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List of Abbreviations

Abbreviation	Denotation
5G	5th Generation of wireless communication
5G PPP	The 5G infrastructure Public Private Partnership
6G	6th Generation of wireless communication
AI	Artificial Intelligence
ASIC	Application Specific Integrated Circuit
BCG	Boston Consulting Group
BiCMOS	Bipolar Complementary Metal Oxide Semiconductor
CAD	Computer Aided Design
CAGR	Compound Annual Growth Rate
CMOS	Complementary Metal Oxide Semiconductor
CPU	Central Processing Unit
ECS	Electronic Components and Systems
ECSEL	Electronic Components and Systems for European Leadership
FEM	Front End Module
GaAs	Gallium Arsenide
GaN	Gallium Nitride
GPU	Graphics Processing Unit
IC	Integrated Circuit
ICT	Information and Communications Technology
IDM	Integrated Device Manufacturer
III-V	Semiconductor with elements from groups III and V of the periodic table
InP	Indium Phosphide
IoT	Internet of Things

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IoX	Internet of X
IP	Intellectual Property
MCU	Microcontroller Unit
ML	Machine Learning
mMIMO	Massive MIMO (multiple input, multiple output)
OEM	Original Equipment Manufacturer
O-RAN	A disaggregated and virtualized RAN, spearheaded by O-RAN Alliance
OS	Operating System
R&I	Research and Innovation
RAN	Radio Access Network
SDG	Sustainable Development Goal
SiGe	Silicon Germanium
SoC	System on chip
UN	United Nations
WP	Work Package (of a project)

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1 Europe's current situation and project motivation

Europe has been a leader in connectivity innovations since the beginning of the mobile communications era. It is currently the home of two of the three largest global equipment vendors, i.e., Ericsson and Nokia, that account for around one third of the $383.86 billion global market and over one quarter of essential patents related to the 5G standard as of 2019 [1]. In recent years, with rising competition from outside Europe and increasing geopolitical interferences, Europe started to rethink and reevaluate its industry strategy, in order to maintain its leadership position in 5G and towards the development of 6G by 2030.

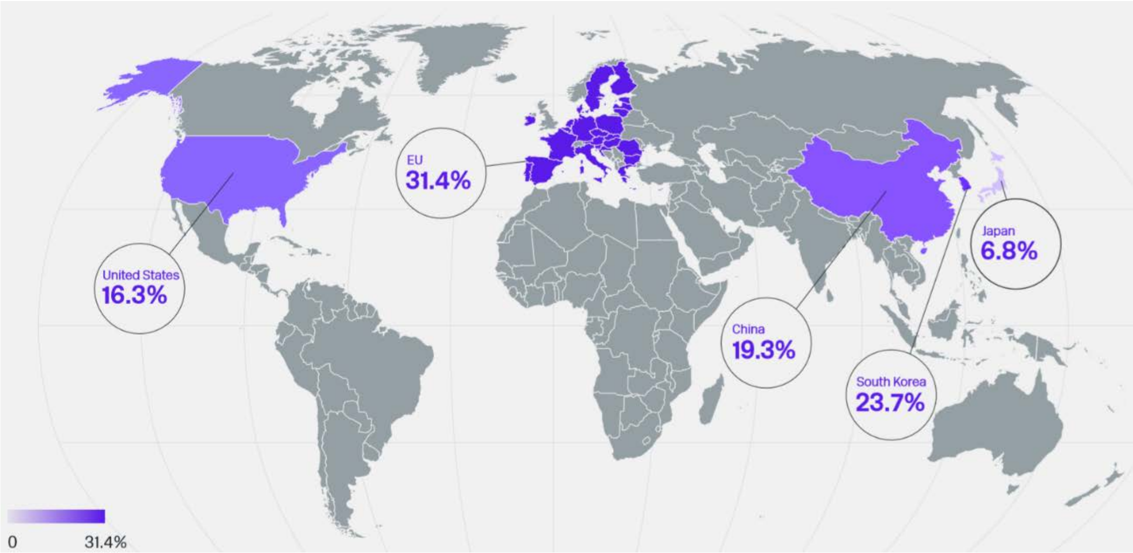

Figure 1 Essential 5G patents mapped to regions as of March 2020 [2].

One of the rising concerns in this context is Europe's strong dependency on chipset vendors from outside Europe, primarily US and Asia. This is an urgent matter to address, both from an economic and a technology autonomy perspective, as this might be a key for Europe to obtain a leadership position. Currently, European microelectronics industry only accounts for 4% of the 408$ billion telecommunications production market [3].

Actions are already being taken by EU member states to strengthen the microelectronics industry as a whole[4]. The COREnect project has been initiated to address the specific issue of components for future connectivity systems, as highlighted above.

COREnect is a Coordination and Support Action that is part of the 5G Public Private Partnership (5G PPP). It started in July 2020 and has a duration of 24 months. COREnect brings major stakeholders from both the telecommunication industry and connectivity-enabled vertical industries together with the aim to develop a strategic roadmap of core component and subsystem technologies for future, connectivity systems as well as connected products. The main objective is to propose a roadmap that aims at decreasing European dependence on other continents when building future systems, and thereby build a European technological sovereignty in 5G and 6G, within the next 10 years.

This document summarizes the initial common vision of the COREnect consortium, as of December 2020. Section 1 provides an analysis of Europe's current position in both the telecommunications and microelectronics industry, as well as the impact that EU research has had in those sectors in the recent years. Europe's position is further detailed in two sectors of critical importance for the evolution of 5G and the development of 6G, i.e., telecommunications and automotive.

Section 2 offers a first outlook towards 2030, where 6G could provide new opportunities and challenges for both industries when it comes to connectivity-related value chains. Information on the situation and foresights on other regions of the world is included. Once again, the outlook is exemplified with examples from the telecommunications and automotive industries.

Based on this analysis, section 3 gives initial recommendations from COREnect on how to proceed by identifying potential technological gaps on core components and subsystems towards 6G as well as the research & innovation (R&I) areas where Europe should seize opportunities and strengthen its capabilities in the next 10 years.

This analysis provides a top-down guideline for the work carried out in COREnect towards the development of a detailed technology roadmap, ensuring its strong relevance to the economy and technology autonomy goals.

This deliverable is part of COREnect Work Package 2 "Strategy, vision and requirements".

1.1 The position of European industries and the relevance of B5G/6G

The era of 5G networks has arrived and their commercial deployment at a worldwide level is picking up pace. A recent report [5] indicates that "the global market for 5G technology is projected to reach USD 5.53 Billion in 2020, reaching USD 667.90 Billion by 2026, showing a CAGR of 122.3 percent from 2021 to 2026". In the SWOT analysis presented in [6], it is indicated that Europe is in a privileged position as it has two out of the three major telecommunication vendors as well as three global satellite operators. Moreover, an analysis [7] of the data in the latest publicly available reports such as IPlytics [8] (January 2020), indicates that European companies have approximately one quarter of the granted patents in 5G related topics. Moreover, we should note that the EU headquartered companies combined share more than 50% of 5G commercial deployment deals [5].

According to Statista [9], the telecommunications market has been stable since 2018 and is expected to remain such for the following years. 5G networks, from their conceptualization phase, have been designed to penetrate and serve indirect markets i.e. so called "vertical industries", thus vastly broadening the sectors that are likely to benefit from communications technologies.

The potential benefits in terms of efficiency and new opportunities in society and economy for such a paradigm shift are expected to be significant. [10] indicates that "M2M connections will grow 2.4-fold, from 6.1 billion in 2018 to 14.7 billion by 2023. There will be 1.8 M2M connections for each member of the global population by 2023". Both numbers considered by the COREnect project to be overly conservative. Another report [11] states that the automation achievable by the internet of things paradigm across a broad range of sectors is expected to lead to a potential economic impact in the range of $4 trillion to $11 trillion by 2025. Advanced connectivity solutions from 5G (and evolved 5G) networks will be the fundamental building block in the digital transformation of both the public sector and industry. A timely adoption of 5G (and later 6G) in sectors as automotive and transportation, smart factories, health, energy, and agriculture,

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where Europe has a very strong position, shall help in retaining and improving Europe's leading position.

The advanced networks can also be a key enabler to efficiently address several strategic goals with a high societal impact. A detailed analysis of this potential can be found in [6], where specific application areas and a roadmap to tackle EU's Green deal [12] and even UN's Sustainable Development Goals [13] are presented. A pan-European mobilization to realize smart networks and services is expected to also create a significant number of high-skill jobs through a close cooperation of the private sector with Europe's Universities and Research Centers.

To complete the picture, one also needs to refer to the role of small and medium enterprises (SME) in such an endeavor. SME represents the backbone of EU's economy as they employ around 100 million people and account for more than half of Europe's GDP [14]. SME play a key role in adding value in every sector of the economy. SME will also play a central role in the ecosystem addressed by COREnect. They are a significant part of the ecosystem of manufacturers and operators and the vertical industries. SME play a key role in early adopting innovation models to different contexts and user needs and flexibility responding to new or niche demands. Their role in the development of core technologies is still to be determined however, c.f. COREnect Deliverable 4.1 "Initial report on community building and outreach strategy".

However, the path ahead is not fully clear. The evolving geopolitical environment has highlighted the need to develop secure infrastructures and to secure European sovereignty in critical technologies and systems [15]. The strategic digital autonomy of the European Union is a major concern with the raise of multiple threats and dependencies involving both technical and socio-economic aspects. Europe is currently lagging in terms of cloud platforms, end devices microelectronics, and photonics in the communications domain [6] and therefore cannot currently fully provide on its own end-to-end solutions. Europe is dependent on solutions developed in other regions.

The following subsections provide a more detailed insight into the current position of the European microelectronics industry and illustrates this position by zooming in on two sectors, telecommunications and automotive.

1.2 Position of the European microelectronics industry today

While Europe still holds a good share in materials and tools for the production of electronic components, the 2017 figures show that Europe's share of production is lower higher up in the value chain, at levels such as electronic equipment, electronic boards and electronic components (including semiconductors), when comparing it with the relative weight of its economy in the world [16].

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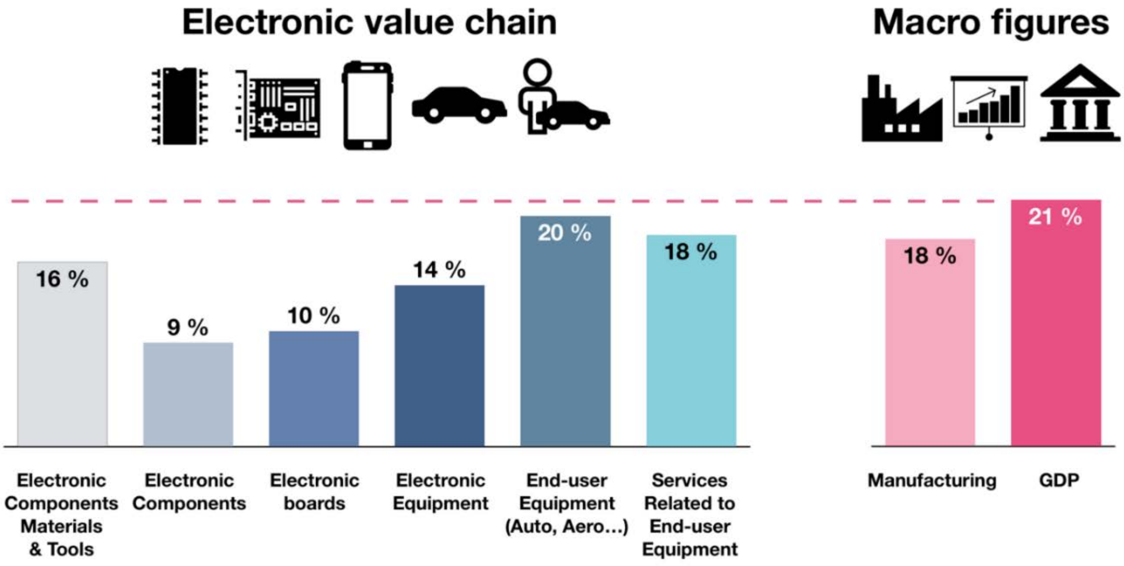

Figure 2 The European share of the world production at every step of the global electronic value chain

Yet this global picture hides very different situations regarding the market segment being addressed. European microelectronics component providers are still strong (with market shares in line with or above the global EU economic weight) overall in the embedded/industrial segment, in particular in automotive (The EU produces 27% of the global automotive electronics), aeronautics/defense/security (22% of the global Aerospace/Defense/Security electronics) and industrial electronics (20%). Clearly, Europe microelectronics industry is strongest in the end markets where Europe also holds a leading position. The leadership technology of the European microelectronics players in these sectors has probably benefited from the geographical proximity of leading customers.

Conversely, the absence of strong European computer companies might be one cause of the weak position of the EU microelectronics industry in this area. With 5.5% of the global computer production, the EU is the 3rd (out of 6) region in the world, on par with the US, after China (54%) and other Asian countries (32%).

The leading European microelectronics providers (Infineon, NXP and STMicroelectronics) have gradually focused their resources on differentiated markets and dropped out of the Moore's law race. This has resulted in turning towards so-called Fab-lite models and retaining the internal manufacturing of derivative technologies (e.g., power semiconductors, BiCMOS) while subcontracting the fabrication of their most advanced designs to mostly Asian foundries. This is mainly due to that they have lacked the market volumes required to obtain the necessary returns on investments in large, very advanced CMOS process technology development and fabrication facilities. This move was not compensated for by the emergence of new fabless market leaders, like in the US. This lack of design capabilities and fabrication technology leadership in very advanced CMOS processes, combined with the absence of a strong fabless ecosystem in Europe, might explain why, although there are strong telecommunication electronics players in Europe (Ericsson, Nokia), the EU only holds 3.5% of the global production in that market. The EU is the 5th region in the world after China (51%), other Asia (29%), the rest of the world (7.6%) and the USA (6.3%).

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A look at a BCG-type graph, plotting expected market growth and world end-user electronics production, shows that the positioning of the EU microelectronics players on the embedded industrial segments mentioned above makes a lot of sense, from the point of view of individual industrial companies, as incumbents in the telecoms and computer markets might be very hard to challenge. However, given the strategic importance of 5G and 6G for European technological sovereignty in the coming years, there might be a need for a European industrial policy to complement the pure market dynamics.

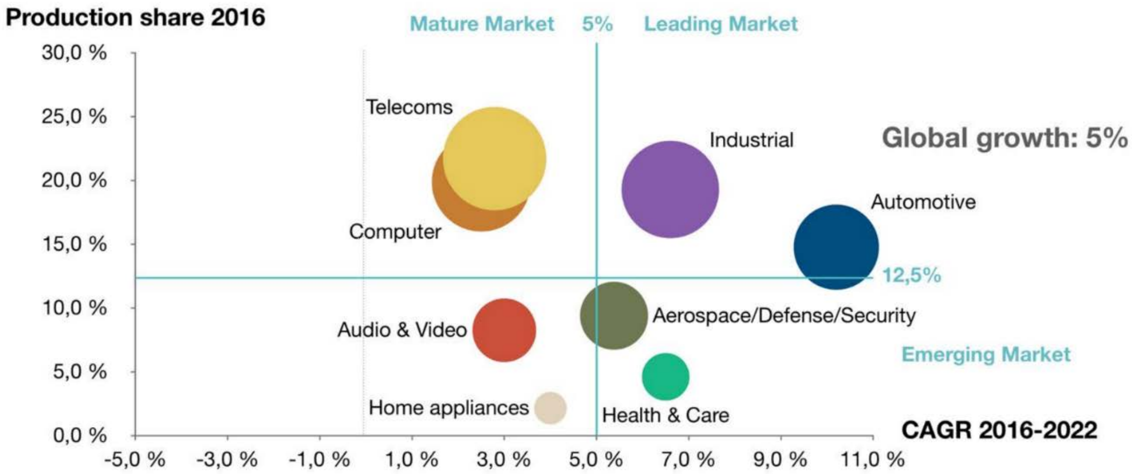

Figure 3 World end-user segment production share in 2016 (B €) & forecast CAGR over the 2016-2022 period

This market analysis by segments gives only part of the picture, as it looks at sales. However, some semiconductor components are almost "bare silicon", without much opportunity for software or ecosystem-based differentiation, leading to low operating margins and lacking investment capabilities in the long run. On the other hand, others are sold together with complex software stacks, or even require a complete ecosystem, allowing for potential higher margins – if the semiconductor provider can influence that ecosystem.

One important, additional technology that stands with microelectronics in B5G/6G era is photonics; the amalgamation of optics and electronics. Europe is recognized as a world leader in the scientific research, technology development, and industrial applications of photonics. Europe is today the world's second-largest supplier of photonics components and products after China, with a global market share of 15% to 17% [17]. In fact, photonics based optical infrastructure will be the central nervous system upon which our European digital society, industry and economy will rely, transporting data at ultrahigh rates in millions of extended fiber-optic networks around the European union to every home and business. In addition, photonics technologies will be a critical building block in Europe's future digital network security via a photonics enabled quantum communication cybersecurity capability.

1.3 Examples of two important value chains

As advanced microelectronics is an essential part of almost all end user products today, it is important to understand how the rapidly changing microelectronics landscape will affect major European industrial ecosystems. To provide a tangible perspective, we will in the following subsections describe two value chains with a strong European footprint and illustrate how these already have entered a significant transition phase, given the impact of microelectronics.

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1.3.1 Telecommunication industry

As the cradle of wireless and mobile communications, Europe has a strong position in telecommunications infrastructure. As mentioned in section 1, Ericsson and Nokia together represent a 30.4% global market share and have leading positions in global telecommunications standardization. However, in consumer telecommunication devices, by far the bigger market in terms of chip volume and total revenue, Europe's position is almost nonexistent. Today, Europe is only delivering microelectronic components to global device OEMs. Europe is more vulnerable than the US, China, or Taiwan, given its incapacity to supply a full system solution, including processors, modem, and high frequency radio modules.

Telecommunications is at the cutting edge of technology development. There are three key component technologies that are common to all wireless communications products: analog and high-frequency electronics, processors and digital electronics, and software. Europe has a strong position in analog and high-frequency electronics but is weak in the other two. However, with the increased digitalization of radio technology, Europe's strong sector, analog and high frequency electronics, is increasingly integrated into subsystems dominated by digital content. Today, the main telecom infrastructure manufacturers design advanced microelectronics in-house, but there is a strong and clear trend to increasingly rely on semi-standard components from semiconductor manufacturers, able and willing to make the necessary R&D investments. Today there is no such manufacturer in Europe.

Since the dawn of GSM and mobile communications, the market has matured, following the same pattern as many other software- and electronics-dominated sectors. The supply chains have become globalized and manufacturing has been increasingly automated and robotized. As a result, major non-European suppliers today leverage investments made for other high-volume applications, such as server blades for data centers, personal computers, or even gaming consoles, to break into the telecommunications value chain, further reducing Europe's market share.

Next to microelectronics, software represents the other major value carrier in the telecom market. The fast development of artificial intelligence and machine learning (AI and ML) has a growing impact on the business, advanced architectures, and processor subsystems. This is strategic for all regions of the world, and whoever manages to dominate this area is likely to be a winner. In AI and ML, not only European academia but academia globally has been outrun by internal research teams in large US software companies. This reduces even more the possibility for Europe to develop world-leading microelectronics.

Given the aforementioned insights, it is obvious that Europe's technology base in wireless and wireline communications is under threat. The relevance of Europe's strength in analog and high-frequency electronics is decreasing, and geopolitical and commercial forces drive a disaggregation of telecommunications infrastructure (e.g., via initiatives such as O-RAN). Such fragmentation of the market not only lowers the entry barriers allowing countries to challenge Europe and build their own capabilities but also offers a path for the big US and Chinese cloud players to compete with, or even replace, Europe's telecom operators.

With the digitalization of essentially all industrial and public sectors, a continued strong European telecommunications technology base, targeting both infrastructure and consumer

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markets, is strategic for Europe's general competitiveness, job creation, and technology sovereignty.

1.3.2 Automotive industry

The European automotive sector has risen to the top of the global industry. It has achieved record sales and is an integral part of European society as a major employer with essential contributions to GDP. This great significance of the car industry to the EU are demonstrated with impressive figures: the motor vehicle production in the EU was around 17.9 million units in 2019, whereas passenger cars have a share of 15.8 million units. This is a substantial part of the world market, with a size of 92.8 million units and 74.2 million, respectively [18].

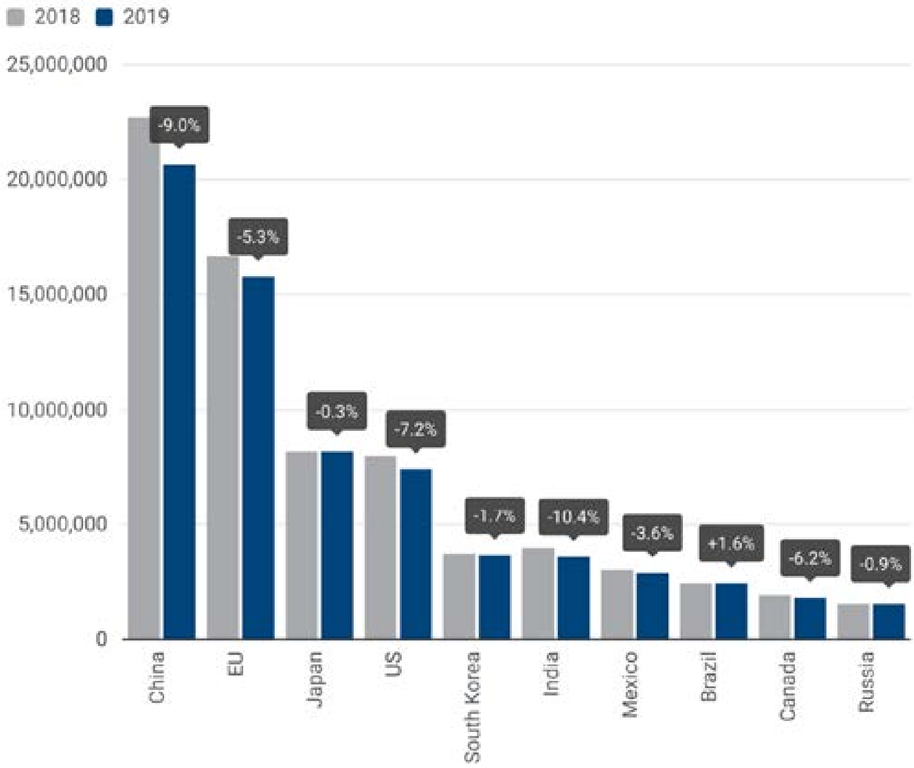

Figure 4 Top 10 countries for passenger car production [18]

The number of employees has increased to 2.7 million people in manufacturing of motor vehicles in the EU. This is only a fraction of the total number of employees in the overall automotive ecosystem which amounts to over 14 million when services and construction are also taken into account [18]. The turnover generated by the automotive industry represents a remarkable 7% of European GDP [19].

However, fundamental changes in the industry threaten Europe's leading position. First, the world-wide production reached a turning point in 2017, with signs of market saturation. Second, technological megatrends such as autonomous driving, connectivity, and electrification are leading to significant changes in the automotive ecosystem (as well as more generally in the whole transport industry). Numerous new technologies enable the mentioned megatrends, where AI, battery technology, 5G connectivity and big data analytics play a major role. These technologies have a huge impact on a vehicle's electronics and software, transforming the vehicle into an "ultimate electronic device". The value share of electronics has risen to more

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than one third of the vehicle. The rapid pace of innovation around intelligent systems in cars is disrupting the business flow, forcing a need to rethink collaboration models and roles. In the past, Tier-1 companies provided requirements to semiconductor companies which implemented the requirements in chips and managed development as well as manufacturing. In addition, the mobility providers such as Uber and Lyft have positioned themselves at the top end of the value chain.

The whole market landscape has started to change. Automakers collaborate directly with semiconductor vendors (e.g. Daimler with Nvidia [2]) and new tech players are even designing their own ICs (e.g. Tesla) [20] or started to provide their own software operating systems. Tier-1s as Mobileye are providing hardware and software with the goal to get access to different types of vehicle data, today the property of OEMs.

Due to the drastically increased importance of electronics, Tier-1s and OEMs are increasingly looking at system-on-chip (SoC) design and architecture ownership. Industry-standard, commercial chip design elements are mixed with highly specialized and differentiating functions such as acceleration of AI algorithms, communications, or image recognition. Small but highly value-adding and differentiating parts of what is often a much larger chip.

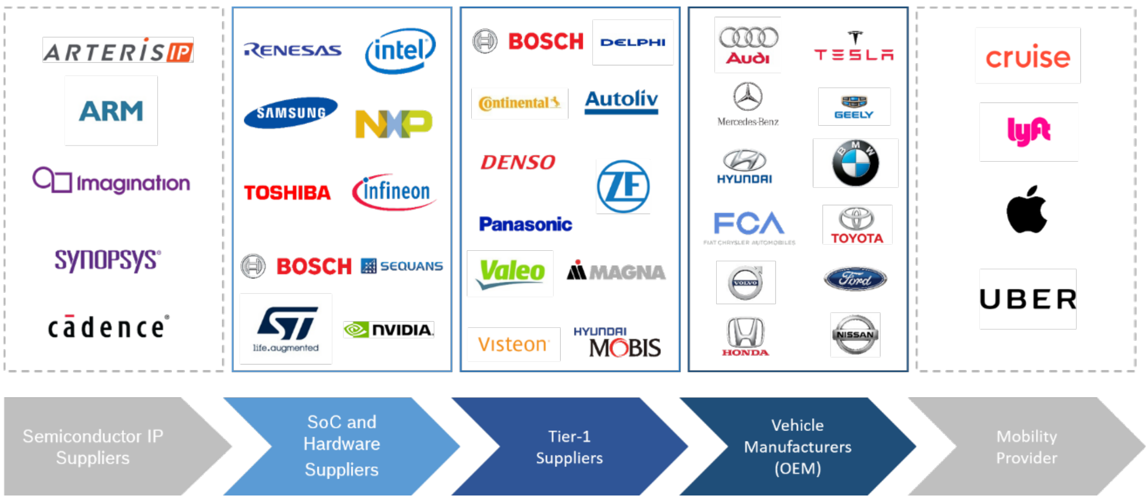

Figure 5 Classical automotive value chain for electronics, derived from [21]

1.4 Key impact of research in European ECS and SNS industries

As mentioned in section 1.2, the European microelectronics industry today is strongest in the vertical markets where Europe also holds a leading position. One of the key factors for success in the past therefore seems to have been the existence of the complete value chain in Europe. This has been true not only at the commercial stage, but also during the research, innovation and development phases, often via collaborative European R&I projects. Here Europe not only benefits from leading industries in many end segments but also from the presence of world-class research and technology organizations as well as fundamental research institutes. Public programs such as the successive EC R&I Framework programs and EUREKA have successfully leveraged all these ingredients. For example, the impact study conducted by Deloitte on the ECSEL Joint Undertaking [22] concluded that “increased levels of research and innovation (R&I) cooperation between organizations is the single most important realized benefit of the ECSEL program. Participation in ECSEL projects results in higher R&D spending for all categories of

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project participants and, ultimately, this yields a stronger and more innovative ecosystem of ECS players which can tackle EU societal and industrial challenges better.” Efficiency and productivity gains in the range of 10 to 30%, increased turnover and market share and positive employment impact (one project resulting into 550 jobs created over a period of 3 years following the end of the project) were among the benefits listed in that study.

Likewise, European research activities have significantly contributed to the European Smart Networks and Services (SNS) industry, notably via the 5G PPP. As captured in related reports [7] this well-structured European research ecosystem has managed to provide significant input to standards developing organizations (more than 800 contributions), produced a significant number of publications related to 5G (more than 1300) in scientific journals and conferences, and assisted European companies to produce intellectual property (e.g. patents) that keep them ahead in the 5G global race. 5G PPP has mobilized huge private investments and has a positive impact on the participation and the innovation capacity of European SME. 5G PPP has facilitated the creation of new societally beneficial services in many different vertical areas, e.g., smart cities, e-health, intelligent transport, power, environmental protection, education, entertainment & media, and others.

The 5G IA’s position paper on “A European Partnership on Smart Networks & Services under Horizon Europe” [23] thus considers that 5G PPP places Europe ahead in the global 5G race. Such activities are expected to not only to continue but pick up pace with the launch of the Smart Networks and Services Partnership in Horizon Europe, where the objective is to build on 5G PPP results and broaden the research, by taking into consideration ICT complementary domains such as distributed high-performance computing, IoT, cloud, cybersecurity, and AI/ML solutions.

Worth mentioning is the strong position taken by Europe in photonics through a dedicated PPP promoted by Photonics 21. In this area, EC support of the research ecosystem led to the emergence of a large number of innovative SME and larger companies working on key areas including semiconductor-based components and subsystems for fiber optic-based telecommunications, (bio)sensors, medical technologies for the instant diagnosis of major diseases, agri-food, etc. that fosters key European challenges such as digital transformation and Industry 4.0.

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2 2030 Outlook

2.1 6G use cases and predicted global investments

2.1.1 Why: drivers of connectivity solutions in 2030

Standing at the dawn of 5G in 2020, the world is now gazing at the future towards 2030. Climate change, pandemics, social inequalities, unemployment, and distrust of democracy – multiple unprecedented challenges have heavily rendered economical, societal, and political agendas of our times. Digital transformation is and will be the key for addressing those challenges [3]. In particular, connectivity is the most fundamental building block and is expected to empower the next era of industry and society "where the physical, digital and biological worlds are coming together" [24]. Towards the 2030 timeframe, 6G networks will continue its evolution from 5G as one of the most critical, powerful and indispensable digital technologies in modern times [24].

Compared to 5G, beyond classical internet, IoT and Tactile Internet, 6G shall support "Internet of Robotics" and "Internet of Senses", integrating them into an "Internet of X (IoX)" paradigm. This shall enable new opportunities for further deepening of digitalization in all industry sectors as well as for creating novel products and services, e.g., robotic and/or sensing enabled "white goods", in consumer markets. As projected in [25], connectivity encompassing 5G/6G will potentially trigger $13.2 trillion global sales across ICT industry sectors by 2035, representing 5% of global real GDP, while the 5G/6G value chain will be able to generate 22.3 million jobs globally by 2035. This estimation does not include the impact of connectivity on non-ICT sectors, e.g., agriculture, manufacturing, public services, transport and storage, and wholesale/retail sales, which may potentially create even higher economic values than ICT sectors themselves and create great growth opportunities for both big industries and SMEs. In addition, ICT and connectivity solutions contribute to energy efficiency, CO_2 reductions, and Green Deal and UN Sustainable Development Goals (SDG) objectives in many other non-ICT sectors.

The coming ten years will be critical for achieving UN SDG goals [26] and Europe's ambition to become the world's first climate-neutral continent by 2050 [12]. As analyzed in [27] connectivity enabled digital infrastructure will have great impact on all SDG and Green Deal goals towards 2030, with higher cost and energy efficiency. In particular, 6G must serve the 3.9 billion currently unconnected people (131 million in Europe) for improved education, business, and health opportunities [28].

Europe must invest now to be a frontrunner in 6G networks [29]. Due to the massive amount of data flowing in 5G networks and its role as critical infrastructure [30], 5G has become a central point in the US-China trade war. At the same time ICT is considered as a true sovereignty concern by policy makers globally [31]. With 10~100 times more data flowing and 10~100 times more industry adoptions, the research, development, and deployment of 6G will be a global race with respect to technology capabilities, economic strength, and global political impact. Europe must leverage and combine its strength in telecommunications industry, microelectronics industry and connectivity-enabled vertical industries, and coordinate its actions with a strategic value chain approach, ensuring its leadership in this global race.

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2.1.2 What is 6G?

Built on 5G that powers industry 4.0 and IoT systems, the connectivity in the 6G era shall be a paradigm of IoX, and a story that pushes further digitalization by allowing real-time connectivity among physical, digital and biological worlds while relying on their digital twin representation or virtual world.

6G shall be optimized for cost reduction of 5G use cases to drive their adoption at scale. As the density of infrastructure increases coupled with use of wider bandwidth signal at high band spectrum beyond 5G (e.g., THz), new opportunities arise for localization and sensing, driving towards a 6G design that is not only optimized for communications but also for perception and understanding of the physical and biological worlds. AI/ML shall bring a major disruption to the 6G network for processing and exploiting massive amount of data from the network of sensors and operational environment [27]. With sustainability goals in mind, the development of 6G should follow an integrated approach which includes energy efficiency and security from the outset. In short, the major expectations from 6G networks are:

- **Non-limiting connectivity**: to provide affordable connectivity for all possible applications and devices, with extreme performance, in terms of e.g. data rate and latency, and provide necessary coverage everywhere including rural areas with integration of satellite systems.
- **The Internet of Senses**: to deliver sensory or multi-sensory experience, e.g., hearing, vision, touch, and smell, over the networks and enable seamless multi-sensory interaction among remote human, devices, robots and physical environment.
- **The Internet of Robotics**: to support the connection of a multitude of autonomous devices including robots and automated environment by enabling reliable and secure interconnection and communications among intelligent machines/robots including AI to AI communications.
- **Programmable physical and biological world**: to serve a fully digitalized, automated and programmable physical and biological worlds, and enable their real-time interactions with the digital world with communications, sensing, actuation, and computing everywhere.
- **Network compute fabric with big data**: to embed compute deep into the network, providing integrated adaptive compute, connectivity, and storage of massive amount of both non-personal data and personal data in any place and any time for any device and any application.
- **Sustainable world**: to empower environmental, social, and economic sustainability as well as resilience reducing energy consumption and CO_2 footprint of ICT industry and connectivity enabled other industry sectors.
- **Trustworthy systems**: to fulfil the requirements of the most mission critical use cases on resilience, privacy, security, dependability (reliability and integrity) and safety, and provide adaptable and verifiable trustworthiness to support real-time data flow among digital, physical and biological worlds.

Brought by its extreme capabilities and new paradigm of IoX, 6G will enable new use cases, e.g., a) remote surgeries, remote operation of machinery, holographic communication, and sustainable vacations in virtual reality with immersive multi-sensory immersive experience; b) connected consumer robots e.g., house-hold helper, human companion and physical/health

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enhancement with joint communications and sensing capability; c) future wearable devices and other novel human-machine interfaces providing natural and intuitive interfaces connecting digital, physical and biological worlds; d) Massive use of mobile robot swarms and drones, in various verticals such as in hospitality, hospitals, warehouses, package delivery, etc. enabled by extremely low latency — as well as many other new use cases that we cannot yet imagine in 2020.

The realization of those new capabilities and new use cases in 6G will heavily depend on not only network technology but also breakthrough in microelectronics industry when THz communications/sensing as well as power efficient and secured (AI) computing are becoming essential.

2.1.3 Current strengths and expected investments in other regions

China

Driven by strong economic interests and motivated by the Chinese government priorities, China has strategically and heavily invested in key digital technologies and gradually grown into a major global technology power especially in the areas of AI and 5G in recent years. However, in the area of microelectronics, Chinese industry remains at least two generations behind their international competitors and supplies less than 5 percent of the global market [32]. Currently Chinese 5G industry can only rely on chipset supply from US and other Asian countries and its survival is threatened due to the US-China trade war [33]. Recently, Huawei announced its plan to build a 20nm chip factory in Shanghai [34]. Huawei's goal is to manufacture 28nm chips for "Internet of Things" equipment by the end of 2021 and 20nm chips for 5G telecom equipment by the end of 2022. The plant will be operated by Shanghai Integrated Circuit Research and Development Center Co., Ltd. (ICRD) supported by the Shanghai Municipal Government.

To pursue self-sufficiency in microelectronics, China did create a "national IC plan" in June 2014 and "made in china 2025" in 2015, endowing the "national IC fund" with $150 billion from the central and provincial governments [32]. To date, this strategic plan has not been very effective, according to [35], due to poor allocation of funds, lack of human capital and trade controls imposed by the US.

Racing towards 6G, learning lessons from 5G and national IC strategy in the past, it is expected that China will not only invest heavily in network technology and standardization but also strategically drive and invest in related microelectronics technology for a stronger, own supply chain. Leveraging its huge domestic market with huge amounts of available data, China has the potential to advance on the path towards self-sufficiency and a complete "in-house" 6G value-chain by investing in home-grown software and services. Nevertheless, the major bottleneck will remain microelectronics. In particular, the US is barring China from access to advanced semiconductor fabrication equipment, including those provided by non-US companies.

USA

The US is the world leader in computing, AI, software, robotics, and internet platforms. In the area of mobile networks, there is currently no major US 5G infrastructure vendor on the global market while US players such as Intel, Qualcomm, Broadcom, Xilinx and Skyworks are dominating the global 5G chipset market. Apple and Google are very strong in the global device market and have absolute dominance in operating systems (OS) as well as applications distribution platforms ("app stores"). Given this position, the US industry, as well as the US government, is promoting the disaggregation of telecom networks (through initiatives such as O-RAN) as a path to further increase its share in the 5G market.

In March 2020, the US administration published a policy paper on "national strategy to secure 5G" [30], addressing potential issues from high-risk vendors on national security and calling for public-private coordination for promoting US leadership in international standards. It is clear that the US administration is dissatisfied with its current lack of leadership and control of 5G and has the ambition to dominate in 6G.

When it comes to 6G, it is expected that the US will leverage its leading industry positions on chipsets, AI, robotic, software, and platforms, and strengthen its control on standardization and on the whole 6G value chain including hardware, software, and services [30]. To support 6G, the FCC opened the spectrum between 95 GHz and 3 THz for experimental purposes in March 2019 [36]. On 13 October 2020, ATIS launched the Next G Alliance, an industry initiative that builds foundations for US leadership in 6G and beyond with 16 industry founding members [37]. To fundamentally address its ambition in 6G leadership, and its concerns on national security, the US may incentivize and promote the (re-)creation of its own 6G infrastructure champion(s) in the next decade.

2.2 Value chain impact

2.2.1 Telecommunication industry

As discussed in section 1.3.1, the European technology base in wireless communications is under threat. In the existing microelectronics value chain for 5G, Europe represents a narrow segment with high-performance components (mainly analog and high-frequency electronics) as cornerstones. Europe is thus vulnerable to value chain movements or technology disruption that would bring value away from this thin ecosystem. Considering this, there is a high probability that digital and software content will increasingly be developed outside Europe.

From a system integration perspective, the design of advanced microelectronics will gain importance for each new telecom generation and the continued uptake of connected devices. As large cabinets evolve into circuit boards and circuit boards evolve into chips, most of the added value of the product will reside in a small piece of silicon and its associated software. If this chip (including its firmware) is purchased from China, and the software is licensed from a US company, very little value creation and differentiation are left for a European manufacturer. In the light of this development, a strengthened system-on-chip ecosystem in Europe and the know-how and capability of complete and complex chip designs are fundamental to keep the added value of European products in Europe. This also includes the products' security, which is more and more defined at chip level. What this means is that to compete with tomorrow's products in defense, automotive, white goods, industrial machinery, consumer goods, etc. Europe needs a world-class competence pool in wireless and wireline communications, microelectronics (at least in design), photonics, and software in industry as well as in academia.

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2.2.2 Automotive industry

The automotive industry remains crucial for Europe's prosperity. Thus, it is important to strengthen the competitiveness of the European automotive industry and secure its future global technological leadership. In the automotive sector technology, market, and value chain currently undergo radical changes.

The centerpiece of future vehicles is Systems on Chips (SoC) with large software assets. Today such complex SoCs are mainly developed and manufactured by US and Asian companies such as Qualcomm, Nvidia, and Samsung. A major effort must be undertaken to strengthen Europe's design capability for high complexity SoC and their associated manufacturing. Those will be key to secure the sovereignty and business interests of the European automotive sector.

As mentioned in 1.3.2, the automotive value chain has started to change, strongly influenced by companies from the ICT sector, leading to a value network. Leading technology players as Google, Baidou, Intel, and Tesla leverage their knowledge in AI and big data analytics to gain market access. Furthermore, mobile communications companies such as Huawei are moving into the automotive market. Classical vehicle manufacturers may rapidly lose their position in the value chain because technical key elements driven or even owned by tech players determine the commercial success of their vehicles. Europe should increase its efforts to develop future main key technologies in the fields of AI, 5G/6G connectivity, big data analytics, and battery technologies.

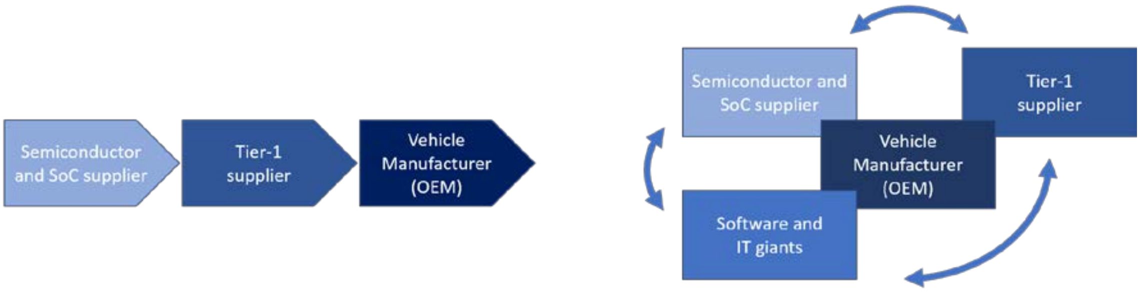

Figure 6 From traditional value chain to value network

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3 Gap analysis and recommendations

3.1 Implications for EU microelectronic industries and ecosystem

To strengthen Europe's position and enable European industry to capture new business opportunities associated with our increasingly connected world, it is vital to support European technological leadership in 5G and 6G semiconductor developments.

Europe has an excellent starting point on 5G and 6G from providing home bases to critical cellular network players like the industry leaders Ericsson and Nokia. These companies drive standardization forward as part of the worldwide initiative 3GPP and leverage a strong position in 5G. For system implementations the companies fully rely on semiconductor and package/assembly solutions from 3rd parties.

Within this package/semiconductor field, European players (Infineon, NXP, ST, etc.) are strong on analogue and radio frequency front end module markets, mainly due to the availability of differentiated technologies developed and manufactured in Europe (for example, bipolar CMOS, BiCMOS, GaN, and RF silicon-on-insulator (RF-SOI) semiconductor technologies). Next to semiconductors, also package/assembly technologies are key areas seeing the thermal and high frequency challenges of 6G. Here Europe plays a limited role though some niche players and institutes with good reputation (e.g. Fraunhofer, IMEC, CEA) are active. On top, critical measurement capabilities and production testing of challenging 6G domain products will need to be addressed. On measurement capabilities Rohde & Schwarz is a worldwide player but subject to heavy competition. Differentiated semiconductor technologies are a key strength of the European ECS industry, especially when considering the connectivity market which could serve as growth driver for a wider ecosystem in European 6G.

Europe's differentiated semiconductor technologies are key assets that should be both preserved and improved upon to secure European leadership in connectivity. Consequently, dedicated research should be encouraged, including the technologies below:

- Advanced BiCMOS: targeting RF and mmW front end modules
- RF SOI: targeting RF and mmW front end modules
- GaN: targeting the high-power infrastructure market
- FD SOI: targeting power-efficient connectivity solutions
- GaAs/InP: targeting mmW applications and photonics

Development areas include:

- Advanced Package / Assembly technologies
- Measurement capabilities at RF frequencies
- Production testing capabilities at RF frequencies

It is important also to pay attention to low-power autonomous end-node technologies, as unwired smart components in the Internet-of-Things which continuously sense their environment, locally analyze the data and detect interesting things like anomalies and transmit alerts to Edge nodes. This is all about ultra-low power fully integrated CMOS solutions (MCU, sensor interfaces or embedded sensors, smart power management, energy harvesting, security, machine learning, etc.).

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While Europe is playing a key role in innovative differentiated semiconductor technologies, there is very little R&D activity or few players in Europe on the advanced packaging and PCB side. This point is clearly a weakness that should be addressed to strengthen Europe's connectivity technology portfolio. 5G/6G frontends demand intensive electronic (photonic)-packaging co-design and therefore requires a strong link between design and manufacturing. An example is the millimeter-wave antenna array and electronics integration as a system-in-package.

Leveraging previously discussed differentiated semiconductor technology portfolio, innovative connectivity solutions (hardware, internet protocol (IP) or software) should be encouraged to enable Europe to take full advantage of its technology and manufacturing assets, and to capture market share at the component level. This action is crucial to secure Europe's position beyond 5G and preliminary 6G investigation and standardization activities.

Since most of the value of a complex connectivity system will be captured at the module level, it is highly desirable to enable European players to climb the value chain. In targeting systems and applications, it is important to consider the interconnection between sub-systems, and focus should be on individual component technology development according to needs identified at the system or application level. To support this system vision, the promotion of innovative technology enabling heterogeneous integration is key.

Heterogeneous integration refers to the integration of separately manufactured components into a higher-level assembly that cumulatively provides enhanced functionality and improved operating characteristics. In this definition, components should be taken to mean any unit (whether individual die, device, component, and assembly or subsystem) that is integrated into a single system. The operating characteristics should also be taken in their broadest meaning, including characteristics such as system-level cost of ownership. This is especially true for the hardware side in the context of the end of Moore's law. It is the interconnection of the transistors and other components in the integrated circuit (IC), package or PCB and at the system and global network level where future limitations in terms of performance, power, latency and cost reside. Overcoming these limitations will require the heterogeneous integration of different materials, devices (logic, memory, sensors, RF, analogue, etc.) and technologies (electronics, photonics, MEMS and sensors).

On the digital side, heterogeneous integration also involves managing trust relations in order to finally have a trustworthy and cybersecure system. Managing trust relations means managing the TCB (trusted computing base), which is part of the tasks of an operating system (well beyond today's traditional operating systems) that uses hardware components for its policy enforcement. Moreover, combining a higher position in the value chain (delivering connectivity module/solution instead of components) with a new strength in heterogeneous integration would enable a European fabless ecosystem able to leverage the advanced processes available in Asian foundries to compete with US and China with an added value proposal. To do so, it is also highly important to keep and expand the design expertise and capabilities in Europe even if the manufacturing is not performed any more in Europe.

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Implications on design

To support the vision presented in the previous paragraphs, we propose that efforts should be focused on the following key focus areas with respect to design:

- Innovative connectivity system design using new spectrums (especially mmW and THz)
- Investigation and standardization targeting 6G cellular applications in the frequency band < 10GHz
- Development of innovative architectures and connectivity technologies using unlicensed frequency bands in the 6GHz - 7GHz band
- Development of innovative connectivity systems using new propagation mediums
- New methods and tools for e.g. thermo-mechanical modelling fully integrated in the design flows and simulation of antenna-package-IC in one tool
- Design of more power efficient and higher performance analogue & RF blocks
- Development of connectivity systems leveraging the concept of edge AI and relying on new AI/ML processor cores
- Evaluation of the AI concept to handle the complexity of future 6G-based connectivity networks, and to improve efficiency and adaptability
- Design of photonics circuits, subsystems, and systems able to support the insatiable need for more transport of data

Implications on manufacturing & testing

To support the vision presented in the previous paragraphs, we propose that efforts should be focused on the following key areas with respect to manufacturing and testing:

- Heterogeneous 3D integration of smart system building blocks (more than Moore) and Systems in Package, including antennas, integrated circuits, and photonics
- Innovative packaging solutions
- Design for Testing technology for testing the complete system including RF/mm-wave ICs and antennas
- Technology requirements and developments for SiGe, GaN, RF-CMOS, InP, Silicon Photonics etc.

Importance of AI

The use of new spectrums or propagation mediums is not the only way to innovative in connectivity technology. As mentioned, 5G has underlined the role of software to promote virtualization and reconfigurability, but those concepts may not be enough to address the challenges related to the more complex 6G connectivity technology. To address this challenge, artificial intelligence is now perceived as a strong enabler. Therefore, the topics below should be supported.

- Investigate AI features at the edge: to improve the power efficiency of communication devices and reduce the amount of data to be transmitted via the wireless and wireline network, the concept of AI at the edge (or edge AI) has been proposed. The idea is to locally process data provided by the sensor using handheld device computing capability. Moreover, processing data locally avoids the problem of streaming and storing a lot of

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data to the cloud, which could create some vulnerabilities from a data privacy perspective and allow to improve reliability and latency.

- Use AI to make the connectivity network more agile and efficient: the idea here is to move to an AI-enabled connectivity network to go beyond the concept of virtualization and achieve new improvement in terms of efficiency and adaptability. For example, AI could play a critical role in designing and optimizing 6G architectures, protocols and operations. This also includes a versatile control of analog hardware, not designed in advanced CMOS, but using SiGe, GaAs, GaN or InP. Complex control circuitry for such hardware requires a tight integration with advanced CMOS.

From value chains to value networks – follow the example of the automotive industry

In the automotive industry we have seen a drastic change of the landscape as illustrated in Figure 7. The changes include new business models, new alliances, many non-traditional market entrants, and an evolution from classical value chains towards value networks where semi-conductor companies are also moving up the value chain.

Figure 7 Car industry landscape

The same development is bound to happen in the connected device and wireless infrastructure business during the evolution of 5G and introduction of 6G. Success will rely on the ability to impact, build and maneuver an integrated and cooperative ecosystem. For Europe this is both a threat and an opportunity. Europe is historically weak in building software ecosystems, but the reshaping of the value chain opens up for European players entering markets or market segments where they are currently absent. In short, European ECS need to become much more active in their respective ecosystems as they reshape.

3.2 Opportunities and challenges for Europe with B5G/6G

Based on the analysis outlined in the previous sections, we propose here a gap analysis of European positions on connectivity systems and components focusing on four key applications.

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Microelectronics for cloud centric applications

We have in Figure 8 illustrated the position of Europe in the supply chain of key microelectronic sub-systems and components required by modern datacenters.

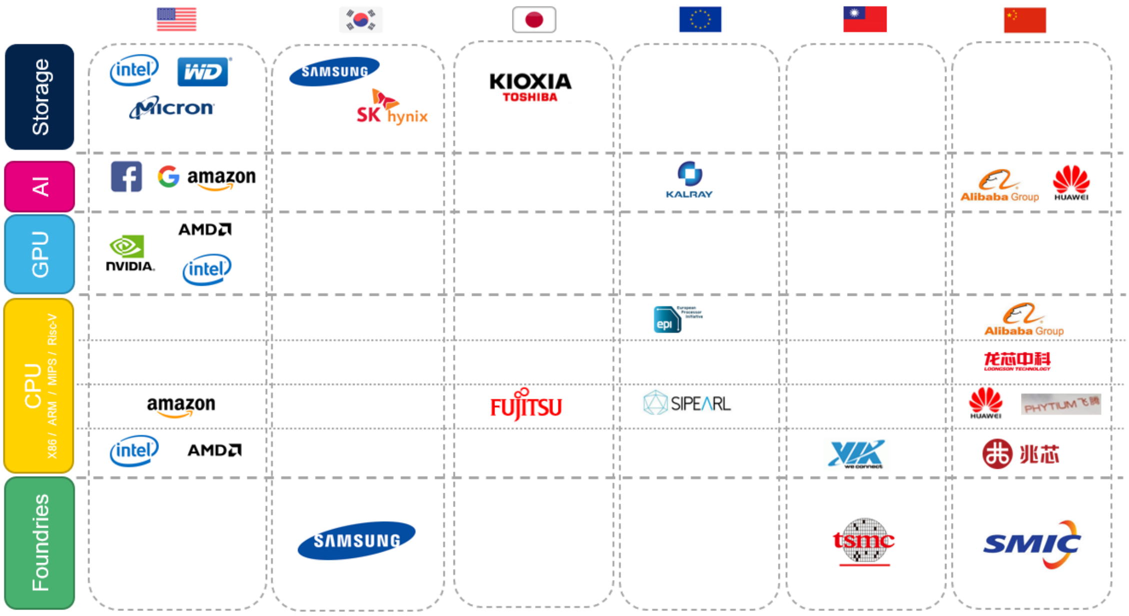

Figure 8 Cloud value chain

In memories, while Europe is absent in this market, US, Korea, and Japan have reached a competitive balance enabling a diversified and resilient supply chain.

Concerning the manufacturing of advanced SoC, Korea (Samsung) and Taiwan (TSMC) are today the only remaining options (also for several US companies). China has heavily invested to develop a domestic solution (SMIC) which has yet to materialize (the most advanced CMOS node manufactured in China being today 14 nm while TSMC is offering 5 nm in volume).

When it comes to CPU, while historically dominated by US (Intel and AMD), the development for the consumer market of ARM processors using TSMC advanced technologies has been leveraged in the datacenter area by US (Amazon), Japan (Fujitsu) and China (Huawei and Pythium). We can note that China has recognized the strategic nature of the CPU topic by heavily investing also on MIPS (Loongson) and RISC-V (Alibaba) solutions. Europe has recently launched an initiative (EPI) to catch up on ARM and RISC-V solutions but today this is not yet competing at the same level.

We can observe a similar situation on GPUs which are completely dominated by US players (Nvidia, AMD and Intel). Due to the importance of GPUs for AI algorithm training, we can note that alternative AI accelerators have been developed by new entrants in US (Facebook, Google and Amazon) and in China (Alibaba and Huawei). Europe is completely absent and is currently forced to rely on US and Chinese hardware to develop its AI capabilities. Consequently, we can identify the following challenges and opportunities for Europe on connectivity systems and components targeting the datacenter infrastructure market:

Challenges:

- No major EU player on CPU or GPU. (A clear sovereignty issue should the US apply export control measures to Europe.)

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- The AI accelerator area is dominated by US and China. (Which is a clear threat for Europe's ability to compete in the future on AI.)
- A very limited European fabless ecosystem to address advanced SoC design.

Opportunities:

- Europe has an excellent track record on IP (ARM) that can be leveraged to enable a fabless ecosystem on advanced SoC design and secure its sovereignty on CPU.
- Current export control imposed by US also creates business opportunities for new entrants (both sovereignty and supply chain management reasons).

Radio access networks

Assuming that the digital baseband functions are performed in a dedicated data center (C-RAN approach), the Radio Access Network can be reduced to three main functions integrated in the active antenna: the Front End Module (FEM) integrating the analog section, the transceiver converting the signal to lower frequencies, and the lower physical layers (PHY) providing the interface with the digital baseband (DBB, typically through interfaces like e-CPRI). In the figure below we have illustrated Europe's position in the RAN supply chain.

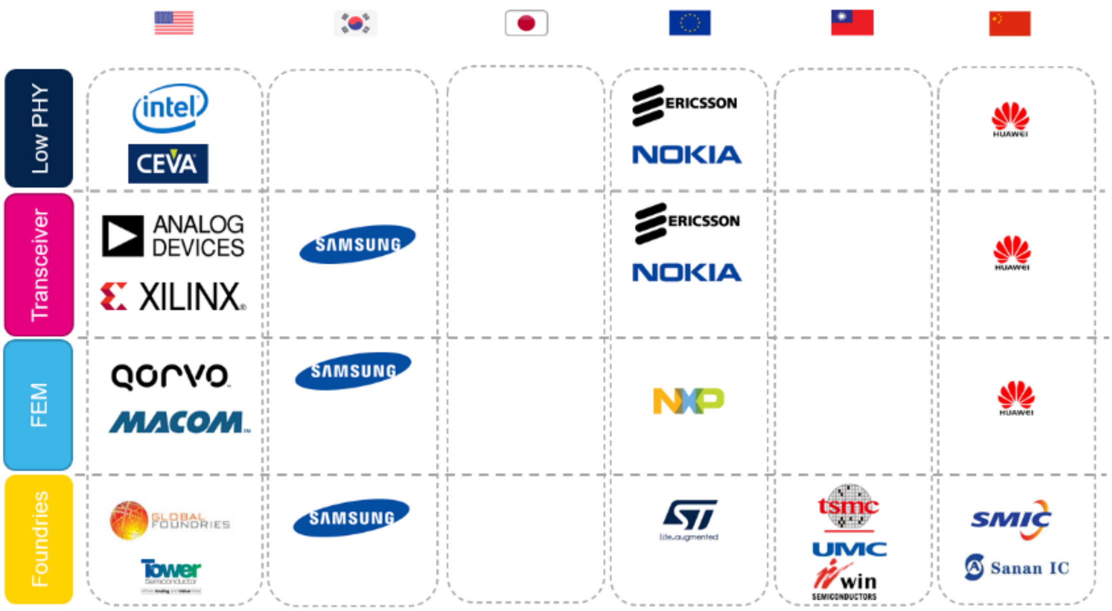

Figure 9 RAN supply chain

We can first note that the RAN market is the only telecommunication space where Europe has key players (Ericsson and Nokia) able to compete with Chinese vendors (i.e., Huawei, ZTE) while US companies only provide components and the remaining actors (mainly Samsung) only have a marginal, but growing, role.

Focusing now on key components, the FEM market today is dominated by US (Qorvo, MACOM) and Europe (NXP) while Huawei has selected a more vertically integrated position. The transceiver market today is mainly dominated by US players (ADI and Xilinx) even if the main RAN players (Ericsson, Nokia, and Huawei) do develop internal SoC. We can identify the following challenges and opportunities for Europe on connectivity systems and components targeting the RAN market.

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Challenges:

- Transceiver design is moving to digital, i.e. a digital front-end approach and the increase of complexity in control and calibration (including AI) of transceiver functions integrated in 7nm CMOS technology and below. To maintain leadership, Europe must secure its capability to design complex ICs in such advanced CMOS processes
- O-RAN (open RAN) may disrupt this market by making RAN equipment commodities.

Opportunities:

- 5G mMIMO deployment is drastically increasing the semiconductor content in RAN, making silicon integration mandatory and opening business opportunities for Europe IDM actors developing derivative technologies
- O-RAN opens the door for new players able to provide COT solutions, also creating business opportunities in all markets (it is not only a threat for Europe)

Local connectivity

We focus here on local connectivity technologies (Low Power Wide Area, Bluetooth, Wi-Fi, Ethernet) and microcontrollers frequently used in industrial applications (basically industrial IoT, health and automotive). Below is a high-level overview of the main players of this market.

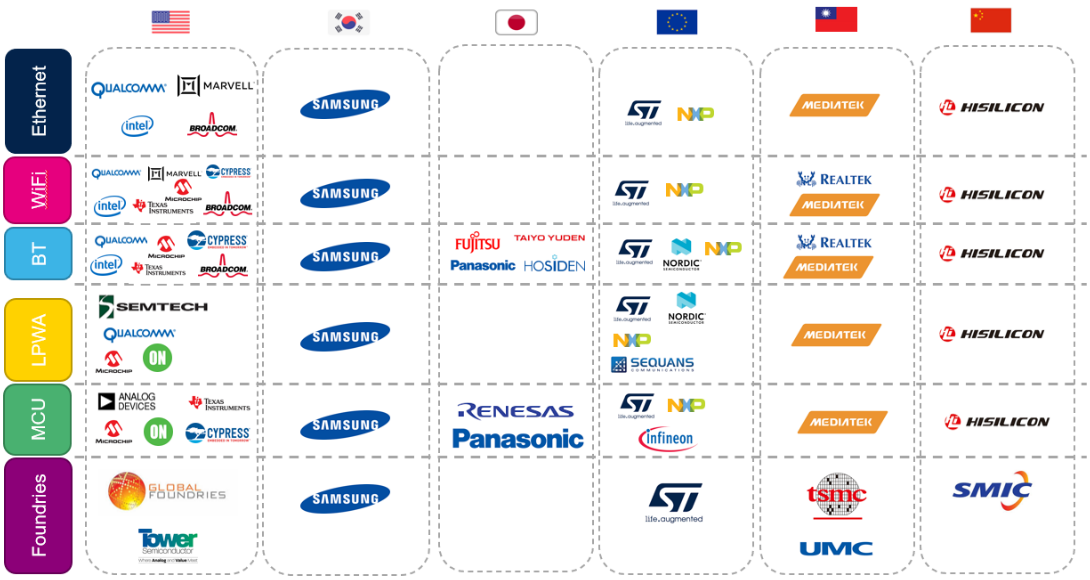

Figure 10 Local connectivity overview

We can first note that the market is highly fragmented, and no geographic region is really dominating. This can be mainly explained by the very wide spectrum of use cases. Moreover, focusing on Europe, the strong automotive ecosystem (with key manufacturers and Tier 1 suppliers) provided a natural business opportunity for connectivity solutions developed in Europe. This comment can also be applied to other sectors, especially on the industrial market.

However, another explanation also lies in the low cost and low power requirements of industrial applications which creates a preference for mature technologies. Most of the current MCU solutions are today manufactured in 90nm CMOS with a slow transition to the 40 nm node (and

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below). Consequently, those markets are thus well suited for European IDM semiconductor manufacturers. This could also explain why Europe is having a key role on the MCU market.

Challenges:

- Integration is also happening here, the capacity to design highly integrated solutions using more advanced nodes will have to be secured to maintain leadership
- IoT will be a key driver for this market, but without any leadership on the side of the cloud, Europe may capture a very limited part of the global value

Opportunities:

- Europe has a clear leadership and can take advantage of a sizeable indigenous market thanks to strong industrial and automotive actors in Europe
- IoT and 6G will create new business opportunities by increasing the semiconductor content on markets where Europe has a leadership position

Consumer and wide-area connectivity

We conclude with the review of the consumer and wide-area connectivity market (mainly driven today by smartphones). Since this market is driving the largest volume, it is strategic. To provide a high-level positioning of Europe, we present below a synthesis of the main actors considering cellular, Bluetooth, and Wi-Fi connectivity.

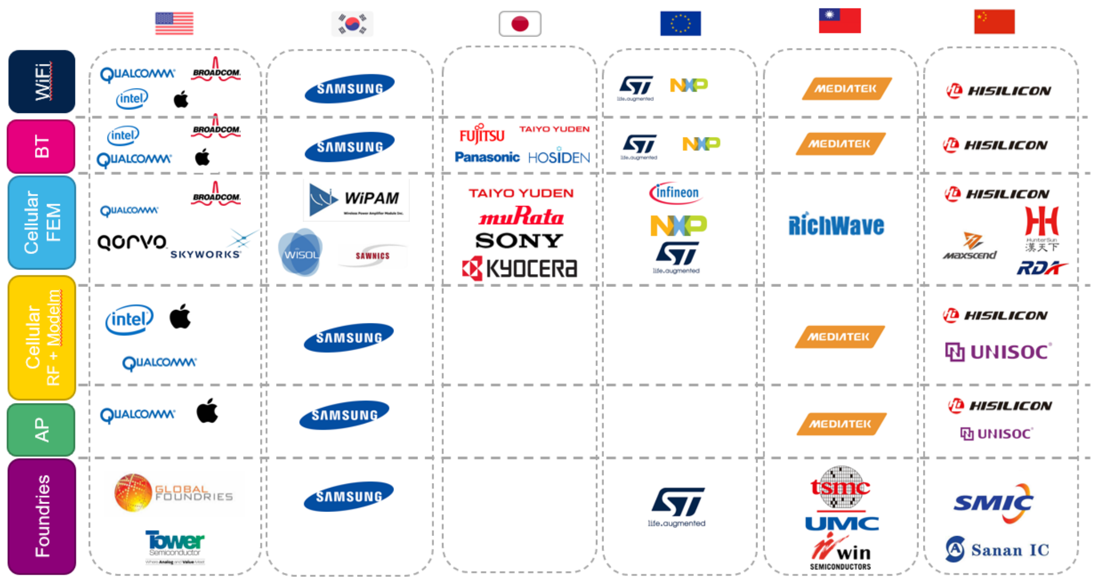

Figure 11 Consumer and wide-area connectivity overview

The first noticeable point concerns the absence of any European player on the consumer cellular connectivity market which is dominated by US (Qualcomm, Intel/Apple), Korea (Samsung), Taiwan (MediaTek) and China (Huawei/HiSilicon and Unisoc). This can be explained by the limited number of actors who moved to a vertical integration strategy (Samsung, Apple, Huawei). However, there are also strong fabless non-European players (Qualcomm and MediaTek). The root cause of this European weakness may lie in the same reasons as for the datacenter market: consumer connectivity solutions must be integrated in very advanced semiconductor manufacturing process and rely on strong software ecosystems.

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Europe has some market share on Bluetooth and Wi-Fi consumer markets, but this position is rapidly eroding since the trend is to integrate such connectivity with the cellular one. The domain of front-end modules is the only one where Europe can still play a significant role on the consumer connectivity market leveraging the derivative technologies developed by major European IDMs. However, we should add that Europe is mainly providing components while most of the value is still captured by module makers in the US (Qorvo, Skyworks) and Japan (Murata).

Challenges:

- No major EU player on consumer cellular connectivity in spite of Europe leading on infrastructure products (Which may be a threat to Europe's ability to play a significant role on 6G.)
- US leadership is challenged by China leading to aggressive export control measures by the US that may limit Europe's ability to use its semiconductor manufacturing capabilities to serve its biggest market (China) which may have impact on opportunities related to 6G.
- All connectivity features are being integrated in the same SoC using advanced manufacturing processes, putting the remaining Europe consumer connectivity business at risk.

Opportunities:

- US export control measures may also create business opportunities if Europe can secure a sovereign and reliable connectivity solution and semiconductor supply chain (this is especially true today for FEMs).
- The current export controls imposed by the US also creates business opportunities for new entrants on the 6G cellular chipset market since MediaTek is today the only viable solution for Chinese OEMs (Huawei, OPPO, Vivo) who dominate the smartphone market

3.3 Investment analysis and recommendations

According to the gap analysis presented in the previous section, we can summarize Europe's general position on connectivity systems and components as follows:

Strengths:

- Leading position on the cellular infrastructure market
- Strong IDM players with a local connectivity solution portfolio and derivative technologies offering
- Leading position on the local connectivity market
- Strong MCU ecosystem well suited for IoT and 6G use cases

Weaknesses:

- Europe does not have anymore any player on the consumer cellular connectivity market
- No advanced CMOS manufacturing facilities in Europe
- No European players are able today to develop advanced CPU or AI accelerators
- Limited capacity for advanced SoC design leveraging advanced manufacturing processes available in Asia

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Moreover, as already mentioned, the current aggressive export control imposed by US (mainly to ensure technology and business leadership) raises additional sovereignty concerns for Europe:

- Potentially limiting Europe's capability to use its installed manufacturing capacity to serve both itself and its business partners.
- It may also restrict Europe's capacity to access key IPs and technologies jeopardizing its ability to compete in key areas (for example AI or 6G).

To address this threat, the goal should not be to aim for a complete autonomy (since associated economy decoupling is neither feasible nor desirable to maintain the global standards ecosystem, e.g. in mobile communication) but to ensure leadership in strategic areas and finding alternate ways of having a secure and trusted access to those technologies where a European supply network cannot be established. By doing so, Europe can speak for itself by providing alternative solutions in the supply chain and thereby gain leverage (since others are as much depending on us on some key topics as we are on them for others). Moreover, such an approach should also create business opportunities by making Europe a sovereign, independent, and reliable source for connectivity solution with a semiconductor supply chain. Consequently, we propose the below investment analysis and recommendation to address Europe's weaknesses and adapt Europe's semiconductor industry to the current geopolitical context.

Manufacturing

- Maintain the current investment effort on derivative technologies (power, sensor, analog, including RF and mm-Wave, photonics etc.) to secure European leadership leveraging its current strength
- Set up new dedicated initiatives to complement Europe's offering on derivative technologies and be able to address key components (for example RF filters and advanced packaging technologies)
- Investing in advanced CMOS manufacturing can be a longer-term objective, but this will need to build on a European ability to design advanced digital SoC (here, serving an indigenous market is a mandatory prerequisite)

Product development

- Focusing on markets where Europe has a leadership position, investments could be targeted to move up in the value chain by delivering systems instead of components
- Additional investments could be dedicated to reinforcing the current CPU development initiative in Europe to enable a sovereign European Cloud solution (e.g., GAIA-X [38])
- New investments should be dedicated to the enablement of one or more advanced digital SoC design companies in Europe (leveraging technology available at e.g. Asian foundries) to both adapt to the market evolution and secure Europe's future position in key markets (for example automotive, industrial, and consumer which will be important use cases for 6G)
- Dedicated investments should also be made for the enablement of AI technologies such as accelerators for cloud-centric applications (since leadership on edge AI may not be enough to ensure sovereignty and business leadership in the 6G area)

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Industry perspectives

The US leadership position on semiconductor manufacturing equipment has been key to implement its export control strategy. Since Europe still also has a strong position in such equipment (as illustrated in Figure 12), dedicated investments would further strengthen this asset and enable a state of the art and independent supply chain. This could be a key strength in securing Europe's sovereignty on semiconductor and connectivity markets.

The US hegemony on CAD solutions is also a threat for Europe concerning its capability to design advanced SoC. Leveraging existing European CAD champions on non-semiconductor markets, dedicated investments could help to enable the emergence of European solutions (to be complemented by an SME ecosystem).

As done by China, the support of the birth of a dynamic fabless ecosystem focused on advanced SoC design is also key for Europe in order to not fall behind the US and China on cloud and AI topics.

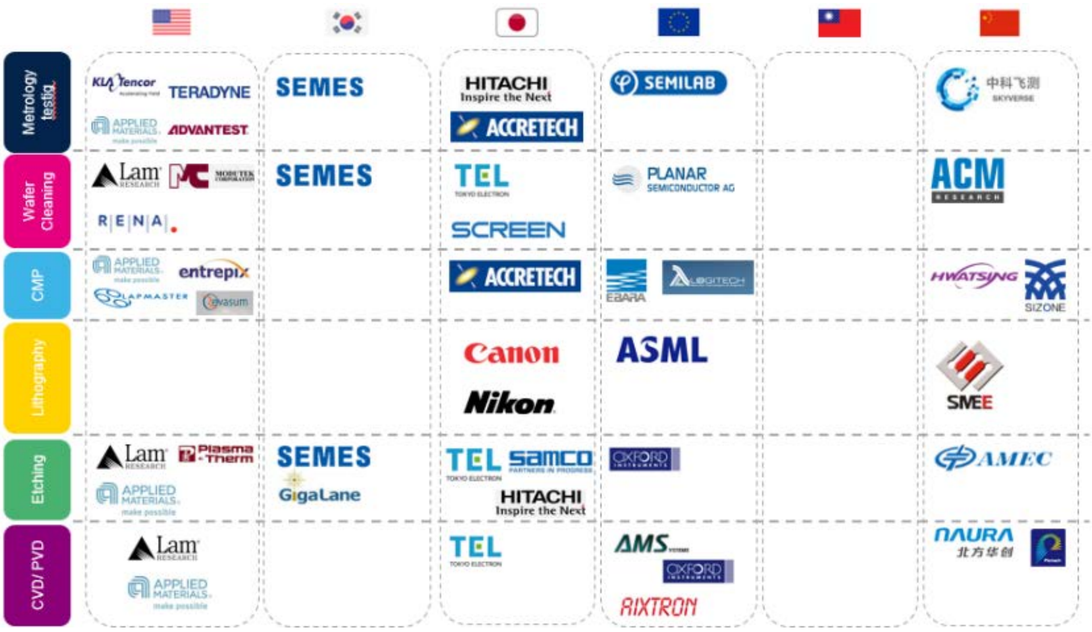

Figure 12 Semiconductor equipment supply chain

Research and innovation

- Cultivating and retaining talent is crucial to support any industrial plan in semiconductor industry, European framework programs are key here
- Encourage academic collaborations with worldwide leading institutions (to both strengthen the training of Europe students and tap into global progress) and attract top research talent abroad to come to Europe
- Continue the effort on derivative technologies (BiCMOS, RF SOI, GaN, Si Photonics, InP, etc.) to maintain a current European strength
- Define new initiatives on advanced digital SoC design of MCUs, CPUs and AI accelerators leveraging advanced Asian semiconductor processing capabilities to support Europe's expertise in this field

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- Links to be made with investments in software to enable a viable and state of the art hardware/software ecosystem (which is vital both devices as well as cloud centric applications)
- A dedicated program on semiconductor equipment manufacturing to make sure Europe can provide state of the art solutions and ensure sovereignty in front of export control challenges
- Launch a program on CAD solution enablement to create alternatives to US incumbents

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4 Conclusion

As pointed out in this report, Europe is facing significant challenges in the coming years to maintain its leadership in telecommunications and microelectronics. China and the US are already acting to secure a high degree of autonomy across the whole telecommunications value chain, including components for connectivity systems. As a result, Europe must invest now to be a frontrunner in evolved 5G and 6G networks. Europe can and must leverage and combine its strengths in telecommunications industry, microelectronics industry and connectivity-enabled vertical industries, and coordinate its actions with a strategic value chain approach, to ensure leadership position in this global race. The recent joint declaration by EU member states in December 2020 on a European initiative on processors and semiconductor technologies [39] is a first and good step in this direction:

"To ensure Europe's technology sovereignty and competitiveness, as well as our capacity to address key environmental and societal challenges and new emerging mass markets, we need to strengthen Europe's capacity to develop the next-generation of processors and semiconductors. This includes chips and embedded systems that offer the best performance for specific applications across a wide range of sectors as well as leading-edge manufacturing progressively advancing towards 2nm nodes for processor technology. Using connectivity, where Europe enjoys global lead, as a major use case driver for developing such capacity enables Europe to set the right level of ambition. This will require a collective effort to pool investment and to coordinate actions, by both public and private stakeholders."

Going forward, the COREnect project will focus on strategic measures to address stated challenges. This includes investment proposals, coordination actions, and the role of different private and public entities.

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