semiconductor industry in Europe also requires a mediumterm orientation to build on existing strengths and specifically eliminate identified weaknesses. In view of the concrete and still increasing demand for production capacities in the 12-40 nm technology corridor, this area should be the priority for the expansion of production capacities in Europe. One further question to be discussed is whether it makes sense to invest very heavily in this technology on a point basis or whether several smaller investments in various technologies that are additionally necessary for future central industrial products in Europe make more sense.

As described above, in addition to digital components, the European industry relies on mixed signal and analogue semiconductor components and related semiconductor processes, primarily III-V semiconductor technologies.

Increasing market share and market power will only succeed in the long term if the technologies, products, and production methods offered are globally attractive in terms of technology and price and offer a high degree of "security." The key is innovation, i.e., always being one step ahead of the competition, in other words being the "leading edge."

It would be an inadmissible abbreviation to apply "leading edge" only to structure sizes of less than 5 nm. "Leading edge" generally means leading technology, which in many applications also includes nodes larger than 5 nm. This becomes clear in the following breakdown:

- 5 nm in digital technology nodes is leading edge.
- The power semiconductors far from 5nm are leading edge.
- The MEMS technologies are also leading edge.
- Optical sensor cells in 130 or 350 nm are leading edge, the same applies for GaAs pHEMT < 100 nm, GaN HEMT < 100 nm, InP HBT < 250 nm, InP HEMT < 100 nm.
- Light emitting devices made of compound semiconductors (AlGaInN, InGaAlP), < 2000 nm

Therefore, design, intellectual property creation, and production must be expanded in a widely understood leading edge concept. In addition, there is a need for targeted promotion of IP development in 6G, edge computing, electromobility, and similar applications to address existing weaknesses, to recognise and "scale up" potentials in good time and thus to achieve societal goals.

However, leading edge fab in the sense of sub-5nm in Europe should be an integral part of a decision to build an innovative and inclusive semiconductor industry ecosystem in the next decade. It must be ensured that any subsidies to be provided for this do not impair other potentials of the industry in Europe, however. A Leading Edge Fab can be a lighthouse project to reset the coordinate system – like GSM, Galileo or the 6G initiative – and to underpin the claim as a leading technology location. This is true not only in Research & Development, but above all in the industrialisation of the technologies developed here. This could have a knockon effect on the further settlement of plant manufacturers and material suppliers around this fab in Europe. Diversification is very important for the downstream industry. Focusing on a (very expensive) project may not solve the many challenges facing European microelectronic consumer carriers in the EU. An alternative strategy for establishing <= 5nm CMOS production in Europe could be adopted to encourage foundry partners who already master this production technology today (TSMC, Samsung) to establish higher manufacturing capacities in Europe. This could massively reduce the development effort required for this technology. However, a market situation in which only two companies worldwide can supply (and only one of which is open) a key technology is indisputably "unhealthy." Based on this reasoning, a third player would not pose a threat for users.

Leading edge and innovation also mean, above all, recognising emerging opportunities and occupying new market segments at an early stage. The semiconductor market is highly diversified. This diversification is continuing. Already today, new applications and technologies can be identified in which a leading position based on innovative concepts is possible for companies in Europe. Examples include: Inmemory computing for AI applications, optical semiconductors for communication, sensor technology and data visualisation, new power semiconductors for electrification and energy transition, new memory technologies as a replacement for flash below 40 nm, quantum sensor technology and quantum computing and technologies for wireless communication at the highest frequencies, e.g., for 6G.

These innovative fields must be occupied as a matter of priority and industrialised in a targeted manner. The speed of innovation in these emerging fields and the KPIs relevant to them is often many times faster than the "timehonoured" Moore's Law, which describes a doubling of transistor density every two years. All this leads to a new claim "We in Europe are (again) top in this industry."

6.1.1 Use System Expertise in Europe

Europe's strength lies in complex systems. These include vehicles, aircraft, automated industry and medical technology. Precisely tailored innovation in microelectronics for these areas leads to competitive advantages that could be defended in the long term. It is the combination and application expertise for the entire range of semiconductor technologies that leads to highly integrated products specialised for the application with a high leverage effect for the subsequent system industry.

The high integration of a wide range of technologies is a European strength and includes not only semiconductor technologies but also packaging technology as well as systemrelated software. This comprehensive approach can be described by using the term "Beyond Moore."

Many of the semiconductor technologies used in Europe therefore also have a high degree of specialisation. Here, a lot of know-how lies in the development and mastery of the processes for presenting the required system function. This interaction of system and technology knowledge also results in a high market entry barrier for competitors.

Today, the interaction of system and technology expertise takes place through established customersupplier relationships, grown networks and geographical proximity. Further potential can be raised through increased partnering along the value chain, new cooperation models and the targeted formation of ecosystems and clusters.

6.1.2 Expanding Design Capabilities in Europe

Innovation does not only lie in the mastery of manufacturing technology. Especially in "standard technologies" such as digital technologies for processors, economic success lies much more in design, architecture, concepts, in short "IP" (intellectual property). It is therefore no coincidence that many successful companies have opted for a "fabless" approach in recent years or have taken this route from the very beginning. ARM, NVidia, AMD, Qualcomm are some of the most successful. The use of standardised digital technologies today also enables companies like Apple or Tesla to develop their own chips. Nearly all the successful design firms in this field are based in the USA.

This is where Europe must catch up. Especially in connection with system users, it is important to create differentiating IP that can be manufactured using standardised digital processes. In this area, there is a danger of the system industry becoming dependent on non-European design firms!

Especially regarding processor core IP, we are experiencing a potential "sellout" in Europe. Here, building and accessing robust and productready IP for the European semiconductor value chain based on RISC-V is needed as an alternative pillar. This should be pursued both through "open source" options and by building an industrial base for licensable European IP.

6.2 Existing and Additional Funding Concepts

The existing funding instruments from IPCEI and KDT at European level and the Microelectronics Framework programme at national level must be continued and improved.

In addition, funding instruments must be made possible that have the expansion of production capacity as their primary goal. The Commission's communication "Europe's Digital Decade" can lead the way here. The new budget structures from "Next Generation EU" must be used to achieve this goal and entrepreneurial investment decisions that lead to an expansion of production capacity in Europe must be supported in a complementary manner. Furthermore, attention must be paid to the expansion and upgrade of existing production facilities. The potential for additional automation in the production of semiconductors in Europe must be raised.

The "Joint declaration on processors and semiconductor technologies" signed by twentytwo Member States of the European Union on December 7, 2020, should be an important means to this end[32]. This is a more than sufficient basis for improving European cooperation, but it must open the door to further funding instruments, especially for expanding the generation of key IP and production capacity. This strategic process should also involve European development banks and the European Investment Bank, as well as other appropriate and interested stakeholders from the financial sector.

6.3 Maintain Global Value Chains, Identify and Secure Control Points

Policy decisions should not be directed at curtailing the global value networks of the semiconductor industry. Even measures developed with the best of intentions in this context can lead to significant welfare losses.

Instead, it should remain an urgent political goal to keep global value creation networks functional, accompanying active industrial policy, risk minimisation and preservation of sovereignty. With functioning free trade, the global division of labour in the semiconductor industry has proven itself in principle and is economically efficient. However, this does not reflect reality. The reality is characterised by market distortions, instrumentalisation and oligopolies, which have been and continue to be politically promoted outside Europe.

In a functioning global production network, not everyone can and must be able to do everything. In the global balance, however, Europe must also become more explicitly aware of its present and future strengths and strategic control points. For example, Europe currently holds a dominant position in the equipment of exposure devices for highperformance processors. The global production of mobile phones and cars would be impossible without micromechanical sensors from Europe. And European solutions for security and trust anchors in electronics are indispensable worldwide. Such an analysis cannot be carried out as part of this initial report and should be carried out by politicians and/or industry, if necessary.

[32] C.f. https://digital-strategy.ec.europa.eu/en/library/joint-declaration-processors-and-semiconductor-technologies

6.4 Create Attractive Economic Framework Conditions

Production facilities in the semiconductor industry face global business competition. On aveage, the cost factor is about 1 (Asia) to 1.5 (USA) to 2 (EU). In this context, the issue of electricity prices, their setting and their underlying political decisions plays a role that should not be underestimated. Therefore, in any discussion on the expansion of semiconductor production in Europe, the issue of energy prices and their exante calculability must be strongly considered in the political flanking of the microelectronics strategy.

In a global comparison, however, other elements also play a role. These include wages, the labour market, education policy (skilled workers), tax incentives, equipment, and the effectiveness of funding instruments. Within this complex of topics, it should also be pointed out that the semiconductor industry contributes significantly to the energy efficiency of all components.

6.5 Enhancing the Attractiveness of School, Vocational and Academic Training for the Electronics Industry

Finally, the future of the semiconductor industry in Europe also depends on new talent seeing career opportunities in the sector. Strengthening STEM education and decreasing the gender gap in technology subjects are just two pressing issues that need to be addressed. In this context, it is of eminent importance that microelectronics has been chosen as one of the three industrial sectors to be considered in the EU Pact for Skills[33]. The initiative's budget of about € 2 billion should make it possible to address and solve this important issue.

More specifically, a "European Competence Centre for Microelectronics" should be considered. Like the existing research institutions, skills in the field of teaching and the curriculum of the relevant courses of study should be bundled. Academic freedom should remain unaffected; the focus should be on closer interlinking of academic institutions and their chairs. The objective is to improve academic, technical and information technology education, to update it along new industrial requirements (keyword: Big Data, AI, ML, ...) and to increase the talent pool for the semiconductor industry in Europe. It is necessary to realise an increase in the number of skilled workers through targeted training.

Above all, it is necessary to increase the attractiveness of the industry through investments, construction of local production facilities, success stories from the market, i.e., to accompany the new success story of microelectronics in the media.

6.6 Ecosystem proposal

The EU Commission has launched a European Semiconductor Alliance. This is should be an open, inclusive, and solutionoriented body. The Alliance should both propagate a cosmopolitan view of microelectronics and confidently represent European interests. The European Semiconductor Alliance should be at the centre of the new semiconductor strategy of Europe. The Alliance should bring together microelectronics companies, downstream industries, the European Commission and Member States. The Alliance should start with a critical review of the status quo of the industry in Europe and a clear stakeholder mapping. Alliance members need to align and commit on concrete targets. Workstreams within the Alliance must be set up, milestones defined, and progress measured.

[33] https://ec.europa.eu/social/main.jsp?catId=1517&langId=en

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