E C S

# Strategic Research Agenda 2018

Electronic
Components
& Systems

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# Strategic Research Agenda 2018

Strategic Research Agenda
for Electronic Components & Systems
prepared on behalf of:

Aeneas

ARTEMIS Industry Association

EPoSS European Technology Platform on Smart Systems Integration

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# PREFACE

A radical, digital transformation is occurring in how we live and how we work. The innovations that lie at the heart of this transformation are founded on the rapid developments of Electronic Components and Systems (ECS)-based applications. For the first time, the three industry associations – AENEAS, ARTEMIS-IA and EPoSS – that represent their members along the ECS value chain have co-authored a joint ECS Strategic Research Agenda (SRA). Valuable feedback was gained from the ECS community during the European Forum for Electronic Components and Systems 2017 (EFECS 2017) in Brussels for this important milestone which sets the strategic priorities and technical pathways to enable European industry to become stronger and more competitive, and to have a significant and beneficial impact on society and the economy.

The ECS SRA aims to foster this digital transformation by supporting the development of technology solutions over the entire ECS value chain, addressing the emergence of new business models with shorter innovation cycles and new transaction mechanisms for improved trust and security. It captures the game changers that have led to a smart economy and society (smart mobility, smart health, smart energy, smart industry and smart life). The ECS SRA acts as a tool to realise the industry-driven, long-term vision of an ECS ecosystem. By focusing on strategic priorities, it aims to align and coordinate research policies in Europe as well as match the allocation of programmes and resources to different technology and policy challenges. The Research, Development and Innovation (R&D&I) strategy identifies the game changers and market drivers, providing a top-down guide to the strategic areas for project generation. It also addresses the essential capabilities required to meet the application needs, dissolving barriers between application sectors to create a complete ecosystem of companies, universities and research institutes together cooperating to develop key technologies and applications. Finally, in establishing an adequate environment to transform the research results into successful solutions, European stakeholders will be strengthened and become a more competitive force.

Implementing the ECS SRA will translate not only into economic value but also have profound societal impact, by contributing to meet the challenges of sustainable living and of the long-term European policy on zero carbon dioxide emissions. In the global competitive arena, the aim of keeping or even bringing back manufacturing to Europe is evident in European and national initiatives like *Industry 4.0, Industrie du Futur* and Digitising European Industry. In terms of the societal needs arising from an ageing society, new approaches based on ECS will help maintain the living standards that have been reached in Europe. In the context of growing protectionism in the US and China, Europe has to retain its sovereignty and autonomy for the provision of its rapidly increasing need for electronic components, embedded/cyber-physical systems and smart integrated systems. The three associations share the firm conviction that the companies, research institutes and universities should remain strongly engaged together in driving the research and innovation agenda impacting our everyday lives.

**Reinhard Ploss**
*President of AENEAS*

**Laila Gide**
*President of ARTEMIS-IA*

**Carmelo Papa**
*Chair of EPoSS*

# 0

# Introductory and overview chapter

# 0.1. WHY THIS SRA? TOWARDS A DIGITAL EUROPE

## 0.1.1. The digital society

Digitalisation[1] and the underlying key technologies are an essential part of the answers to many of the daunting challenges that we are facing today: mounting insecurity, ageing population, air quality degradation in large cities, traffic congestion, limited energy resources, unemployment, to name but a few. They will impact the everyday lives of citizens as well as all business sectors. Shaping the digital transformation of Europe opens huge opportunities for the deployment and take-up of digital technologies: digital transformation facilitates the use of new technologies and widens the business scope worldwide with innovative digital products and services. **The future of Europe is digital.** It must be substantially shaped by a strong European electronic components and systems industry.

McKinsey estimates that digitalisation will potentially add 1 trillion EUR to the GDP in Europe as our daily lives and economies become increasingly dependent on digital technologies.

## 0.1.2. ECS at the core of a digital Europe

The core enablers for this digital transformation are Electronic Components and Systems (ECS), where the components are the hardware and software parts of the systems, and the word "systems" is used in this context for the respective highest level of development targeted within the given part of the value chain. A "system" designed and implemented within a given development process may be integrated as a "component" into a higher level "system" within another development process. These Systems typically include hardware and software parts.

Electronic Components and Systems are core enablers and differentiators for the development of many innovative products and services in all sectors of the economy. As developed in section 3, Europe's ECS industry is still strong: the ability to develop and produce highly performing and reliable systems to the needs of customers is based on the availability of components that are tailored to the needs of the systems.

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[1] *For the sake of clarity, the following definitions are used in this report to distinguish between digitisation and digitalisation:* Digitisation: *the conversion of text, pictures or sound into a digital form that can be processed by a computer. i.e. from analog to digital. Digitalisation: the use of digital technologies to transform business models, generate new revenue and value-producing opportunities, interact with the world. i.e. putting the digital into practice.*


**F.1** *The electronics value chain*

The key differentiators for the success of European systems are:

- application-specific semiconductor technologies ('More-than-Moore technologies') like RF [2], MEMS, and Power semiconductors, as well as the very low power CMOS technologies like FD-SOI where European companies are world market leaders;
- the traditional European strength in Cyber Physical Systems and the on-going revolution of the Ubiquitous Computing that present an opportunity to position European actors as world-class leaders;
- design of highly complex, efficient and reliable software solutions operating from micro-controllers up to complex products such as aircraft, satellites, cars and trains, to cite a few;
- highly miniaturised and tailored packaging and assembly technologies to integrate the heterogeneous components of the ECS into a low-space, energy-efficient package;
- a world-class equipment industry which serves not only the local S/C industry but also manufacturers of high-volume standard products like microprocessors and/or memories that are produced mainly outside Europe but whose performance and reliability form the basis of successful SW within any ECS.
- world-class industry sectors in aeronautics and space, automotive, health and energy.

The importance of such capabilities for the success of European ECS-based systems will dramatically increase as European Society undergoes a digital transformation, so it is essential to boost innovation here in order to support this transformation.

Europe digitilisation represents a great opportunity, as well as a pressing need, to undertake ambitious R&D&I to generate market products and services that benefit citizens, businesses and society. This requires a wide range of Research and Innovation topics to be addressed, covering the whole ECS value chain from equipment, materials, production technologies, packaging and assembly technologies, embedded software through architecture and design tools, modelling and models, libraries and complete functional blocks over the different levels of abstraction up to the level of Smart System Integration [3] and to complex Cyber-Physical Systems [4] or even Cyber-Physical Systems of Systems such as aircraft, cars, complex lithography systems and ECS manufacturing clusters.

Europe has to recognise the opportunities as well as the threats provided by the digital society if we are to maintain those key technologies and capabilities in-house.

### 0.1.3. Aligning R&I priorities across technologies and applications

**This ECS-SRA aims to foster the digital transformation by supporting the development of technology solutions over the full ECS value chain. It focuses on the strategic priorities to bring innovation through smart digitised applications, products and services in a large variety of activity sectors.**

The pan-European ECS Strategic Research Agenda is a tool to realise the industry-driven, long-term vision on ECS. By focusing on strategic priorities, it aims to help align, and coordinate research policies in Europe and match the allocation of programmes and resources to different technology and policy challenges, and to ultimately strengthen European stakeholders in the ECS.

Until the turn of the century, the electronics industry advances have been mainly powered by Moore's law and by the concurrent progress in software engineering. As transistors became smaller, they were cheaper, faster and less power-consuming. Whatever the application needs (performance, cost or energy-driven), miniaturisation was the answer. As a result, the technology development roadmaps for integrated circuits could be largely decoupled from the applications roadmaps.

As scaling reached physical and economic limits, new technologies to increase functionality, which were no longer "market agnostic", grew in importance. In particular, the European ecosystem (industry, RTOs and academia) took a leadership position in the development of market-specific components and technologies, described in the section "game

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[2] *The reader will find the meaning of this and other acronyms used in the SRA in chapter 17*

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[3] *Smart System Integration: combines multiple technologies, functions and materials utilising nanoelectronics, micro-electro-mechanic, magnetic, photonic, micro-fluidic, acoustic, bio- and chemical principles, radiation and RF as well as completely new technologies to form smart systems that are reliable, robust and secure, often miniaturised, networked, predictive, can learn and can be autonomous. They bring together sensing, diagnosing, managing, actuation, communication and collaborative capabilities to enhance the quality of life and address societal challenges.*

[4] *Cyber-Physical Systems are « embedded Intelligent ICT systems" that make products smarter, more interconnected, interdependent, collaborative and autonomous. They provide computing and communication, monitoring and control of physical components and processes in various applications. Harnessing these capabilities in time and across space creates applications with enormous and disruptive new functionalities with unprecedented societal impact and economic benefit for citizens and societies.*

changers". New functions and new figures of merit have emerged, and technology and application roadmaps are now interrelated: applications needs determine the technology development priorities while applications base their development roadmaps on expected new technological capabilities. Consequently, this document was elaborated by bringing together over 250 experts from applications and technology domains alike, across the whole R&D&I spectrum from university labs to large companies, and from RTOs to SMEs.

## 0.2. GAME CHANGERS

Innovation along with rapid developments across all ECS-based application areas are creating the foundation to transform the way we work and live. The falling cost of all semiconductor components, the advent of software elasticity [5], the rise of broadband, ubiquitous connectivity, the omnipresence of autonomy and virtualisation, the efficiency increase in power management, "clean" mobility and miniaturised systems, the use of sensors and actuators as connectors, the Human Machine Interfaces (graphical, touch, holographic, voices, gesture, ..) with the outer digital world have been combined to create the dawn of a digital era filled with the accelerating evolution of technologies. Radically and rapidly changing business models and lifestyles are leading to a Software Defined Everything to support the investment costs by adding multi-tenant and agility to the deployed ECS based applications. The emerging ecosystems around embedded intelligence and artificial intelligence technologies, blockchain and security, the Internet of Things (IoT) [6], High Performance Computing, the ever-growing miniaturisation, as well as increasing physical and functional integration into devices and Smart Systems, among others, have quickly moved from cutting-edge to being on the verge of mainstream thus creating new paradigms. In parallel to the change of daily life by available technologies, the challenges regarding sustainable living and the fulfilment of a long-term European policy on zero carbon dioxide emissions and zero fatalities in road transport demand disruptive solutions. In the global competitive arena, the aim to keep or even bring back manufacturing to Europe through initiatives such as Industry 4.0, Industrie du futur and the like are now digitalising European industry. For the societal needs of an ageing society new approaches based on ECS will pave the way in the future to maintain living standards which we have achieved in Europe. We review these main trends [7] below, which we call "game changers" due to their disruptive nature.

*[5] Ability for the software to use more or less hardware at runtime (adapting to the workload).*

*[6] IoT: McKinsey & Company Global Institute in its report: Internet of Things: Mapping the value beyond the hype – June 2015 define IoT as: sensors and actuators connected by networks to computing systems. These systems can monitor or manage the health and actions of connected objects and machines. Connected sensors can also monitor the natural world, people and animals. They exclude systems in which all of the sensors primary purpose is to receive intentional human input, such as smartphone apps where data input comes primarily through a touchscreen, or other networked computer software where the sensors consist of the standard keyboard and mouse.*

*[7] Only generic game changers, affecting most or all technology and application domains covered by the SRA, are included in this chapter. If they exist, domain-specific game changers are also mentioned in the relevant domain chapter.*

### 0.2.1. New technological paradigms

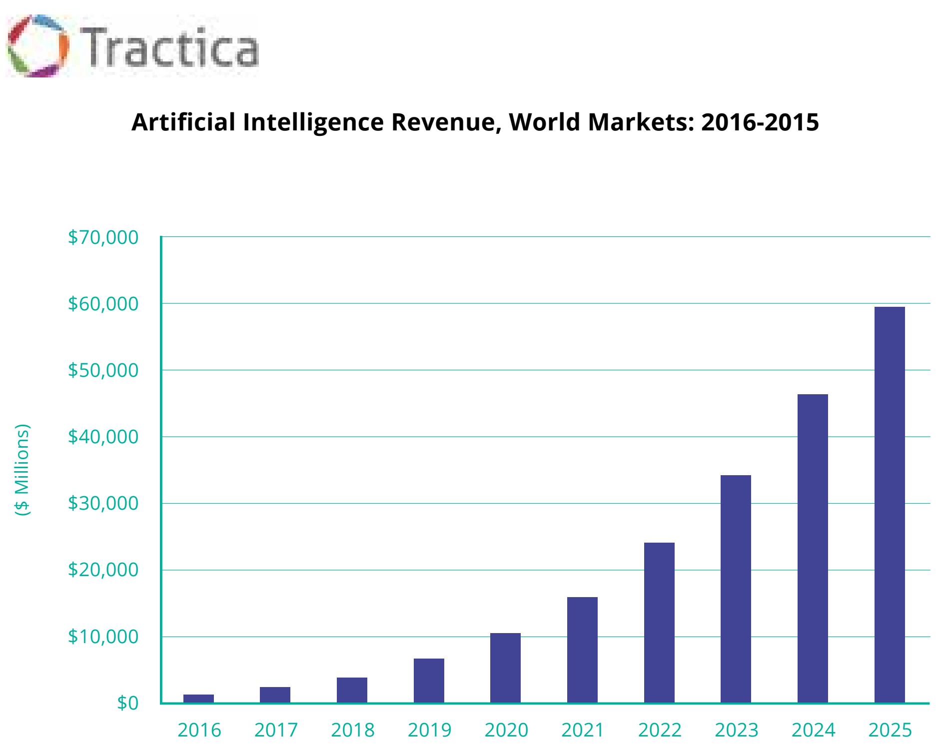
**Advances in computing: Facing a new software complexity**

Thanks to the achievements of 50 years of Moore's law, mentioned in section 1.3, computers have reached unprecedented power, leading to challenges in the software and programming fields. With gigantic computing solutions come gigantic problems for programming them. The large amount of data (*"data deluge"*), resilience, safety, security and autonomy require new innovative computing solutions to satisfy the emerging needs that are no longer satisfied.

In a world where protectionism is on the rise, a lack of high-end processing capabilities in Europe (i.e. relying on buying them from countries outside Europe) might become a weakness. China, Japan, India and Russia are starting to develop their own processing capabilities in order to prevent potential shortage.

**Advent of artificial intelligence and data analytics**

After a period of disillusion, Artificial Intelligence has recently been scoring huge public successes, with machines now defeating humans in many fields, from general culture to strategy games. This technology aims to have a disruptive impact in many of the domains covered by the Strategic Research Agenda, whether in our daily life (with apps including cloud-based advanced assistant systems) or in specialised domains such as healthcare (e.g., advanced systems to help provide clinical support for healthcare professionals), energy, or industry (preventive and predictive maintenance). In general, data and data science are a new sort of material that fuel the AI applications, and together they also represent a significant driver of the research strategy of the essential capabilities, e.g. requiring adaptation of the computing models being developed.




*Forecast of AI revenues until 2025* Source: Tractica **F.2**

According to a report from Tractica (Figure 2), the revenues generated by the direct and indirect application of AI software will grow from USD1.4 billion in 2016 to USD59.8 billion by 2025.

In addition to intensive embedded intelligence capabilities, the Autonomous Cyber-Physical Systems (ACPS) develop new ways to interface with the real world in general and humans in particular: Virtual Reality, Augmented Reality, Brain-Computer Interfaces, Deep Learning and cognitive computing are changing the way humans interact with the digital world, and drive research and innovation priorities. In providing a range of novel functionalities provided by artificial intelligence, smart systems may also become a driving force behind almost all product innovations in almost every application field: transportation, health, manufacturing, the Internet of things (IoT), energy, natural resources and security.

Humanoid robots, able to interpret human body language and read emotion, will support the improvement of patient care and wellbeing, and could have impact beyond that in our daily life as well as on the factory floor.

While this major game changer represents a clear opportunity for improving our lives, it also carries a threat:

- for Europe, since the current big players in hardware and software are mostly non-European;
- and maybe also on a wider scope, as some futurists are predicting that supercomputing power together with cognitive capabilities would lead to a situation where machines will autonomously invent more and more machines with no or few human intention / interventions.

The slowing down of Moore's law and the arrival of radically new paradigms for computing provide an opportunity for Europe to come back in that field, in terms of both hardware and software technologies. In particular, the emergence of neuromorphic and quantum solutions will open new opportunities for computing hardware platforms where no entrenched incumbents exist. This represents a new playing field, in which a window of opportunity exists for Europe to retake leadership in computing.

### Increased Connectivity

The next phase of the Internet, including the Internet of Things where we are always on and always connected, has the potential to transform our economy and personal lives even further. While this represents huge opportunities, it is not exempt from threats: as previously isolated safe systems are getting connected to the outside world, novel integrated approaches are needed to ensure both safety and robust security for products.

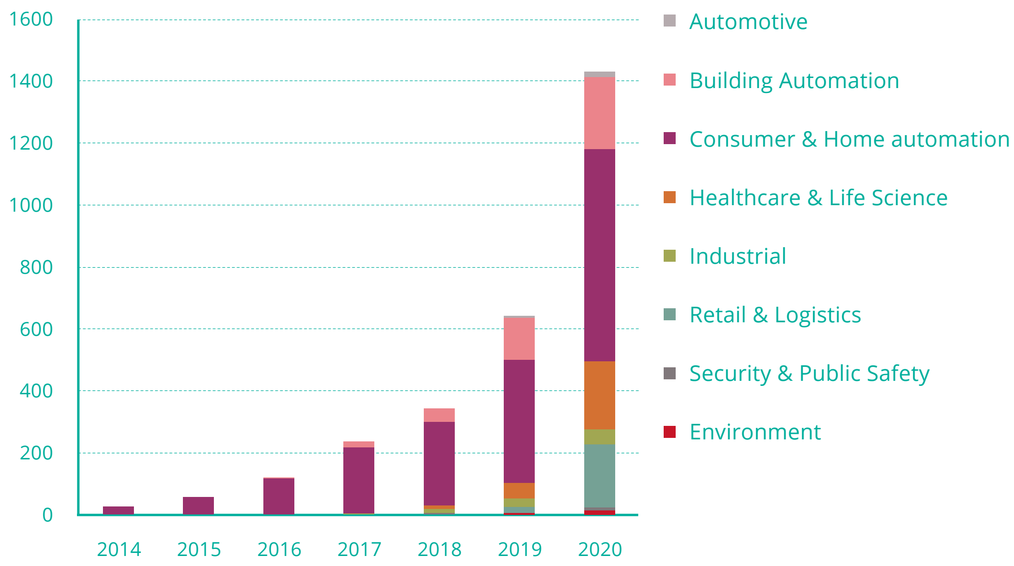
In particular, it is essential for the European ECS industry to be at the forefront of the 5G research and innovation and access to safe cloud solutions, both to reap the benefits of this future huge market and to allow Europe to leverage this technology for an improved competitive position by sharing and combining data. More generally, Europe must remain at the forefront of the Next Generation Internet, which requires the development of advanced technologies for faster access, higher capacity, ubiquitous connectivity, energy saving and virtualised network / network management.

### Application-specific semiconductor technologies

In recent years application-specific semiconductor technologies have been playing an ever-increasing role in our day-to-day lives: without the advances in sensor and actuator technologies, and the embedded software in current ADAS systems, passive and active safety solutions in cars or the smartness of smart phones (a smart phone is now able to contain more than one million lines of code) would even be unthinkable. Similarly, the introduction of the renewable energies, minimised chargers, electric powertrains in vehicles – these are all dependent on the capabilities to achieve higher power densities and far less dissipation losses to enable smaller and smaller form factors.

Those technologies are evolving towards smaller component sizes and/or fabrication on larger wafer diameters to further reduce cost and improve performance. Along with the performance increases of the next "More Moore" generations, they are enabling as well as benefiting from further developments of the market for ECS. For example, figure 3 illustrates the impact of the IoT expected development on the MEMS market.

**FORECAST MEMS-WORLDMARKET FOR IOT (M$)**




*Market Forecast for MEMS world market for IoT* source: ©2014 | www.yole.fr **F.3**

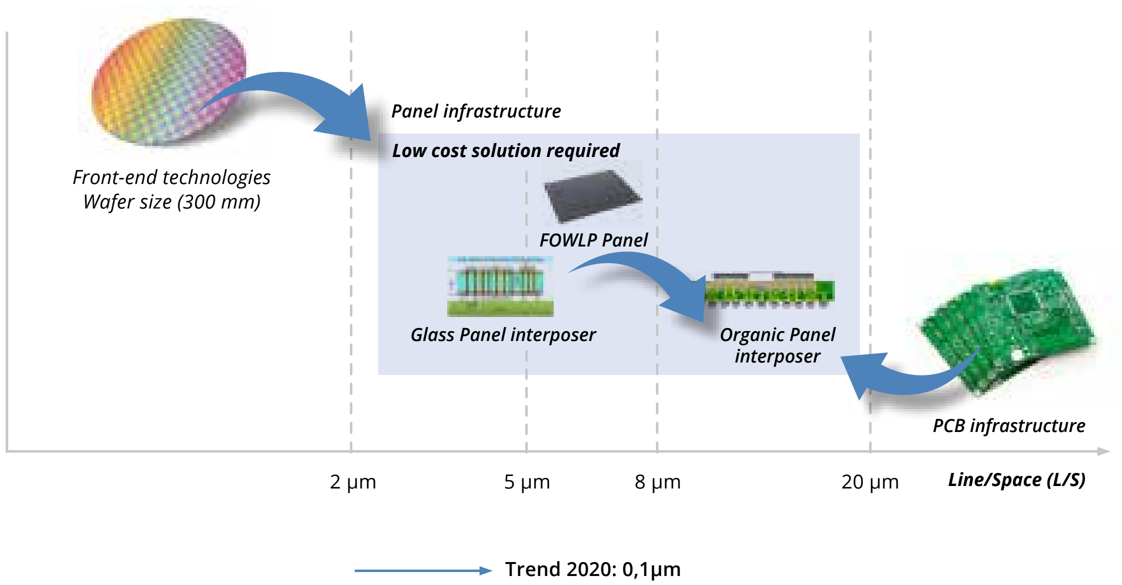
Those advanced application-specific technologies were made possible thanks to the development of processes and materials (such as SiC and GaN for power devices) as well as the necessary equipment. They enable innovative emerging applications, while leveraging synergies with processing and manufacturing technologies of More-Moore devices.

### Heterogeneous Integration / Comprehensive Smart Miniaturised Systems

The realisation of smart electronic components and systems for Europe's critical applications requires complementing logic and memories with additional features, non-scalable with Moore's Law, needed to handle functions like sensing (MEMS and imagers), actuating, communication, data protection and power management. These heterogeneous functionalities can be monolithically integrated into a single System-on-Chip (SiC), as for embedded memories, analogue and Smart Power, or realised as discrete components by heterogeneous System-in-Package (SiP) integration.

To meet the demanding specifications and boundary conditions of major applications, more functionality must be integrated in a smaller volume, requiring new assembly and packaging materials, compatible chip/package interfaces as well as heterogeneous integration of chips with different functionalities like MEMS/sensors, power chips, processors or memory. A special focus on electrical capabilities and temperature constraints must keep the applications robust and reliable.

Therefore, heterogeneous integration and packaging/assembly technologies have become a key issue for the performance/reliability and cost of an ECS.




**F.4** *The heterogeneous integration domain in electronic components merges the conventional PCB with the wafer level technologies (source: Fraunhofer IZM).*

Going beyond components, this game changer impacts R&I strategy in many domains covered by the SRA, such as:

- "Computing and Storage", where it leads to research on hardware/software specialisation according to the task at hand, and on the management of heterogeneity and complexity;
- System level whereby research aims to combine software functionalities with sensing, actuation, data communication and energy management in an integrated way to develop knowhow that enables high-volume, manufacturable devices based on a multitude of different systems or sub-systems;
- Connectivity and interoperability, whose R&I priorities include the development of methods and tools enabling the use of heterogeneous protocols over heterogeneous hardware;

- Physical integration at all levels, in which the use of 3D architectures provides opportunities for increasing the functional density and improving the performance of the devices;
- Physical integration at system level, whereby energy autonomy [8] becomes an important consideration for IoT schemes, as well as the local vs global split of computing / data treatment capabilities in relation to functional autonomy and response time of the overall distributed system and its individual nodes.

These new technologies enable the creation of systems that are comprehensively capable of sensing, diagnosing, managing and actuating in a communicative and collaborative way. Already today, these systems are often highly miniaturised; operate in networks, feature predictive and energy autonomy capabilities, constituting the embodiment of what is now known as the “Internet of Things”. In future, they will increasingly integrate physical artificial intelligence, feature self-organising, self-healing and truly cognitive functionalities. They will be designed to meet the growing requirements in terms of reliability, functional safety and security that result from the new applications and the demanding environments in the fields of personal and freight transport, digital industry, health and wellbeing, smart energy and digital life. At the same time, many of these systems will be fabricated for business-to-business sectors and for the general public, i.e., at costs appropriate to the markets of commercial and individual end users. With this large penetration, these new systems will address and substantially contribute to the mastering of the societal challenges.

### Additive manufacturing / 3D printing

The constraints of current manufacturing infrastructure, optimised for low-cost/high-quality products that are mass produced in enormous quantities in Asia lead to standardised components and product designs, limited shape freedom, a rigid supply chain and pressure to minimise variation to allow the high fixed manufacturing costs to be amortised over many produced units. Additive manufacturing techniques have the potential to introduce a major paradigm change in the industry, enabling Europe to regain leadership in the fabrication of the increasingly customised products demanded by today’s markets. One striking example is the health sector, where these technologies enable the fabrication of patient–specific anatomical models. Beyond that, they could even disrupt supply chains and business models, as parts made centrally and subsequently shipped across the world could now be 3D-printed in decentralised locations.

### Micro Nano Bio Systems (MNBS)

Combined with the continuous development of new materials (such as graphene and metamaterials for medical devices) and 3D Printing

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[8] *low-power operation (sensing/ acting, computing, communicating) coupled to feasible unwired power (energy harvesting and storage)*

using even biological materials, Computerized Numerical Control machining should allow the printing of implants and prosthetics adapted to individuals. Leveraging the latest advances in energy harvesting and power management will enable devices that may never need to be replaced.

Nano devices will change diagnostics, targeted drug treatment and local treatments. Bio sensing, molecular biology and genomics will provide more insight towards personalised treatments.

One step further, the in vitro technologies used today to develop organs on a chip should lead to *in vivo* implantable organs on chip or implantable organs in a package that could substitute donor organs or assist ailing deficient organs. They will be the path towards regenerative medicine, aiming to restore degenerated, diseased or damaged tissues and organs, thereby increasing vital functioning and reducing the cost of healthcare.

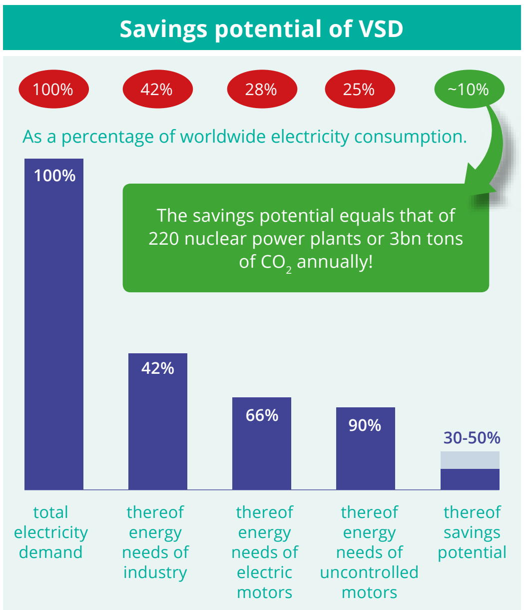
### Energy landscape

The ambition to achieve zero emissions towards 2050 drives the need for a change in the energy landscape. ECS supports the setting up of this landscape with the lowest dissipation losses, integrated intelligence and smallest form factors.

By way of complementing its contribution to more efficient energy generation and distribution, ECS and, in particular, power technologies also have a huge potential impact on energy consumption in the industry domain, as illustrated by figure 5.

**FACTORY AUTOMATION:**
**HUGE SAVINGS POSSIBLE WITH VARIABLE SPEED DRIVES (VSD)**

- About 300 million electric motors are in use worldwide
- Rising electric energy cost and ErP (Energy-related Prodcts) directive force energy efficiency
- Rising labor cost in low labor cost countries drives automation level.
- “Mechanic goes electric”; e.g. hydraulic is replaced by electric motors.




**F.5** *Energy-saving potential of S/C power technologies*

### The Fourth Industrial Revolution

The First Industrial Revolution used water and steam power to mechanise production. The Second used electric power to create mass production. The Third used electronics and information technology to automate production. Now, the Fourth Industrial Revolution (such as **Industry 4.0,** Industrie du Futur and Digitising European Industry) heralds a fusion of technologies in which the lines between the physical, digital and biological spheres are becoming blurred.

In parallel or in combination with the new manufacturing technologies mentioned above, advances in ICT (Information and Communication Technologies) now allow large horizontal integration across multiple value chains on processes, data and companies, as well as vertical integration among corporate levels, from the enterprise resource planning (ERP) level down to the field level (robots, sensors and actuators, shop floor). Connected enterprises can attain increased efficiency in processes, performance and output, giving rise to virtual network enterprises.

In addition, the concept of mass customisation (a.k.a "Agile value networks" or "lot size 1"), i.e. by manufacturing only what the customer wants, will significantly reduce the waste and inefficiency of current mass-market production, directly decreasing environmental impact and increasing responsible consumption and production, one of the Sustainable Development Goals of the European Union.

EU companies that focus on high-quality and personalised products/services could provide them at significantly lower costs, while maintaining the attention to design and functionality that makes companies successful. This could give a significant competitive advantage to EU manufacturers compared to low-cost mass manufacturers.

All these changes are an opportunity for Europe to reverse the current trend of shifting production to countries with low labour (and other societal) costs thanks to flexible and cost-effective production enabled by Electronic Components and Systems technologies.

Like the earlier revolutions, the Fourth Industrial Revolution has the potential to raise global wealth and improve the quality of life for populations around the world. The full impact on business, governments and people will be as unprecedented as it will be unpredictable.

## 0.2.2. New business model paradigms

### Everything as a service - new business models / internet economy

Initiated in the IT world, the trend of replacing ownership with a pay-per-use system – also known as "Everything as a service", or XaaS - is now entering the physical space. For example, Mobility-as-a-Service (MaaS) will increasingly catalyse the public-private co-development and co-delivery of mobility and transport systems and services, as well as shared and open use of public space, data and infrastructure.

The Mobility market is now regarded as multimodal, combining all kinds of transport means, including mobility data and information, and access to it.

### Faster and shorter innovation cycles

The challenge is to cope with the adversary requirements of the ever-decreasing time-to-market and the need for a longer "time on market", which directly impact technology requirement definitions. The challenge can be met, e.g., by providing upgradable ECS for later adaptation at the customer's site.

### New transaction mechanisms for improved trust and security: blockchain

Initially confined to the world of security experts, distributed ledger technology (for example, blockchain) has the potential to enable innovation across the economy. For example:

- For Healthcare: health and life insurers are among the many players scrambling to determine how blockchain could be adapted to improve the way we maintain health records, execute transactions and interact with stakeholders.
- For energy: to enable transactions and micro-trading in the new smart distributed energy resource grids
- For the cashless economy: virtual currencies and crypto-currencies.

### Vertical integration & leadership

Hyper-scale businesses are vertically extending their range of activities by creating customer lock over the complete value chain. For example, in the domain of consumer electronics, companies that have gained control over the complete value chain (from silicon design through retail or internet shops up to end-user applications) have recently shown a high level of success and seem to be more resilient to the economic crisis as they have created ecosystems and customer lock-in over the complete value chain.

The vision of 'virtual vertical integration' encourages market leaders to define the conditions for successful business innovation building on emerging technological developments, and vice versa, to coordinate technological platform developments (hardware and manufacturing to system design and software engineering). On an organisational level, the horizontally specialised European industry faces a critical situation in this competition, unless vertical ecosystems emerge. Based on this assumption, the present SRA strategy highlights the importance of the contribution to standardisation activities and setting adequate new standards, as standards are essential enablers for scalability and interoperability functionalities. Also important is the development of design environments that efficiently cover the ECS design process over the whole value chain.

### When consumers become prosumers

New technologies enable consumers to become co-designers and/or actors of the services and products they are using. In health, patients can provide first-level self-diagnosis. A consumer of digital content has evolved into a prosumer with the advent of social media platforms like YouTube. A home owner installing a solar panel is as much a supplier as a customer of his electric utility company. Companies turn to their end-customer for the design of new products. This trend requires in turn that products be designed with in-field personalisation in mind.

Energy and power management are clear examples where these new paradigms are being developed:

- At the macro level, the growth of alternative energy sources such as solar and wind power, and the importance of efficient energy management for the development of smart cities, are changing the nature of the world's power grids. The increasing distribution of power generation leads from today's uni-directional to a distributed and bi-directional power flow, requiring so-called smart grids, and the development of new electricity storage solutions. The emerging wide bandgap semiconductor [9] and integration technologies are key enabling factors for these new electrical architectures.
- At the micro-level, the development of ultra-low power sensing and data processing capabilities, combined with new energy harvesting technologies, allow the creation of systems that are energy autonomous over their entire lifetime i.e., they are able to produce all the energy they need to consume. This will have a profound impact on many application domains, such as health, where lifelong implantable devices can now be envisioned.

### 0.2.3. New non-technical, societal paradigms

The game changers considered so far are technology or business-related. However, other major trends are at work, shaping our future and which need to be taken into account when deriving a strategy for Europe ECS Industry Research and Innovation:

- **Political:** We are witnessing an era of economic protectionism, which makes it all the more important for Europe to secure its access to essential technologies and to avoid strategic and economic critical dependencies. Regions and territories also intend to play a greater role in technological roadmap and implementation.
- **Economic:** Developing economies in Asia and Africa represent both opportunities (expanding markets) and threats (increased competition). They also prompt us to develop new approaches to innovation, where ECS technology can be a key enabler.
- **Societal:** The European population is ageing, putting a strain on already constrained health budgets, changing the nature of the digital services which we need, and having an impact on our production infrastructure. This is to be viewed both as a threat and as an opportunity, since it also forces us to solve now challenges which other regions of the world will be facing in the future. The increased urbanisation also requires new approaches (in energy management, transport and mobility, etc…) which, once developed for Europe, will find new markets beyond our borders.
- **Environmental:** The impact of climate change and the need to safeguard the environment are raising challenges which cannot be solved without the ECS industry. As an illustration, energy efficiency levels in IEA member countries improved, on average, by 14% between 2000 and 2015. This generated energy savings of 19 exajoules (EJ) or 450 million tonnes of oil equivalent (Mtoe) in 2015. On the other hand, the ECS industry might also be a source of non-environmentally friendly materials, for example with the use of rare earth.
- **Feeling safe and secure:** Faced with many threats in their daily lives, from terrorism to disruptive changes in their way of living, through food and health crises, the citizens of Europe are increasingly demanding safety, security and protection of their privacy and personal data. ECS technology should be part of the solution, but at the same time it needs to take this requirement into account, at the design phase if it doesn't want to add to the problem (e.g., unprotected IoT devices providing entry doors to hackers and privacy breaches).
- **Legal:** Local legislation has a major impact on the deployment of some ECS-driven applications such as autonomous driving and Micro-Bio-Nano-Systems. Discrepancies between the rules applicable in various European countries might hamper

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[9] *Wide-bandgap semiconductors (WBG or WBGS) are semiconductor materials which have a relatively large band gap compared to typical semiconductors, such as GaN, SiC, etc… Compared to circuits built with usual semiconductors, wide-bandgap semiconductors permit devices to operate at much higher voltages, frequencies and temperatures than conventional semiconductor materials.*

the development of these technologies, and of the corresponding European-based industry, compared with what happens in regions benefiting from a unified legal framework. Adequate legal environments are required to achieve the full potential of future ECS systems for European citizens.

# 0.3. COMPETITIVE SITUATION

## 0.3.1. Key application areas

European industry has strengths in several vertically integrated markets where ECS are the main drivers of performance, such as transportation (automotive, railroad, aerospace), energy, health, urban services (from building construction to water provisioning), and industrial digitalisation.

### Transport and smart mobility:

- **Automotive:** The EU is among the world's biggest producers of motor vehicles and the sector represents the largest private investors, providing jobs for 12 million people and accounting for 4% of the EU GDP, with 3 million manufacturing jobs.
- **Rail:** the overall rail sector in the EU, including the rail operators and infrastructure managers, employs approximately 1.8 million people with an estimated 817,000 dependent individuals. The European rail supply industry employs nearly 400,000 people and is a top exporter, accounting for nearly half of the world market for rail products with a market share of 84% in Europe and a total production value of 40 billion euros (2010). The railway management systems market is expected to grow from 29.27 billion in 2016 to 57.88 billion by 2021.
- **Aerospace:** The European aerospace industry is a world leader in the production of civil and military aircraft, helicopters, drones, aero-engines and equipment, exporting them all over the world. Aerospace within the EU provides more than 500,000 jobs and generated a turnover of 140 billion euros in 2013. The aircraft flight control systems market is projected to grow from USD 11.85 billion to 16.59 billion by 2011.

### Health and wellbeing

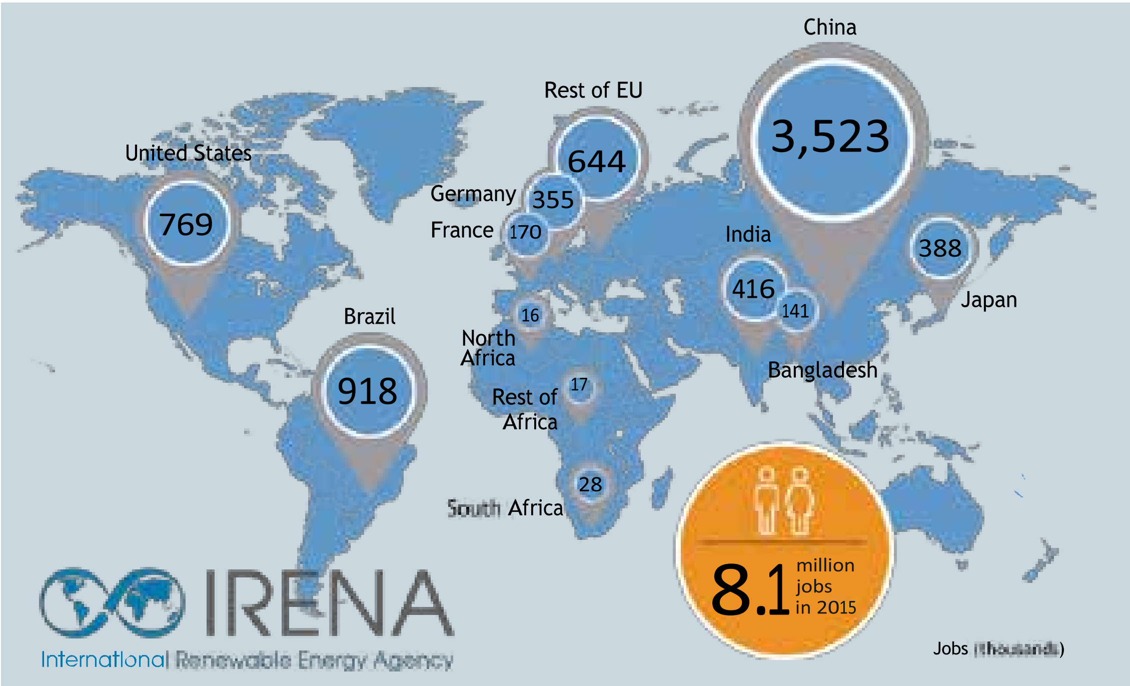
Healthcare spending as a percentage of gross domestic product (GDP) should rise slightly, from an estimated 10.4% in 2015 to 10.5% In 2020. Government healthcare expenditure as a percentage of GDP is projected to rise more quickly in low-income countries than other income groups.

Global healthcare expenditure is projected to reach EUR8.7 trillion by 2020, from EUR7 trillion in 2015, driven by improving treatments in therapeutic areas coupled with rising labour costs and increased life expectancy.

The healthcare sector accounts for 10% of all employment and is expected to grow by a further 1.8 million jobs up to 2025. The healthcare IT market is projected to reach EUR200 bn by 2021 from EUR115 bn in 2016.

### Energy

More than 9.8 million people were employed in the renewable energy sector in 2016, according to a recent report from the International Renewable Energy Agency (IRENA). In 2015, Europe was employing close to 1.2 million people in this fast growing sector.




*Renewable energy employment in countries and regions* [10]

**F.6**

In 2015, the worldwide renewable energy generation amounted to 5512 TWh, Europe's share of which was 1168 TWh, or 21%.

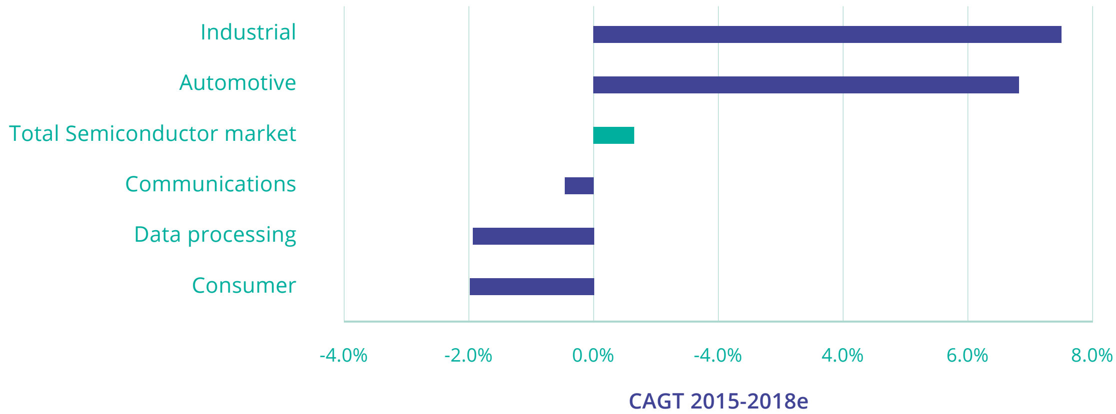
### Sustainable production

The manufacturing sector accounts for 15% GDP and provides around 33 million jobs in Europe. Europe is a frontrunner in manufacturing excellence with the vision of smart and connected factories swiftly becoming a reality. The industrial control and factory automation market, comprising control system manufacturers, field components manufacturer, systems integrators and software manufacturers is projected to reach USD153.3 billion by 2022. By 2025 additive manufacturing is expected to create a EUR6.3 bn opportunity in the consumer electronics, automotive and aerospace industries.

↑

[10] *Source: IRENA International Renewable Energy Agency. Renewable Energy and Jobs Annual Review 2016*

Many of these application domains, where Europe has a leadership position, are expected to generate higher than average growth for ECS components:




**F.7** *Source: WSTS; IHS; Bryan, Garnier & Co ests.*

Overall, the forecast of the annual growth rates for demand of ECS components in Europe is given as being higher than for other regions.

| Spring 2017 - Q2 Update | Amounts in US€M | | | | Year on Year Growth in % | | | |
|---|---|---|---|---|---|---|---|---|
| | 2016 | 2017 | 2018 | 2019 | 2016 | 2017 | 2018 | 2019 |
| Americas | 65,537 | 79,555 | 83,464 | 83,116 | -4.7 | 21.1 | 4.9 | -0.4 |
| Europe | 32,707 | 37,760 | 39,639 | 39,998 | -4.5 | 15.4 | 5.0 | 0.9 |
| Japan | 32,292 | 36,005 | 37,331 | 37,358 | 3.8 | 11.5 | 3.7 | 0.1 |
| Asia Pacific | 208,395 | 243,328 | 253,087 | 250,621 | 3.6 | 16.8 | 4.0 | -1.0 |
| Total World - €M | 338,931 | 396,649 | 413,522 | 411,094 | 1.1 | 17.0 | 4.3 | -0.6 |
| Discrete Semiconductors | 19,418 | 21,299 | 22,168 | 22,744 | 4.3 | 9.7 | 4.1 | 2.6 |
| Optoelectronics | 31,994 | 33,403 | 34,574 | 35,405 | -3.8 | 4.4 | 3.5 | 2.4 |
| Sensors | 10,821 | 12,336 | 13,135 | 13,899 | 22.7 | 14.0 | 6.5 | 5.8 |
| Integrated Circuits | 276,698 | 329,11 | 343,645 | 339,045 | 0.8 | 19.1 | 4.3 | -1.3 |
| Analog | 47,848 | 51,663 | 54,284 | 56,129 | 5.8 | 8.0 | 5.1 | 3.4 |
| Micro | 60,585 | 62,829 | 65,173 | 66,907 | -1.2 | 3.7 | 3.7 | 2.7 |
| Logic | 91,498 | 99,558 | 102,579 | 105,088 | 0.8 | 8.8 | 3.1 | 2.4 |
| Memory | 76,767 | 115,561 | 121,597 | 110,921 | -0.6 | 50.5 | 5.2 | -8.8 |
| Total Products - €M | 338,931 | 396,649 | 413,522 | 411,094 | 1.1 | 17.0 | 4.3 | -0.6 |

**F.8** *Source WSTS forecast, August 2017*

### 0.3.2. Essential capabilities

The development of these key application areas relies heavily on the availability of and further research in ECS essential capabilities:

- Systems and components architecture, design and integration;
- Connectivity and interoperability;
- Safety, security and reliability;
- Computing and storage;
- ECS process technology, equipment, materials and manufacturing.

Europe displays valuable assets in many of those basic technologies and integration knowhow:

**ECS process technology, equipment, materials and manufacturing**
The semiconductor market is expected to grow from USD343 bn in 2016 to USD415 bn in 2021 (Ref. Gartner Q1, 2017 update), driving up the global Semiconductor Equipment market (SCE) to the order of USD 43 bn (2016 Forecast, source: VLSI May 2017) composed of USD36 bn wafer front-end, USD3 bn test and USD4 bn assembly equipment.

In the past the market has been extremely volatile with year-on-year variations as large as +/- 30%. More recent data shows that the industry and the market have become more stable. Still, a high total R&D investment is required in order to keep up with the ever-changing industry and in this sector R&D investment rates as high as 10 to 20% of the total revenue are no exception.

As a result, in some areas European industry is dominant, as in lithography, where it has a market share in excess of 80%, and in other areas significant, especially at the high-end side (high-resolution imaging, atomic layer depositions, assembly & packaging, etc.). Furthermore, over the last decades, the European ecosystem (industry, RTOs & academia) invested heavily in the "More than Moore" technologies. Europe has now leadership positions in the global markets for MEMS technology based sensors and actuators, power semiconductors and systems in package, whereas FD SOI, a technology developed in Europe, is enabling the development of ultra-low power processors.

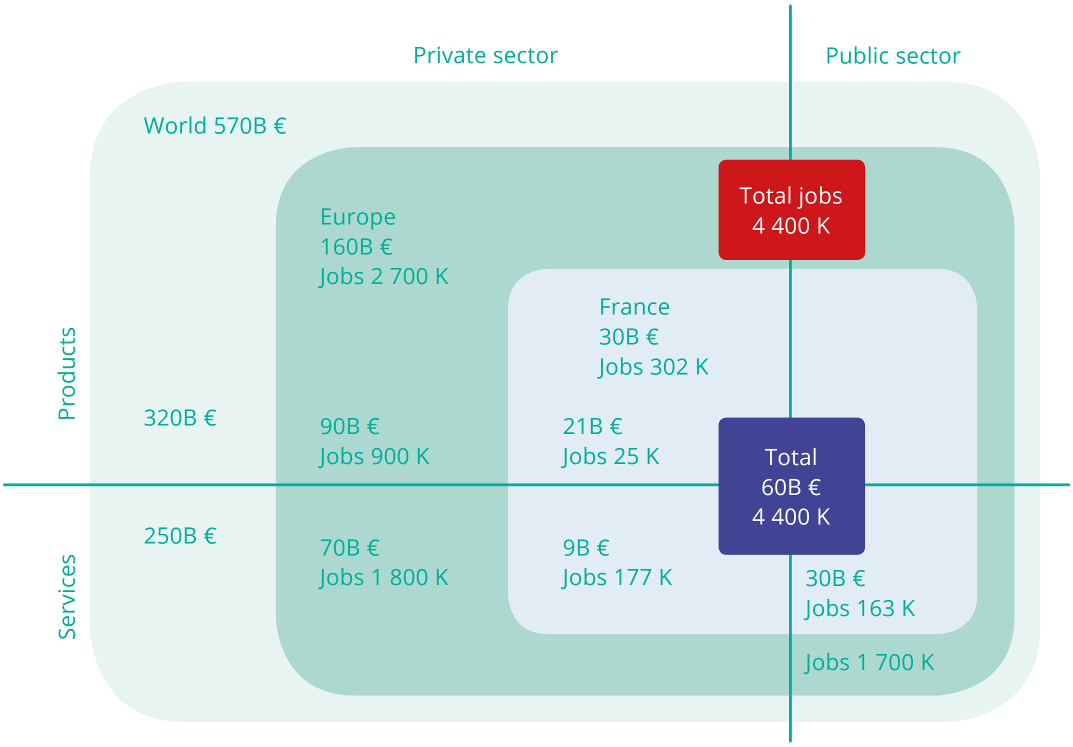
The increased business demand driving Moore's law will provide growth to the total semiconductor equipment market of at least 25% (2021 – USD54 bn). The lithography content, now estimated to be over USD8 bn (VLSI, May 2017), is likely to exceed this growth as it will be driven mainly by new technology nodes.

The strength of the European semiconductor equipment ecosystem finds its roots in the above-mentioned consistency in R&D investments in the areas of lithography, imaging, deposition and assembly technologies. Moreover, this ecosystem taps into a strong knowledge base in Research Institutes, Academia and Industry together with a world-class, interconnected supply chain.

The knowledge base includes fields such as light-, electron- and EUV-optics, plasma physics, surface physics and chemistry, heat- and fluid-transport, precision mechanics, electronics, applied mathematics, materials science, vacuum technology, contamination control, embedded system technology, thin-film technology, fast data processing, etc

### Safety, security and reliability

The world leaders in security are European. On top of being an essential capability, this sector also represents a huge market. Figure 7 below shows the size of this market in France, Europe and worldwide, split between products and services on one hand, and public and private on the other hand.




**F.9** *Iinter-ministerial French study done in 2015 (2013 numbers) on safety and security markets*

### Systems and components architecture, design and integration

Europe has built up specific strengths in the functional and physical integration of various technologies, features and materials into systems across the value chain, from semiconductor companies to system houses.

The overall value chain of equipment, materials, system integration, applications and services employs over 2,500,000 people in Europe.

# 0.4. SWOT

The various factors listed in sections 0.2 and 0.3 can be summarised in the following SWOT table.

| | POSITIVE FACTORS | NEGATIVE FACTORS |
|---|---|---|
| Internal factors<br>To the EU ECS industry [11] | **Strengths:**<br>Key application markets: Transportation, Energy, Health, Urban Services, Industry Automation;<br>Essential capabilities:<br>Security, Sensors, MEMS, low power devices, power semiconductors, Physical and functional integration capabilities<br>from IC to Systems of Systems<br>World-class semiconductor industry<br>World-class Equipment and Materials Industry<br>RTOs and Universities<br>Collaborative Skills | **Weaknesses:**<br>No sub-10 nm manufacturing capabilities<br>No IT industry leaders |
| External factors<br>To the EU ECS industry | **Opportunities:**<br>Need for alternative performance approaches besides miniaturization<br>Advances in AI and Human-Computer Interfaces creating new solutions and market opportunities<br>Ubiquitous connectivity / 5G deployment<br>New security paradigm (blockchain)<br>Internet of Things<br>New energy paradigm<br>Solutions for zero fatalities in road transport<br>Disruption in design, manufacturing and business models<br>Societal changes requiring ECS-based solutions | **Threats:**<br>Advances in AI and HCI are largely led by companies outside Europe<br>Economic protectionism<br>Increased competition<br>Societal changes: ageing population, increased urbanization<br>Environmental changes<br>Fragmented legislations |

*SWOT analysis* [11] **F.10**

[11] *EU industry here means the full Large Industry + SME + RTO + University eco-system*

# 0.5.
# VISION, AMBITION

Our **Vision and Ambition** are for Europe to take a leadership role in the digital transformation by developing its capability to provide the digital innovation and technologies Europe needs. To generate growth, create value, jobs and prosperity, and safeguard Europe's competitiveness and sovereignty.

To achieve this Vision and Ambition, the European ECS industry, supported by Public Authorities at European, national and regional levels, must:

- Address the major technological challenges identified in the SRA.
- Pool research efforts on a number of shared priorities to avoid fragmentation and reach critical mass; setting greater synergies across the complete ECS value chain and its eco-system for a high Return on Investment.
- Foster innovative business models, coupled with adequate funding schemes for a faster go-to-market.

Proper execution of the above will reinforce EU-based ECS industry, allowing its players to remain at the forefront in this domain.

# 0.6.
# STRATEGY

## 0.6.1. SRA focus areas

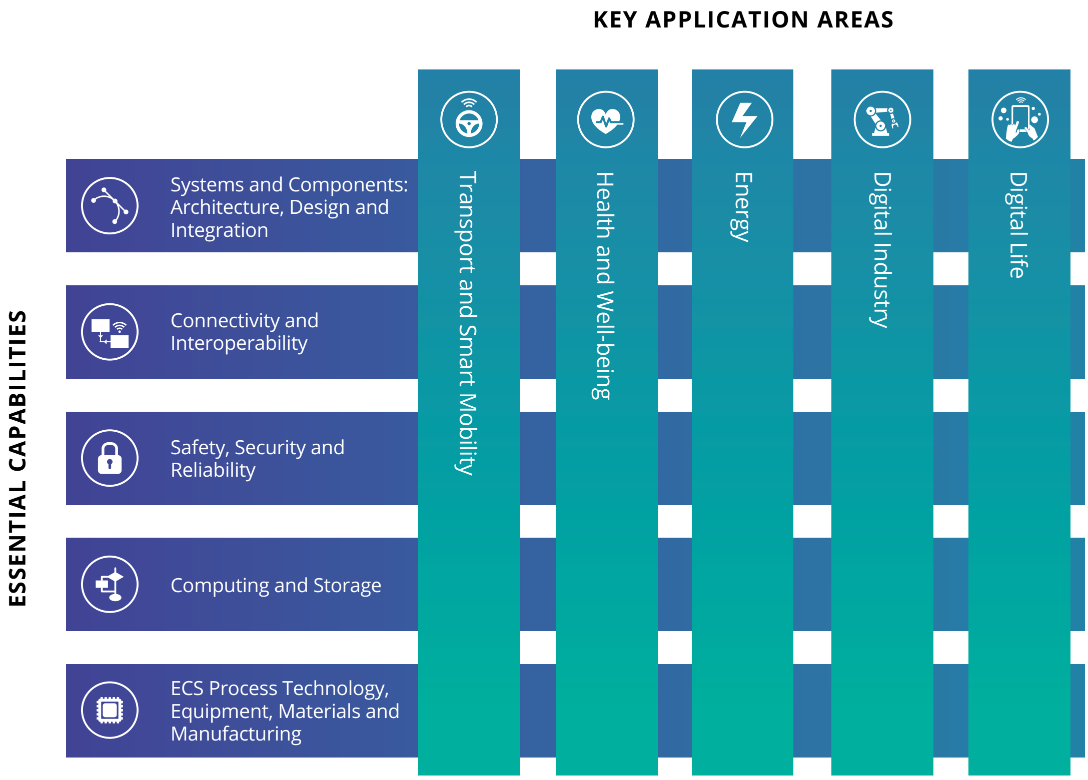
To fulfil the above Vision and Ambition, the R&D&I strategy will be based on top-down guidance on the strategic areas for projects generation by identifying the game changers and the market drivers to derive the major challenges (societal or technological) with the ultimate purpose of generating the right set of projects responding to short-term, medium-term and longer-term targets, thus covering the TRL scales from basic to applied and innovative research.

At the risk of stating the obvious, one guideline to select R&D&I priorities for the ECS industry in Europe should be to use our strengths to capture opportunities. Most societal challenges facing us are in domains where Europe hosts world-level champions: Health, Transportation, Energy, Digitalisation of Industry, and where solutions will be built on essential capabilities mastered by Europe. Focusing on these domains will not only help solve these challenges for Europe, but also allow our industry to develop markets beyond our frontiers, since the issues addressed here are shared by the rest of the world. Significant investments in innovation are needed to keep the competitive advantages against fierce worldwide competitors not only from the US, but also from Asia, mainly China.

In addition, the SRA addresses essential capabilities required to meet the application needs. Europe is well positioned for many of them, and further R&D&I is required to maintain and develop that leading edge (e.g., all the building blocks required for a successful deployment of the internet of things). However, we cannot limit ourselves to work on our strengths: there is a real danger with the current situation where most of the leading companies providing computer and network infrastructure and services, and the sub-10 nm silicon technologies using them, are non-Europeans. This is not a lost battle: As new paradigms are emerging (neuromorphic computing, quantum computing, transaction-based ledgers), which will require new technologies, Europe has a chance to position itself competitively, leveraging its cooperative capabilities and its great scientific base. But time is of essence.

Jointly considering key application areas and essential capabilities allows us to leverage our strengths for the benefit of other sectors. For example, industrial applications (such as Industry 4.0) and automotive (such as autonomous car) are launch pads for new technologies trying to cope with the challenges that are shared by embedded, mobile, server and HPC domains: energy and power dissipation, and complexity management.

Overall, the SRA focuses on a set of 5 key applications areas, and 5 essential capabilities, as depicted in the figure below. These market sectors represent all together over 50% of Europe GDP.




SRA focus areas

F.11

Implementing this Strategic Research Agenda, the ECS industry will leverage a strong and enabling position in multiple value chains and hold a pivotal position in research, development and the deployment of innovative solutions to create visible impact on society.

### 0.6.2. R&D&I priorities selection and description

The top-down guidance of the above themes is backed by an open, bottom-up process to detail R&D&I priorities in separate chapters, created and maintained by partners from industry and science. Each chapter follows the same structure, opening with the relevance of the theme, in terms of competitive value and societal benefits, then outlining the foremost grand challenges with the connected vision, scope and ambition, and explaining the high priority R&D&I areas, the competitive situation, and the expected achievements. The chapters conclude with high-level timeframes for the relevant roadmaps over the period 2018-2027, and main synergies with other themes.

The road maps indicated in the various chapters list, for each high priority R&D&I topic, the foreseen progress over time. Each timeline is divided in three parts, corresponding to project results of TRL2-4, 4-6, and 6-8 respectively. The concrete significance of this TRL indication is to envision, in a given year, the start of projects which will produce results of this TRL level or higher (i.e., a project aiming at a higher TRL level than denoted in the table might start that year). This, however, does not prevent to have also lower TRL projects starting that year, to work on the next generation solutions for the research topic related to that timeline.

### 0.6.3. Deriving work programmes

Defining R&D&I priorities, as this SRA has done, is just the starting point. An essential part of the Strategy is to prepare work programmes that generate projects that fulfil the major challenges of each of the chapters. It follows two threads:

Strategy thread 1: Address next generation digital technologies and potential breakthroughs to build a strong EU based ECS, positioning Europe at the forefront of the digital economy

- Achieve excellence in priority areas to remain or to join the frontrunners of the new era, while taking into account the European societal requirements of quality of life, safety and security, ethics and sustainability;
- Build on existing technological strengths of Europe to improve their sovereignty and reinforce them in areas such as low-power consumption, high-performance computing and high power, sensors, smart systems integration, safety and security;
- Develop those technologies to a high TRL (pilot lines) to make sure that the innovation will be brought to market
- Think big and act fast: in new areas such as AI and HPC, speed is of the essence, in order to achieve economy of scale and to act efficiently to bring innovative solutions to the global market (the way GAFA and Asian competitors act);
- Pool the research of stakeholder's efforts around a "Grand Mission" approach to leverage on their multi-disciplinarity and specialisations to achieve together ambitous targets in priority areas for European growth and competitiveness.

Strategy thread 2: Pooling research efforts on a number of priorities and remove barriers between application sectors

- Build better and more efficient European technological solutions for greater combined strength in the context of global competition, foster proposals where there is real value creation;
- Encourage projects that address the whole value chain and leverage vertical integration, to enhance user benefits and experience;
- Adoption of a platform approach as described in the section "innovation accelerator" for a faster "go-to-market"

While the SRA is structured by key application areas and essential capabilities, which are in turn subdivided into 5 chapters each, this by no means implies that the resulting work programmes and projects should be developed in "silos". As already mentioned, applications and technologies are becoming increasingly intertwined:

- As they go through the document, the readers will realise that many capabilities are required across most if not all applications. This is the case, for example, for Artificial Intelligence or Security solutions. By identifying generic technologies, this SRA help the submission of projects that address specific technological areas together with their use in a variety of applications.
- Conversely, many applications will come to life only when combining many essential capabilities, as witnessed in the smart sensors of the Internet of Things, requiring the integration of ultra-low power computing and storage, network, sensing, actuating and power management functionalities.

As a complement to these cross-domain projects, low TRL, in-depth research projects in specific capabilities are also required and encouraged.

## 0.6.4. Strategy implementation via R&D support programmes

### 0.6.4.1. Research funding programmes

To facilitate the implementation of the SRA, research funding programmes should:

- Encourage the development of a holistic Electronic Components and Systems innovation ecosystem in Europe spanning all R&D&I actors in these domains, with the goal to streamline (disruptive) innovations from Universities, RTOs and industry research teams into global sales by SMEs and large enterprises alike;
- Allow participants to publicly funded research projects to leverage the funding (from EC, national and regional); but this requires the harmonisation of participation rules, funding rates and procedures
- Encourage the combination of R&D efforts across Europe for future proven application domains and technologies, while pooling resources in key areas, and involving relevant players with the ability to ensure successful valorisation and uptake of the results.
- Put in place appropriate metrics and regular follow-up processes in order to assess the impact of projects and measure return on investment for the EU, Member States and Industry.

#### 0.6.4.2. Lighthouse initiatives

- "Lighthouse Initiatives" is a concept set-up by the ECSEL JU to signpost a specific subject of common European interest that calls for a set of coordinated activities including, but not limited to, facilitating the cooperation of ECSEL projects with Horizon2020 (e.g. FET Flagships), EUREKA projects and national or regional projects.
- Lighthouse initiatives encourage joining forces across projects to increase impact at EU level, have a strong emphasis on standardisation and regulatory aspects. Conducting non-technical activities is important to pull together the eco-systems actors in a field and investigate issues of social acceptance, regulatory environment and business models, in order to increase the impact of the individual project achievements.
- There are currently two lighthouse initiatives, on Mobility and Digital Industry. More are needed, especially in areas where standardisation and regulatory aspects have a crucial role, such as Health and Wellbeing, and Energy.

## 0.7. INNOVATION ACCELERATORS / MAKE IT HAPPEN

By themselves, however successful they may be, research projects do not resolve societal challenges and create economic value for Europe.

This will happen only if a number of "innovation accelerators" are in place, which will bring the research results to market. Major ECS industry innovation accelerators fostering the implementation of the present SRA are:

### 0.7.1. Standardisation and regulation

Standards enable the development of open markets for Electronic Components and Systems. Open markets offer opportunities for new businesses, including SMEs, to bring new products and services to market. In this context, standardisation contributes to increased interoperability, security, privacy and safety of electronic systems and applications, so it is essential to build trust with customers and users and create confidence between stakeholders in the market.

Regulation is needed to allow the deployment of many applications in Europe.

- For instance, a reduction in the number of accidents, fatalities and injuries could contribute strongly to the fulfilment of future EU guidelines, targets and regulations while meeting increasing customer demand for safe and convenient road transport. ADAS technology already provides the necessary sensing capabilities to operate the vehicle in a complex and interacting environment (for example, other vehicles, objects and infrastructures).

- For health and wellbeing, non-technological issues need to be addressed, such as ethics, regulation, privacy, accessibility and equality, which are key to increasing the acceptance and adoption of innovation in healthcare.
- For repair and recycling, regulations for the collection, recycling and disposal of technological products at the end of their useful life are well-established in the EU, particularly for electronic goods and cars (although disposal has overtaken repair and routine maintenance in this field).
- Security concerns are one of the main concerns and constraints to the widespread adoption of electronic components and systems. If there is ability to manipulate physical assets remotely, then there is the danger of privacy violations and safety problems. Such issues can then, in turn, promulgate worries about trust, security and privacy. It is hoped that regulation will also help alleviate some of these concerns, and thus be an enabler of electronic components and systems technologies.

### 0.7.2. Platform concept and the hyper-scalability business models

The platform concept, common in the Internet economy, is a characteristic of the Digital Transformation. It provides facilities to experiment and test innovative ideas, integrate research results into innovative products and validate service concepts. It helps organisations to scale up their development activities by sharing efforts and minimising investments to rapidly deliver such products and services to the market. The GAFA and similar business models have demonstrated the unprecedented and tremendous growth potential of their platforms.

### 0.7.3. Pilot lines

In the report about 'Key Enabling Technologies' the EC stated that despite a leading position of European RTOs in inventing new technologies and applications, Europe is weak in bringing those innovations to the market. To bridge this 'valley of death', it is necessary to support the development and installation of pilot lines, which require huge and risky investments especially for semiconductor technologies and equipment. In former ENIAC and ECSEL projects, pilot lines had proven to be essential in transferring the benefit of the ECS projects to society.

### 0.7.4. Education and training

While the EU is boosting the Digital Single Market taking care to make it secure and trustworthy, currently companies are struggling with what experts are calling the "largest human capital shortage in the world". Effective education and training is crucial to maintaining competitive leadership. It is a pre-condition for any so-called "sustainable innovation ecosystem".

The rapid evolution of the new global Digital Economy is generating needs and challenges with such a high growth rate that even the human capital market is not able to keep pace. The availability of graduates that meet industry and new job requirements is a major concern, with a shortage of up to 900,000 ICT professional currently forecasted. So, education and skill-building and 'Making education a specific deliverable for all EU projects' will be key pillars in the EU strategy if it is to have a relevant role (and so a relevant economic impact) in the Digital Transformation of society and, as part of the Digital Single Market strategy, the European Commission initiative on Digital Skills and Jobs Coalition (https://ec.europa.eu/digital-single-market/en/digital-skills-jobs-coalition).

### 0.7.5. From start-ups and scale-ups to SMEs

SMEs and start-ups are an essential component of European industry landscape:

- In 2015, just under 23 million SMEs in EU28 generated EUR3.9 trillion in added value and employed 90 million people. In 2015 they accounted for two-thirds of EU28 employment and slightly less than three-fifths of EU28 added value in the non-financial business sector.
- EU28 SME employment growth is, on average, entirely due to the growing number of SMEs (start-ups) as the average number of staff employed by a SME remained stable in 2014 and 2015 after falling markedly from 2008 to 2013.

Below we list some ways that need to be explored to encourage the participation of SME and start-ups in order to more closely meet the goals sets within H2020 (20% of allocated budget allocated to SMEs):

- An overall approach towards SMEs, including start-ups and scale-ups, should involve LEs and cover the complete process: coaching (identifying value proposal), acceleration (validation of technology as to its business value), and investment (financial support so scale up and productize). CSAs or other measures could be employed to facilitate ecosystem development and validate such an approach, for example within lighthouse initiatives.
- Attention should also be paid to attracting Corporate Venture Capital funds to invest in the ECS value chain or application domains, since SMEs participating in ECSEL calls should fit their investment portfolio. There are many large enterprises involved in ECSEL projects that have established CVCs. The opportunity to work with VCs and CVCs will be beneficial not only for start-ups but also for scale-ups and new product spin-offs established to mature and commercialise technology resulting from ECSEL projects.

It is expected that increased participation of SMEs in funded cooperative research programmes will allow them to grow and increase their presence and competitiveness in international markets, while start-ups will benefit from exposure of their technology to other consortium partners.

### 0.7.6. Research infrastructures

There is a need to balance the mainly single science / technology thinking into multidisciplinary thinking. Infrastructures that are focused on cooperation and on sharing of knowledge and expensive equipment or large-scale field experiments should be sustained. Serving the same aim, European governments should sustain the creation of new and the improvement of existing research infrastructures such as science parks, fabrication and prototyping facilities, incubators and venture partnering to support the creation of new, high-tech SMEs.

Setting such infrastructures will reinforce the global competitiveness of European Research Infrastructures (including e-infrastructure).

### 0.7.7. Relationship with other relevant initiatives and PPPs

Fostering the synergies and relationships with the various European, multinational (such as Eureka), national and regional initiatives, such as European Technology Platforms (ETP), Public Private Partnerships (PPP), Joint

Undertakings (JU) or the industry associations such as AIoTI, BDVA, EuRobotics, ERTRAC and EFFRA is needed. Each of these initiatives and PPPs shows a high commitment in its respective area. But they also have the same need of relying on each other's specificities and sharing a number of challenges and opportunities. As a key enabler in optimising investments in R&D&I programmes and in avoiding duplications of effort, the ECS technologies as such have a major role to play.

### 0.7.8. International cooperation

Research and innovation are becoming global, ignoring frontiers and being performed where creative individuals and ecosystems exist. The race is now about being 'best in the world' or the 'world of the best'. International collaboration should fit into a global win-win strategy geared to achieving the participants' long-range aims. Defining such a vision and strategy is important for guiding international collaboration.

## 0.8. LONG-TERM VISION

This section probes the distant future, looking further out to project which embryonic, emerging or disruptive technologies at the lowest TRL today will determine the future of the ECS domain tomorrow, in Europe. The identification and amplification of these efforts will shape the technological landscape 25-40 years out.

The first clear strength of Europe lies in the many research areas that constitute the expertise basis for the ECS domain. This asset, residing in an extensive ecosystem of universities, RTOs and industrial research organisations, provides the incubator for new disruptive technologies that will enable the creation of novel devices and systems, and consequently sustain the competitiveness of the European ECS industry now and in the future. This ecosystem is centred around the ever-growing networked scientific environment and the interdependencies created mainly through the basic and fundamental research actions in the European Framework Programmes. This, in turn, creates the fertile humus where industry can create substantial synergies and deliver breakthroughs to maintain pan-European technological excellence and leadership. It is not an exaggeration to state that this is the cornerstone of European long-term leadership in basic technology.

Over the last few decades, the ECS domain has evolved from a technology-driven field to an environment where societal needs and application requirements guide the research agendas of the centres of expertise. The European competencies in both 'More Moore' and 'More than Moore' have been instrumental in bringing about this change, resulting in a strong European position in markets that require complex multifunctional smart systems. There is no doubt that the safeguarding and further extension of these competencies are essential for a continuous offering of disruptive technologies that will ensure the preservation of the European competitive position.

A list of anticipated disruptive technologies can, by its very nature, never be complete. The following themes, or bundles of technologies are highlighted, as these will certainly be of high importance:

- **New computing paradigms ('Beyond CMOS').** In due time, physics and economics will combine to bring CMOS-scaling to a close. This limit will bring about a revolution in electronics by forcing the semiconductor industry (and society) to consider different strategies. These include finding novel ways to design microchips that generate more processing power without additional miniaturisation; finding new materials that can be manipulated at far smaller scales than silicon to squeeze ever greater numbers of transistors into even denser microchips; and designing new software and cloud infrastructure that can operate faster and more efficiently without needing denser/smaller microchips. Probably, all these options will be pursued and encompass new computing paradigms using nanomaterials (like carbon nanotubes), optical computing, neuromorphic computing, possibly also 'resistive computing' (memristors) and 'in-memory computing' (cf. the Eurolab-4-HPC report), ending in the quantum world, with quantum computing. These systems may incorporate non-charge based devices and couple state-variables (photons/RF, photons/phonons, phonons/electrons, phonons/magnons, topological states…). These computing paradigms require electronics that will enable the low-power implementation of Artificial Intelligence closer to sensors.

- **Big Data science and Artificial Intelligence.** Humanity, as of today, is already past the Zettabyte era. In 25 years from now, these technologies will require new storage solutions and new NVM memory concepts, coupled with new hybrid architectures able to process, fuse, exploit and disseminate the information much further at the edge of the network than before. Space exploration and pharmaceutical drug development are among application areas that will be revolutionised by these technologies. Similarly, everyday life will be affected. Personal and wearable gadgets will be able to connect more effectively with the cloud and crunch big data.

- **Cyborgisation.** Future Brain-Computer Interface technology, will enable new ways of communication, e.g. for people with severe disabilities. By the 2040s wearable or implantable BCI technology will probably make smartphones obsolete. Due to the massive exposition of physical and biological world in cyberspace, BCI systems will have to incorporate new means of protection of technology, data and consciousness – like heartbeat, venous system, fMRI or 'Brainprints' as the top measures of security.

- The progress in **DNA sequencing** and synthesis open the way to design nanomachine and defect tolerant self-organising nanoscale computing architectures. Fabrication of such devices will use molecular properties and will be radically different from the current silicon-based industry. Applications may of course be in the medical domain, but also in other domains where massive parallelism of very small devices is relevant.

- Non-covalent functionalisation of **2D materials** has already been applied in catalysts and sensors. With the current surge of activity on building van der Waals heterostructures from atomically thin crystals, molecular self-assembly has the potential to add an extra level of flexibility and functionality for applications ranging from flexible electronics and OLEDs to novel electronic devices and spintronics.

- **Molecular motors**, also called molecular machines, which are either natural or synthetic molecules that convert chemical energy into mechanical forces and motion. An example of a biological motor is the protein kinesin, which uses the hydrolysis of adenosine triphosphate to move along microtubule filaments. We will probably see many nanomachine applications in real life in 5 to 10 years


vehicles
vehicles

# 1

# *Transport & Smart Mobility*

[12] *More about the competitive situation of European automotive industry can be found in the appendix to Chapter 1, section 11.1 "Competitive situation of automotive industry in Europe".*

## 1.1. EXECUTIVE SUMMARY

The major Challenges in Transport & Smart Mobility are:

- Clean, affordable and sustainable propulsion
- Secure connected, cooperative and automated mobility and transportation
- Interaction between humans and vehicles
- Infrastructure and services for smart personal mobility and logistics.

These four major Challenges aim to keep Europe in the lead for innovations throughout the automotive value chain and to broaden the Research & Development & Innovation (RDI) horizon so that future research and innovation focuses more on holistic, cross-domain and sustainable mobility solutions for all the main transportation domains (Road, Rail, Aviation (incl. drones) and Maritime).

Key aspects to cover throughout the 4 challenges are increasing performance, security, privacy protection features, safety, sustainability, affordability, human interaction and societal acceptance. The defined Transport & Smart Mobility challenges not only address the most urgent Research and Innovation priorities in the sector, but also focus on developments that could be substantially driven by innovations in the European micro-electronics, nano-electronics and embedded systems industry in combination with the European IoT community.

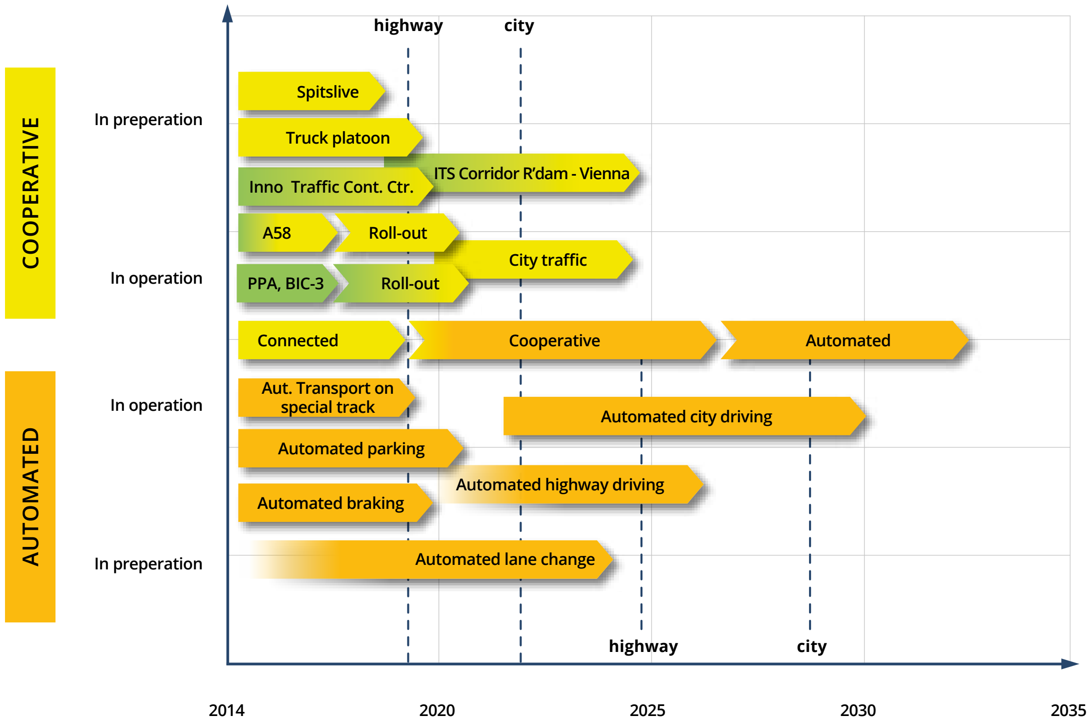
## 1.2. RELEVANCE

### 1.2.1. Competitive value

Mobility is not only a visible expression of Europe's economic and societal prosperity; it is also an important source of that prosperity. Employing about 3 million people in manufacturing and another 11 million in services the transportation system is of high socio-economic relevance for Europe. Currently, the transportation sector is undergoing a fundamental and complex transformation across all modes. The European Commission's Strategic Transport Research and Innovation Agenda (STRIA) describing this transformation distinguishes seven transversal dimensions ranging from low emission, alternative propulsion system to smart mobility systems [12].

Connected cars are the first and important step towards highly automated and autonomous self-driving cars. Even though basic safety functions have to be provided by vehicle based sensor systems even if connectivity fails, the comfort and efficiency of automated operation will increase if additional information from other vehicles, dynamic maps and traffic management systems is available. Connectivity will be based on multiple protocols and standards, as e.g. camera's, vision systems, radar, Lidar, C2X 820.11p (G5), NFC, 5G, etc. It will also be of crucial importance towards connecting the car and the vulnerable road user. Security is a crucial issue that needs to be resolved prior to deploying large scale connectivity solutions.

The expected timeline is the following:




**F.12** *Source: Gear 2030 Discussion Paper – Roadmap on Highly Automated Vehicles (Group E. C., 2016)*

In the area of automated vehicles, the main challenge is the transition from niche market products to mainstream products. Three things must happen to enable a large market penetration of automated vehicles:

- there must be a large reduction in cost of the components, the embedded SW, the system integration as well as the validation effort
- the problem of homologation and validation of automated vehicles has to be solved
- A compatible road and traffic infrastructure has to be established

Vehicle automation can play also an important role in the success of electrified vehicles. The management of charging stations and driving to and from the charging stations can increase the societal acceptance as it is than easier to utilise especially expensive super-chargers without tedious waiting time from drivers.

The expert group in the European commission stated in a report *"that digitisation is currently reshaping the sector"* (Commission, STRIA Roadmap 3 - Smart mobility and Transport Services and Systems, 2017). Additional information about roadmaps on introduction of connected and automated vehicles can be found in (ERTRAC, New Automated Driving Roadmap, 2017).

### 1.2.2. Societal benefits

The EU-project "Action Plan for Future Mobility in Europe" (Mobility4EU) has identified and assessed societal challenges that influence future transport demand and supply. Societal trends, economic and political factors and stakeholder needs have been summarised in a context map (Mobility4EU, 2017).

Mobility is a subject that concerns everyone. It is a subject that progresses of course rapidly in urban areas, but it is also concerns rural areas. Developing the right solutions for mobility across Europe can have a great impact on the overall image of Europe. Today, many people in the rural areas feel disconnected. They feel disconnected from mobility, from progress, from Europe. This feeling is at the origin of fatigue for the European case. The right developments can reverse this trend and bring all populations back on track.

The average age of the European population is growing constantly. In order to provide the elderly with personal mobility, automation in transportation and smart mobility will play an important part to increase the quality of life. Fewer auto-related accidents and fatalities could reduce costs for emergency medical services and related legal fees. Furthermore, more time available through autonomous drive and shared smart mobility will increase consumption of multimedia and information and generally enhance the time spent in transit (Deloitte, 2016).

$CO_2$ reduction in transportation as agreed in the Paris treaty also requires significant advances in the automotive, maritime, aerospace electronics and embedded cyber-physical software technologies. Consumers and governments have more and more concerns about combustion engines; this forms an impetus to accelerate the exploration of new ways of propulsion, as e.g. hydrogen, electrical and other means.

# 1.3. MAJOR CHALLENGES

## 1.3.1. SWOT analysis

The table below presents a SWOT analysis on the current European position in Transport and Smart Mobility. These points are addressed in the individual major challenges and expected results.

| | POSITIVE FACTORS | NEGATIVE FACTORS |
|---|---|---|
| Internal factors<br>To the EU industry [13] | **Strengths:**<br>Presence of strong stakeholders in the automotive value chain in the EU<br>Market leaders in rail & air in EU<br>Many pilot sites for autonomous driving<br>Great design capabilities and experience in semiconductors & embedded systems in EU | **Weaknesses:**<br>High price & slow expansion of electric cars in some countries in EU<br>Limited cross-border cooperation<br>Security & privacy threats could slow down the societal acceptance of autonomous driving |
| External factors<br>To the EU industry | **Opportunities:**<br>Advent of IoT, 5G and AI/Deep Learning will open new opportunities for future vehicles and other modes of transportation<br>New mobility services and business models<br>Electrification of vehicles<br>Introduction of fuel-cell electric vehicles | **Threats:**<br>Competition from other continents (US: Tesla/Apple/Google & China local industry)<br>Legislative requirements different in different continents |

**F.13** *SWOT analysis of European position in Transport and Smart Mobility*

## 1.3.2. Major Challenge 1: Developing clean, affordable and sustainable propulsion

### 1.3.2.1. Vision

Road transportation alone accounts for 21% of Europe's fossil fuel consumption and 60% of its oil consumption. The increasing effect of the $CO_2$ emission as well as gases that are detrimental to health like $NO_x$ emitted by conventional vehicles motivates the global community to introduce new environmental friendly mobility. The Paris Agreement of 2016 (Nations, 2015) is an important international step towards a $CO_2$ neutral world. Several countries announced the banning of new vehicles

[13] *EU industry here means the full Large Industry + SME + RTO + University eco-system*

based on ICE engines. An example is the UK's plans to ban them in 2040 (online, 2017). Electro-mobility will be based on either plug-in battery charged or $H_2$ based fuel cells as energy system. The next 7 years will see the strongly progressive replacement of traditional combustion engine powered cars. In parallel, conventional vehicles need more sophisticated sensors and software systems in order to also reduce their emissions and energy consumption in the interim period. Predictive maintenance and smart service concepts will secure constant and stable low emission and energy consumption levels over the lifetime as well as the **availability of the vehicles** at reasonable costs. (Association E. I., 2017), (ERTRAC, Integrated Urban Mobility Roadmap, 2017)

### 1.3.2.2. Scope and ambition

The scope of the development efforts covers all aspects including intelligent vehicles, optimal energy utilisation, increased energy efficiency (especially longer range for battery electric vehicles), reduction of emissions from conventional combustion engines by embedded intelligence, reduction of costs, increased reliability, ….

This requires advanced embedded software taking advantage of new concepts such as deep learning neural networks or model predictive control algorithms, advanced sensors and powerful, fast and energy-optimised actuators (e.g. power electronics in the case of electrified vehicles) to semi-conductor component level up to a full electronic system design. An additional challenge is posed by the validation of partially or fully electrified vehicles and their infrastructure (e.g. charging devices for battery electric vehicles (conductive or inductive) for personal mobility or fully electric good transports over short and long distances, or hydrogen fuelling stations).

The smart usage of the additional information from the infrastructure or connected vehicles is another mean to reduce energy consumption and emission dangerous for the health of humans as well as to increase the safety and comfort for passengers and vulnerable road users.

### 1.3.2.3. Competitive situation and game changers

Asia in particular is active in this area with Chinese, South Korean and Japanese car manufacturers and their related suppliers working on integrated solutions for electric and fuel-cell based powertrains. Especially in $H_2$ based electric vehicles, the first 3 commercial vehicles were introduced from far east companies. Furthermore, China aims to become number one manufacturer of electric vehicles in some years and is pushing its industry to accelerate the research on related technologies.

US companies are increasingly teaming up with the very large local IT giants working on electric (and automated) vehicles. This may endanger the current leading position of the automotive industry in the future.

### 1.3.2.4. High priority R&D&I areas

In order to achieve the abovementioned ambitions, the following R&D&I topics have priority as they are enabling the efficient development of electronic components and their embedded software, which are the heart of in the clean, energy-efficient transportation and smart mobility system.

#### New energy efficient system architectural concepts (EE as well as embedded SW)

As the automotive industry is in the transition from conventional internal combustion engine to hybrid, battery and fuel cell electric powertrains, energy efficiency has several implications for electronic components and systems as well as its embedded intelligence, the embedded software. The improvement of conventional powertrain concepts is also needed to already contribute to the $CO_2$ reduction during the transition period. New, faster and more complex control algorithms are essential. The technologies and R&D&I tasks described in chapter 3 are closely related to the R&D&I topics listed below.

The following R&D&I topics have to be addressed:

- Architecture for the control systems of alternative powertrains
- Energy-efficient electric/electronics/embedded-SW architectures (e.g. using energy harvesting, …) for alternative powered vehicles,
- Ultra-low power / high-performance control units
- Higher energy efficiency of electrified vehicles (e.g. using higher frequencies of power electronics, better control software and advanced thermal management systems; the use of wide bandgap technologies)
- Improved / new safety concepts for high voltage powertrain systems
- Connected vehicles
- More efficient control algorithms conventional and hybrid powertrains to support the transition period to alternative $CO_2$ neutral mobility.

#### Filling/charging and energy & power storage and management

The successful adoption of electrification (either battery or fuel cell based) requires the implementation of a charging/refuelling and energy / power management systems. Only if mainly electricity from renewable sources is used will the desired positive impact of the transport sector on $CO_2$ reduction be achieved.

- ECS for efficient electrical or $H_2$ energy storage
- Electrical charging infrastructure and their smart control (conductive or inductive) for fully electric good transports over short or long distance as well as for passenger cars.
- Dynamic charging, charging-on-the-move
- Fully automatic high power (10x higher than today) and quick charging near highways

#### Control strategies and predictive health management

Electro-chemical or thermodynamic components as well as advanced emission after-treatment systems are controlled by complex control systems. They are optimised to achieve the best energy efficiency while also fulfilling other requirements like low emissions or protecting elements from overheating. The ageing of those components affect their behaviour over time significantly, thus decreasing the energy efficiency or other requirements. Therefore, predictive maintenance systems are necessary to allow optimal lowest-cost service interventions. Research in smart maintenance concepts will help to achieve those goals.

- Modelling predictive control algorithms supported by high-performance multi-core real-time operating systems that provide the necessary intelligence is another research direction.
- Energy-efficient power management of electric vehicles
- ECS for next generation of fuel-cell electric vehicles
- Predictive monitoring and diagnostics for electric, hybrid or fuel-cell electric vehicles to increase the lifetime
- Predictive maintenance for vehicles to reduce costs for the operation of vehicles

#### Smart sensors

Reduction in weight is another means to increase energy efficiency. As the amount of electronics in vehicles has exploded, the weight of sensor and communication cables has increased accordingly. Wireless non-safety critical vehicular networks will have to improve significantly and guarantee highly dependable communication for distributed automotive, maritime, aerospace or rail powertrain systems.

- Development of smart sensors for the next generation of FCEV, Battery Electric vehicles, Hybrid vehicles

- Integrated smart sensor systems to increase battery or fuel cell systems by individually controlled cells using smart sensors – e.g. Embedded sensors in batteries, fuel cells or exhaust after treatment systems

**Smart actuators and motors in transport systems**
Similarly, smart actuators and motors will decrease weight and contribute to the efficiency targets.

- Smart actuators for energy-efficient powertrains
- New topology (multi-phase for improved availability) for e-motors with reduced amount of rare-earth materials.

#### 1.3.2.5. Expected achievements

The European supplier industry together with the OEMs and relevant research and development specialists need to get competitive and ultimately become the global leader in electrified propulsion.
The deployment of alternative resource-efficient vehicles in Europe is expected to follow a series of milestones which link the market penetration to the availability and affordability of key technologies under the assumption of major breakthroughs (see also (Association E. I., 2017), (ERTRAC, Integrated Urban Mobility Roadmap, 2017), (ERTRAC, New Automated Driving Roadmap, 2017)). Europe will also see progress in biofuel-based vehicles. Similar roadmaps exist for other domains of mobility as rail, aerospace, off-road vehicles, trucks, etc.

Overall, safety, security and transparent mobility services are a prerequisite for successful market penetration. Parallel to the advancement of electric and plug-in hybrid passenger cars as well as light-duty vehicle technologies, electrified trucks and buses or fuel-cell vehicles will be developed. However, the ramp-up of their deployment is expected to start later. Furthermore, resource efficiency is the driving force of research and innovation in other transport modes, e.g. air transport (JTI, 2014).

### 1.3.3. **Major Challenge 2:** Ensuring secure connected, cooperative and automated mobility and transportation

#### 1.3.3.1. Vision

European transportation industries have to strengthen their leading position to provide sustainable solutions for safe and green mobility across all transportation domains (automotive, avionics, aerospace, maritime (over water as well as under water transport) and rail). Their competitive asset is a profound expertise in developing complex electronic components, cyber-physical systems and embedded intelligence. Nevertheless, a bundle of challenges in terms of autonomy, complexity, safety, availability, controllability, economy and comfort have to be addressed to harvest the opportunities from increasingly higher levels of automation and related capabilities.

Currently, we are only at the beginning of an evolution of automated and autonomously acting machines. This movement is characterised by

- increasingly autonomous behaviour
- in increasingly complex and unpredictable environments
- fulfilling missions of increasing complexity
- the ability to collaborate with other machines and humans and
- the capability to learn from experiences and adopt the appropriate behaviour.

No single organisation will be able to capture these tremendous efforts for research and development. In order to maintain a leading European position, it is therefore necessary to establish collaborations in and across industrial domains, learn from operational field data and jointly drive the strategic actions.

The overall vision is to realise safe and secure always connected, cooperative and automated transportation systems based on highly reliable and affordable electronic components and systems of European origin as well as technologies for new ways of interacting between humans and machines.

#### 1.3.3.2. Scope and ambition

Connected, cooperative and, ultimately, automated mobility and transportation are seen as one of the key technologies and major technological advancements influencing and shaping our future quality of life. ECS will enable different levels of partial, conditional, highly and fully automated transportation posing new challenges to traffic safety and security in mixed scenarios where vehicles with different automation levels coexist with non-automated vehicles. Both development approaches – evolutionary (gradual increase of automation level, "conversion design") and revolutionary (SAE level 5, "purpose design", e.g. people mover in structured environment) – should be covered as well as cross-fertilisation with other industrial domains like Industry 4.0.

As the proportion of electronics and software as a percentage of the total construction cost of a vehicle [14] increases, so does the demand for the safe, secure, reliable and non-hackable operation of these systems. In addition, privacy protection is a key element for car owners and drivers/ operators. These requirements demand fail-operational technologies that deliver intrinsically safe operation and fail-safe fall-back from component to subsystem along with a fall-back for interaction problems with the cloud. This demands new developments in terms of multicore-/ many-core-based platforms and sensing devices, combining advanced sensing in harsh conditions, novel micro- and nano-electronics sensors, filtering, advanced sensor fusion, noise reduction, fault detection, low-power operation, self-testing and reliable predictable actuation.

Research, development, and innovation will focus on capabilities in the fields of sensing, communication, navigation/positioning, computing and decision-making, control and actuation based on smart systems for mobility and the necessary tools, methods, and processed for development and validation. Along with deterministic control strategies, data-driven algorithms based on artificial intelligence (AI) are covered in both ECS development phase and in-vehicle operation. It will be necessary to find new ways to perform fast and repeatable validation and non-regression tests independent of real-world tests. An additional

[14] *The term "vehicle" includes cars, aircraft, trucks, vessels, trains, off-road vehicles, satellites, drones.*

research field arises from the challenges of safe cooperation of manual and automated traffic during the transition period towards automated and connected mobility.

### 1.3.3.3. Competitive situation and game changers

Especially in European countries, the mobility and transportation industry plays a central role for the internal market as well as for export markets. In the automotive sector - according to Europe's car manufacturers and transporters – around 12 million people (approximately 2.2 million directly and 10 million indirectly) are employed contributing 16 per cent to the European Union's GDP.

However, competition is getting fiercer. Since 2013, China has overtaken Europe in number of cars produced. European car manufacturers are competing in a worldwide race toward vehicle automation and connectivity with newcomers from the IT sector. The value is being reshuffled across the value chains. According to several studies, 30 to 40 per cent of the value in the automotive value chain will pass through digital platforms in the near future. Dependence on a reliable low-latency IT infrastructure and its maintenance adds complexity to the value chain, and is an important issue to consider in order to realise the expected benefits of automation. If Europe safeguards its well-established market position by developing innovative and effective safety features, many jobs in the automotive, aeronautics and railway industries will be preserved as well as newly created.

### 1.3.3.4. High priority R&D&I areas

The following research, development and innovations areas and their subtopics are identified (more details can be found in the Details to high priority R&D&I topics for Grand Challenge 2 in Application Chapter Transport & Smart Mobility":

- Environment recognition
- Localisation, maps and positioning
- Control strategies
- HW and SW platforms for control units for automated mobility and transportation (including also support for artificial intelligence)
- Communication inside and outside the vehicle
- Testing and dependability
- Swarm data collection and continuous updating
- Predictive health monitoring for connected and automated mobility
- Functional safety and fail-operational architecture and functions (sensors, electronics, embedded software and system integration)
- Management of mixed automated and manual traffic

### 1.3.3.5. Expected achievements

The impact of automated and connected vehicles could be huge. It could help to drastically reduce road fatalities and road accidents. New transport services could also be provided especially when the vehicle is provided with connectivity in addition to automation, e.g. traffic safety related warnings, traffic management, car sharing, new possibilities for elderly people or impaired people. Automation will also enable user freedom for other activities when automated systems are active. Drivers/operators can expect more individual comfort and convenience which is likely to be the major motivation for upcoming automated driving. In the long term, automation could have a revolutionary impact on travel behaviour and urban development. It could also result in new business models, such as shared and seamless intermodal mobility which could have an impact on the number of vehicles on our roads.

Connected, cooperative and automated mobility also brings new challenges for regulators concerning road safety, security, traffic law, access to data, protection of personal data, financing, etc., which have to be addressed.

Multiple innovative components and systems are expected for making highly secured automated and connected vehicles, including:

- Interacting information systems for safe and secure connection between vehicles and between vehicles and infrastructure, also enabling intelligent traffic/logistics management systems
- Intelligent on-board traffic management and navigation systems to achieve maximum efficiency and range/mileage
- Energy harvesting sensor & actuator systems in harsh conditions
- Next generation multi-core/many-core-based architectures
- Industrialisation of AI-based systems
- Safe fall-back vehicle sensing and actuation systems
- High-precision low-cost localisation platform for civil use
- Fail-operational and 24/7 available ECS at low cost
- Methods and tools to virtually validate and approve connected, cooperative, automated vehicles

The development of such systems will be accomplished through the use of innovative new components and systems, methods and tools, and standards (e.g. sensors, embedded mixed criticality systems, actuators, communication protocols, etc.), new system-on-chip and system-in-package technologies, and new design/ validation/verification methodologies on component and system level.

## 1.3.4. Major Challenge 3: Managing interaction between humans and vehicles

### 1.3.4.1. Vision

Vehicles are being increasingly equipped with massive computing power, artificial intelligence, numerous assistance/ infotainment/ communication systems and partially autonomous functions. Individual transport has never been so distracting, easy and safe at the same time. One clear and shared vision of all industry branches related to transportation is that in the future there will be a broad variety of partially and fully autonomous operating vehicles, ships, drones, aircraft, trains, etc. In this world the exchange of information between humans and the technical systems is essential.

### 1.3.4.2. Scope and ambition

The great challenge in this future coexistence of humans, "traditionally" operated vehicles and (partially) autonomous systems is the dynamic interaction between them: How does the human know what the machine is going to do? How does the human tell the machine what to do and what not to do?

There is a clear demand for interfaces between humans inside and outside such transportation systems and the technical systems that have to be easy to understand, intuitive, easily adaptable, safe, secure, unobtrusive and reliable.

### 1.3.4.3. Competitive situation and game changers

With the rising number of capabilities of electronic systems also the number of possible use cases is rising. One example is the hype of speech recognition and home assistance systems, being pushed by Google, Amazon, Microsoft, Samsung etc. Adapting these solutions to the transportation sector is one of the next tasks.

### 1.3.4.4. High priority R&D&I areas

The following research, development and innovations areas and their subtopics are identified:

- **Driver activities and vital signs monitoring:** (Partially) Autonomous vehicles have to know, in a non-invasive manner, the current status of the "driver" in order to notify adequately if any manual driving action needs to be done. This starts, for example, from the exact seating position and extends to monitoring the vital signs in order to be able to undertake emergency driving manoeuvres in the case of a sudden onset of sleep (ref. Commission Directive 2014/85/EU regarding OSAS as a risk factor for driving) or a heart attack. Here the new generation of wearable sensing devices can play a role, being interconnected with the vehicle network.
- **Future human interaction technologies and concepts:** More and more functions in today's and even tomorrow's vehicles mean that easy usage will be a great challenge. We need concepts and technologies to tell the technical systems what to do and what not to do. In addition to this, we need ways for the systems to clearly tell/ show the humans what is happening right now, what will be happening next and which options there are. This is not restricted to persons sitting in an autonomous car, for example, but also includes all other road actors like pedestrians in the "world out there". This will need new components to interact between driver and automobiles, ships, airplanes, etc. (haptic, optical, acoustic, … sensors). The support of mixed manual and automated traffic will play an increasing role.
- **"Online" Personalisation of vehicles:** With "Shareconomy" and on-demand services getting more and more popular in the transportation sector there is a clear need for the quick and easy individualisation/ personalisation of vehicles. We need concepts, technologies and systems which allow all the functions and services of such a vehicle to adapt to the user/ passenger instantaneously.
- **Smart mobility for the elderly, very young or non technical:** With an ageing society there is a clear demand for smart concepts which allow elderly people unlimited mobility. Seniority needs have to be considered for interaction concepts and systems.
- **Smart mobility for digital natives:** Digital natives are used to always-on connectivity, digital interaction and fast information exchange. Concerning mobility there is the expectation of a seamless and instantaneous experience which can be fully managed by digital devices. Mobility clearly is a service.
- **Smart mobility for handicapped people:** Mobility for handicapped people needs special concepts that allow adaptation to various types of physical and mental disabilities and ideally allow these people to travel individually in a safe and secure way.

### 1.3.4.5. Expected achievements

The expected outputs are described in chapter 1.3.4.4.

## 1.3.5. **Major Challenge 4:** Implementing infrastructure and services for smart personal mobility and logistics

### 1.3.5.1. Vision

An important future trend in transportation and mobility is the shift away from the paradigm of either exclusively personally owned or publicly operated modes towards integrated mobility solutions that are consumed as a service. Smart mobility services will establish more seamless, economic and sustainable mobility across all transportation modes in the smart cities of the future. This is enabled by combining transportation services from public and private providers through a unified IT platform and supported by jointly used physical and digital infrastructures. Both the transport of people and goods could be organised more efficiently in response to demand in this way. The challenges to create smart multimodal spaces is covered in the chapter "Digital life - Major Challenge 4: Ensuring sustainable spaces", the challenge to offer multimodal transport means is covered in this chapter.

### 1.3.5.2. Scope and ambition

The solutions to be considered under this Major Challenge are manifold but highly dependent on electronic components and systems; e.g. advanced V2X technology, traffic management systems, 2-/3-D navigation and guidance solutions in combination with mobility-as-a-service concepts will be fundamental to providing the optimal utilisation of new vehicle concepts for personal mobility and transportation in congested urban areas. These services will also be the basis for radically new mobility models – including robot taxis, shared self-driving shuttles and cooperative fleets of drones for last-mile delivery.

### 1.3.5.3. Competitive situation and game changers

Countries like Japan already have a communication infrastructure deployed that allows the development and full-scale testing of systems in real conditions. ECSEL needs such an environment to be able to develop competitive solutions. V2X regulations have accelerated developments in the US, for example.

V2X communication technology (ETSI ITS-G5 in Europe and US DSRC based on 802.11p) offers low-latency short-range communication in highly dynamic mobile environments, and is the basis for large-scale deployments in several European countries. While the access layer technology has matured through extensive testing in the last decade, the main challenges in connected driving are vertical to the access layer: safety-critical functions need to be ensured under security and privacy constraints. Services offered among infrastructure and vehicles need to be discovered in an ad-hoc fashion and made available in a seamless and transparent way. Automation functions such as platooning require very robust short-range wireless links with low latency. The same is true for the guidance of vehicles by traffic management and sharing of sensor perception between infrastructure and vehicles.

While the access technology is already available, communication protocols ensuring robustness and synchronisation with other services using shared communication channels need to be developed, along with the methodology. Especially the mobility domain is characterised by highly dynamic, open and interconnected systems of systems, which requires design methodologies to develop protocols for such open environments and appropriate design methodology to ensure safety and security.

Single vehicle data enables the traffic management to obtain the traffic status very precisely as well as gather information about the environment (local weather conditions, slippery road, etc.). This can be seen as an evolutionary path from today's probe-vehicle data to comprehensive data allowing collaborative environment perception. Real-time data from infrastructure sensors will augment the vehicle's perception capabilities.

The above technologies together with increasing difficulties to provide enough space for the increasing traffic especially in mega cities lead to radically new mobility concepts like mobility as a service. The paradigm shifts from owning the devices providing mobility to purchasing only the services to move oneself or goods from one place to another. This requires new digital platforms and business systems to manage the mobility services with secure communication to the vehicles providing the mobility service.

The traffic management of the future needs to provide an optimal combination of different transport modes in response and anticipation of user demands. Traffic management will guide automated and non-automated vehicles. Road conditions, traffic situation, transport demands, weather conditions, etc. need to be monitored very precisely using new infrastructure and distributed smart sensor technology including complex local pre-processing (e.g. machine learning).

New traffic sensor technology needs to support robust, precise mobility detection. Combinations of several technologies such as high-resolution short-range radars, time-of-flight cameras might be a way forward. Guidance systems for truck platoons and automated vehicles require robust wireless links in real-time, fast and reliable detection by on-board and infrastructure sensors and reliable connection of this data, such that the central traffic management or a lead vehicle of a platoon can be sure to communicate and interact with the vehicles which are perceived by its sensors.

### 1.3.5.4. High priority R&D&I areas

The following research, development and innovations areas and their subtopics are identified:

- V2x Communication
- Privacy by design
- Traffic management for single-modes (multi-modal traffic management is covered in the WG "Digital Life")
- Management systems for multimodal transport means including necessary distributed smart sensors, interfaces, privacy protection, data management, traffic prediction, route optimisation
- Guidance systems (remotely operated drones, trucks, ships,...)
- Mobility platforms for mobility as a service with seamless billing and payment systems (incl. e.g. personalised cards for users, usage of mobility services)
- Mobility as a (smart) service communication, security and privacy systems
- Predictive and remote maintenance
- Efficient logistics in freight and goods
- Vehicles offering services (also during parking) (e.g. WiFi extender, monitoring traffic density, airplanes acting as communication repeaters,...)
- Security and reliable availability of V2x communication

### 1.3.5.5. Expected achievements

The development of further solutions for connectivity going from the individual car to the full system including infrastructure will prepare the ground for the development of new services.

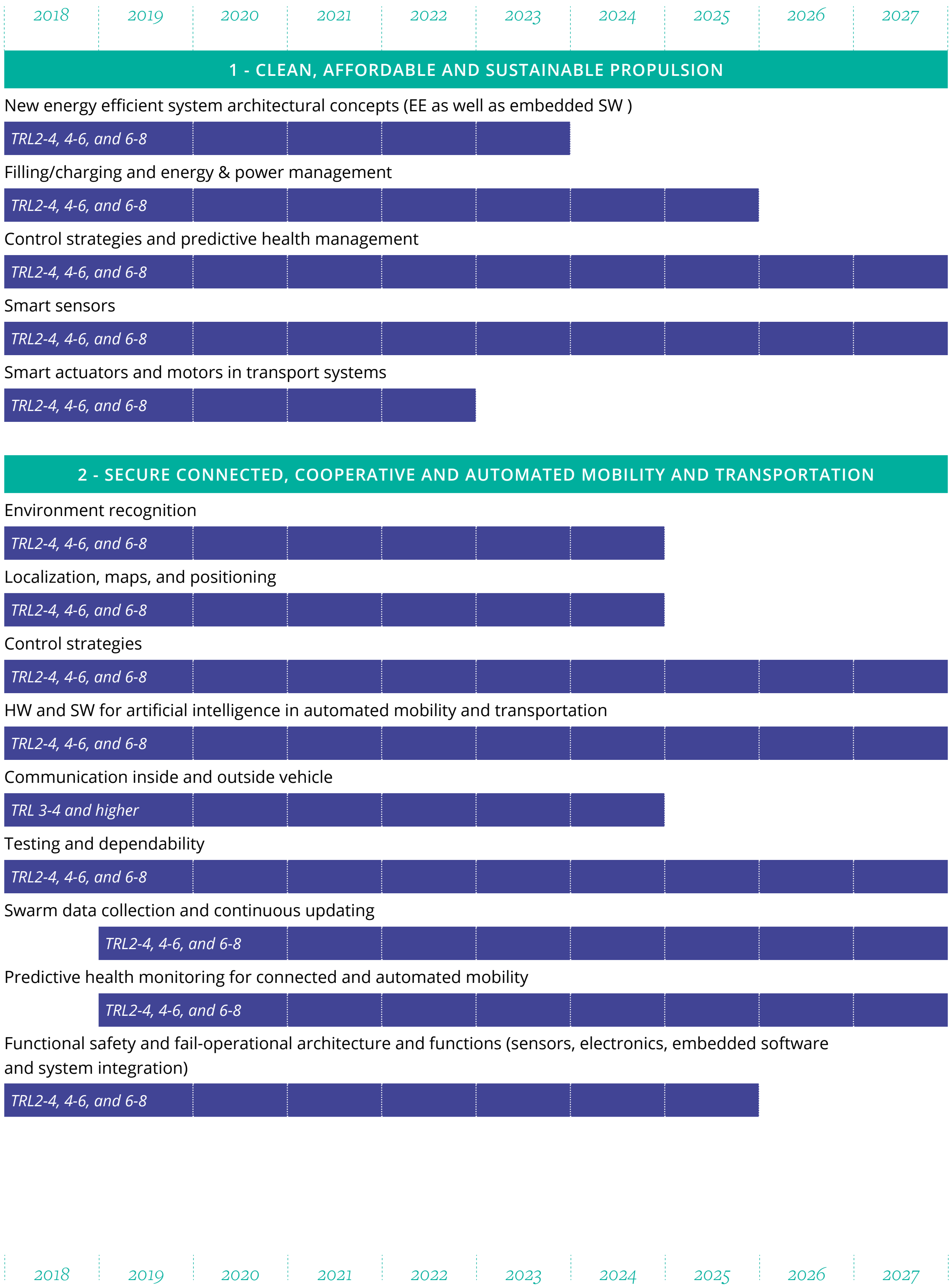
## 1.4. MAKE IT HAPPEN

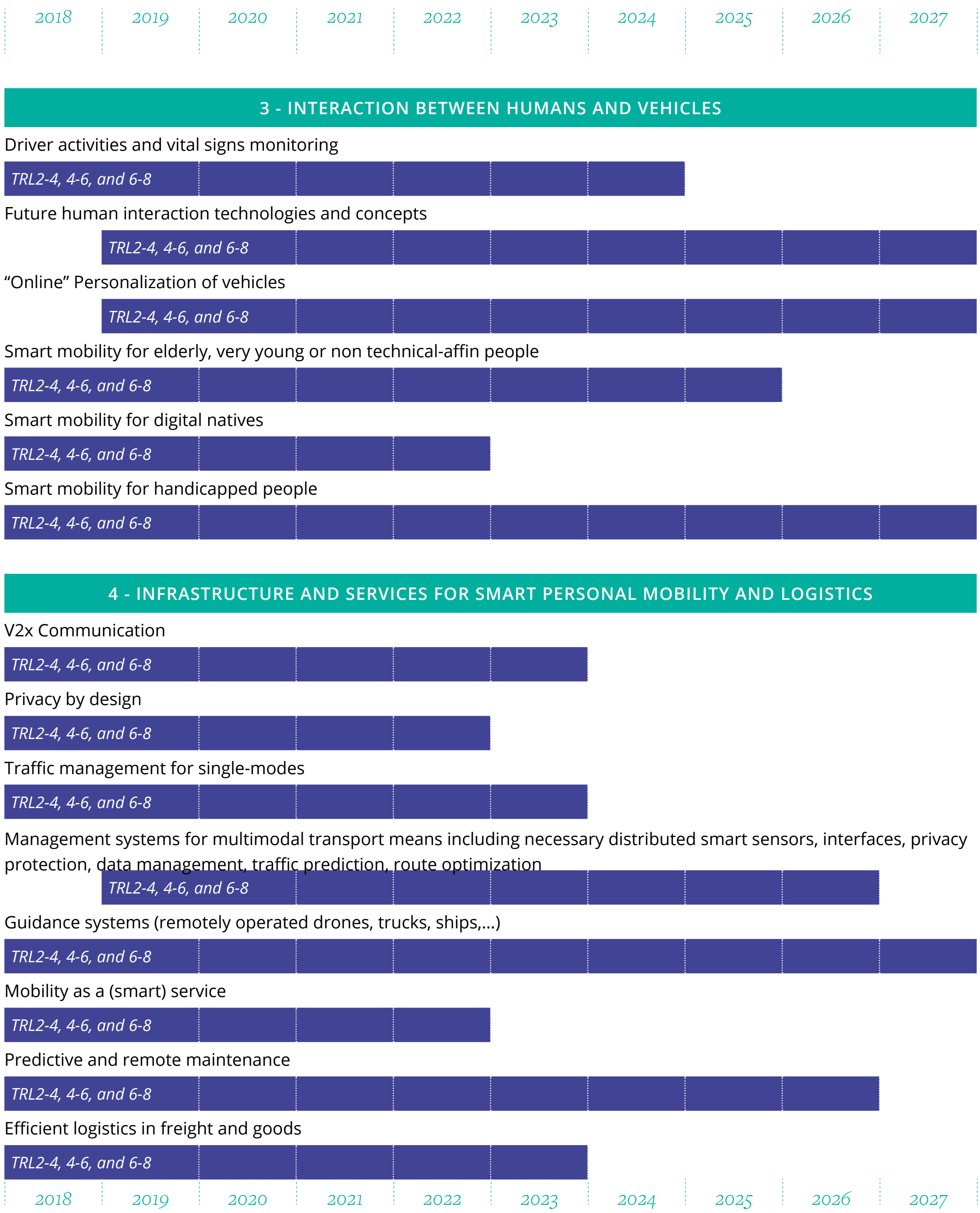
The stakeholders in the Industry Associations involved in ECSEL are capable of achieving the aforementioned goals because its members adopt a focused strategic approach that combines R&D competencies from across Europe and involves all stakeholders in the value chain. Most of the mentioned research topics will require several innovation steps in order to solve technological barriers and establish adequate price levels of the semiconductor, sensor and system components and necessary embedded cyber-physical software base. Therefore, the cooperative research at different TRL levels will be necessary in order to achieve the necessary innovation speed required to keep the European industry at the forefront in the world in the field of transportation and smart mobility. The TLR level of RDI work depends always on the position of the research partner working on a task in the supply chain. Low-level components typically have higher TRL levels than the application systems into which they are integrated. Therefore, all task in the roadmap can be addressed by RIA or IAs.

Special attention will have to be paid to the interaction with legislative actions in this domain and societal acceptance of highly automated vehicles and new business models of future mobility. Furthermore, standardisation will be crucial for future automated and autonomous cars, including the embedding of enhanced safety, security and privacy protection features.

Finally, governments will be needed to increase the amount of pilot test sites on both private as well as public grounds.

# 1.5.
# TIMEFRAMES






**F.14** *Timeframes*

# 1.6. SYNERGIES WITH OTHER THEMES

The widespread expectation of modern information and communication societies is that individuals take advantage of all existing services regardless of where those individuals are located – in the office, at home or on the move. Therefore, there is a synergy with the theme of **"Digital Lifestyle"**. Whereas "Digital Lifestyle" will focus on the future life from a static point of view, meaning the citizen on a specific location or in a specific environment, the theme "Transportation and Smart Mobility" will focus on the dynamics and moving of the citizen in the society.

When moving to autonomous vehicles, the driver behaviour and monitoring will become more and more important. For that purpose, there is a synergy with the theme **"Health and Well-Being"**. Within "Transportation and Smart Mobility", seamless connectivity, interoperability and privacy protection become more and more important. This should be supported by cross-domain use of the themes of **"Connectivity & Interoperability"** and **"Dependability and Trustworthiness"**.

In contrast to other domains, Automotive & Transport applications are characterised by stringent real-time requirements and severely limited energy resources. To meet these requirements, robust technologies, components, simulation modelling & tools and domain-specific implementations of the same functionality are needed. Therefore, there is a synergy with the theme of **"From Systems to Components"**.

# 2

# *Health and Wellbeing*

# 2.1.
# EXECUTIVE SUMMARY

Healthcare systems face a huge challenge in providing the same level of care, in an appropriate, efficient and cost-effective way, to a rapidly growing and aging population. By 2030, the world population will have risen by 1.3 billion to 8.5 billion people; due to ageing, the world's population in the age bracket 65+ is projected to increase by 436 million to 1.3 billion people and the urban population by 1.5 billion to 5 billion, who all will require increased access to healthcare facilities and services.

Innovative technologies in health have long been integrated into devices that treat acute or chronic diseases, and which affect vital prognoses or alter drastically the quality of life of numerous patients. However, tremendous progress in research fields such as imaged guided interventions, smart catheters, genomics, bionic, biomedical, bio-sensing, regenerative medicine, energy harvesting and low-power electronics for communicating securely and extending processing and memory capacities now offer completely new approaches based on artificial intelligence, deep learning and the understanding of biological mechanisms at the origins of diseases that will radically change the way diseases are diagnosed, treated and followed-up. This is true for both professional healthcare as well vitality, wellbeing and prevention.

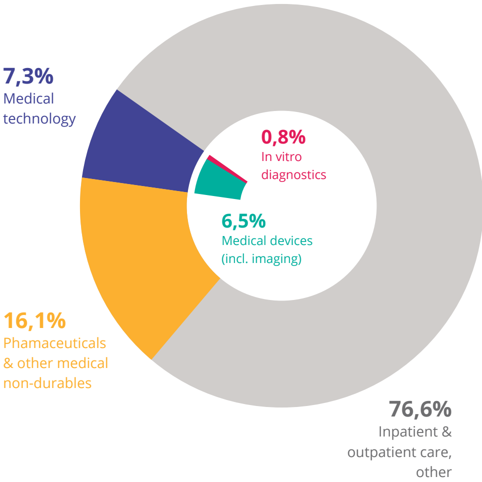
The way healthcare is provided is changing substantially, as medical interventions in the future are no longer confined to hospitals, clinics or medical offices, but are occurring anywhere in people's life, especially in their home. Ambulatory, "point-of-care" and "home care" are terms that will gain significance in the future.

This trend of "decentralised" healthcare will not only have an impact on how medicine reaches the patient, but will require a redefinition of the role and positioning of healthcare providers. ECS have the potential to provide suitable systems solutions, both to support the rising importance of personalised delivery of healthcare and to smarten existing healthcare providers and to assist the population in changing behaviours to improve their health.

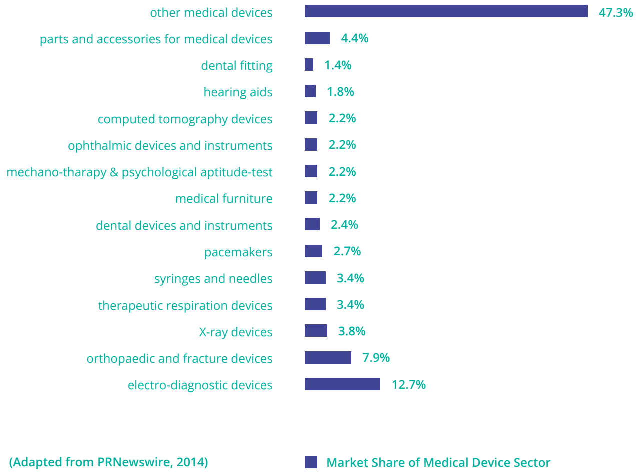
## 2.2.
# RELEVANCE

### 2.2.1. Competitive value

**BREAKDOWN OF TOTAL HEALTHCARE EXPENDITURE IN EUROPE**




**GLOBAL MARKET SHARE OF MEDICAL DEVICES**




**F.15** *Breakdown of total healthcare expenditure in Europe, Global Market Share of Medical Devices. There are 26,000 medical technology companies in Europe, 95% SMEs*

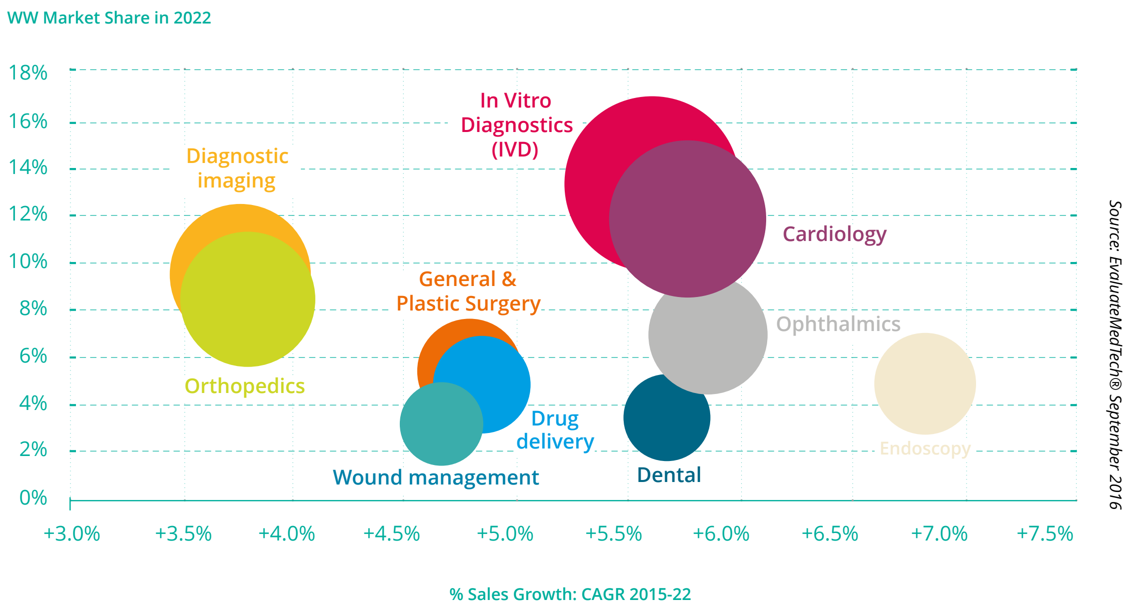
**In Europe, an average of 10% of gross domestic product** (GDP) is spent on healthcare. Of this figure, around 1% of GDP is attributed to medical technologies. Expenditure on medical technology per capita in Europe is at around EUR197 (weighted average).

The European medical technology market has been growing on average by 4.6% per annum over the past 8 years.

EvaluateMedTech® consensus forecasts that the Medtech world market will achieve sales of USD529.8 bn in 2022, growing by 5.2% per year (CAGR) between 2015 and 2022. *In vitro* diagnostics (IVD) will be the largest device area in 2022, with sales forecast to reach USD70.8 bn. Cardiology takes the second spot, with annual sales increasing to USD62.3 bn in 2022. Neurology is forecast to be the fastest-growing device area, with a CAGR of 7.6% between 2015 and 2022.

The market of Image guided intervention and decision support will grow substantially. A complete new area is the connected care and hospital informatics, which will focus on workflow and digital solutions both in the hospital and other care facilities. The area of personal health will also grow considerably.

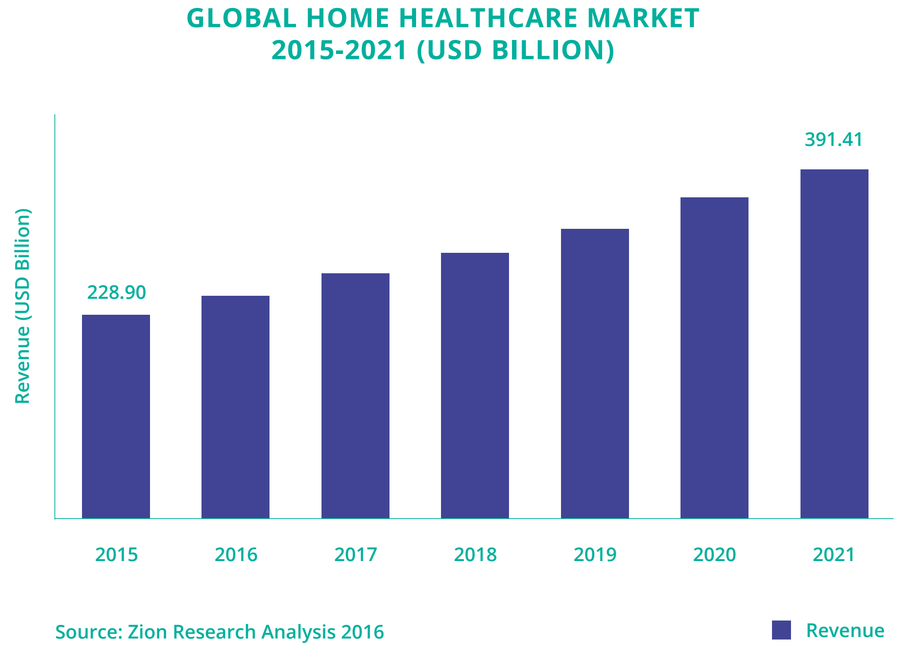
**WORLD MEDICAL TECHNOLOGY MARKET
BY AREA AND SALES GROWTH, 2015-2022**




*Analysis of Top 10 Device Areas in 2022, Market Share & Sales Growth (2015-22)*

**F.16**

The global home healthcare market is mainly driven by an increasingly geriatric population, rising healthcare costs and technological advancements in healthcare devices. With increasing health awareness among people, growing numbers of people diagnosed with chronic diseases such as diabetes cardiac disorders and respiratory diseases, the demand for home healthcare market is expected to grow in the near future. The population of geriatric people is growing rapidly across the world, a population that is more vulnerable to non-communicable diseases such as diabetes. This, in turn, is expected to fuel the growth of home healthcare market. However, changing reimbursement policies and limited insurance coverage may pose a challenge to the home healthcare market growth in the near future. Rapid decentralised job growth, especially in home healthcare services, is expected open alluring avenues for the market to grow over the next few years.




**F.17** *Global home healthcare market 2015-2021*

### 2.2.2. Societal benefits

Healthcare provision is in the process of "industrialisation" in that it is undergoing changes in the organisation of work, mirroring those that began in other industries a century ago. This process is characterised by an increasing division of labour, standardisation of roles and tasks, the rise of a managerial superstructure, and the degradation (or de-skilling) of work. The consolidation of the healthcare industry, the fragmentation of physician roles, and the increasing numbers of non-physician clinicians is likely to accelerate this process. Although these changes hold the promise of more efficient and effective healthcare, physicians should be concerned about the resultant loss of autonomy, disruption of continuity of care and the potential erosion of professional values. On the other hand, physician roles will become more complex because patients will be multi-morbid and can only treated by an integral approach to all disorders simultaneously.

Healthcare will also become more personalised. Besides age, blood pressure and cholesterol levels, personalised healthcare also looks at biological information, biomarkers, social and environmental information to gauge the risk of disease in individuals. Furthermore, it means providing individuals with tools like digital health and fitness apps, telemedicine providers and at-home testing kits. These on-demand health solutions enable people to understand their health on their own terms, while receiving doctor input. Personalised health also applies patient-specific optimisation of diagnostic imaging and image-guided therapy and tailored settings of automated implanted medical devices based on an individual's personal data.

In many cases, poor nutrition is a primary source of ill health and significantly impacts health expenditure. For this reason, health policy-makers are now investing more resources in the early detection of causes of ill health related to food, rather than simply focus on diagnosis and treatment. In such way, policy makers can possibly reduce the burden of food-related disease on the health services and improve the health of the population at large.

The ambition is to influence all stakeholders in the entire health continuum. The stakeholders are individual patients, healthcare professionals, industry and the economy as a whole.

For patients, benefits should address shorter hospital stays; safer and more secure access to healthcare information; relevant, correct and without information overload; better personalised prevention, information about environmental factors, diagnoses, management and treatment; improved quality of life and productivity; and reduced risk to further complications that could result from hospital treatment.

For healthcare professionals, benefits are directed towards improving decision support; providing safer and more secure access to healthcare information, precise and without information overload; unlocking totally new clinical applications; and enabling better training programmes leading to better trained professionals.

The impact on European industry is targeted at maintaining and extending leadership positions of European Industry; creating new market opportunities in the digital world for European large industry and SMEs; opening up a new world of cloud-based collaborative care; and increasing efficiency of health prevention, diagnoses and treatment.

Benefits for the European society at large include the creation of a European ecosystem around digital healthcare; contributing to the reduction of growth of healthcare cost; increasing people's years of healthy life; improving quality of life, wellbeing and productivity of the workforce; and decreasing or considerably slowing down morbidity among society.

Benefits for healthcare payers (such as insurance companies, national authorities and citizens themselves) target health prevention, a reduction of cost and a leaner approach to healthcare provision coupled with an improved quality of treatment.

### 2.2.3. Game changers

To realise the abovementioned benefits, we should focus on innovations and technologies that have the potential to become game changers in the health industry. The most important technologies are listed below:

- Cognitive computing.
- Transaction mechanisms for Data Security with Blockchain.
- Humanoid robots
- 3D Printing and Computerised Numerical Control machining
- Battery-free body worn or implantable medical device
- Nano devices.
- Organs on chip or organs in package
- New (Bio) materials.
- Regenerative medicine.
- Imaging whereby images will be combined with other sensor data to get precise models of the person's health. Precise imaging will be needed at many levels: from molecular imaging up to whole body imaging. This will be the main source of decision support for image guided treatment and monitoring.

# 2.3. MAJOR CHALLENGES

## 2.3.1. SWOT analysis

Below you can find a SWOT analysis on the current European position in healthcare. These points are addressed in the individual Major challenges and expected results

| | POSITIVE FACTORS | NEGATIVE FACTORS |
|---|---|---|
| Internal factors<br>To the EU ECS industry [15] | **Strengths:**<br>Presence of strong industrial players in EU (e.g., Philips, Elektra, Siemens, B Braun)<br>Much creativity in EU<br>Great design capabilities in EU<br>Strong entire value chain<br>Strong presence of small Medtech companies<br>Good cooperation between universities, RTO, companies and hospitals<br>Experience from past EU projects – pilot tests<br>Leading position of Europe in MtM/sensor domain<br>Strong, well developed mobile telecom with good territory coverage<br>Health insurance systems in Europe are in general very elaborate | **Weaknesses:**<br>Fragmented market across countries<br>Limited start-up / VC culture<br>Personalised cloud providers from US<br>Fragmented solutions, no integrated solutions at hand<br>Limited cross-border cooperation<br>Necessity of multi-lingual solutions |
| External factors<br>To the EU ECS industry | **Opportunities:**<br>Move from hospitals to homes and care centres will enable high volumes<br>Ubiquitous availability of smartphones will enable new eHealth services<br>Low-cost availability of accurate health sensors will enable remote health monitoring<br>Formulation of unified requirements concerning semantic interoperability and process interoperability will enable flexible modular solutions<br>Availability of personal data enables new services and solutions<br>European market is the largest in number of treated patients<br>Faster market introduction due to EU directive on medical devices<br>Similar cultural background in Europe might help in user acceptance<br>Increasing demand of medical devices (prediction until 2022)<br>Predicted growth of R&D expenses<br>Ageing population results in growing market | **Threats:**<br>Ageing population results in growing needs for integrated care<br>Not all legislation uniform in EU<br>Reimbursement schedules vary per EU member state<br>Increasing competition from less fragmented markets<br>Lack of widely accepted, advanced privacy and security technical standards |

**F.18** *SWOT analysis on current European position in healthcare*

### 2.3.2. Moving healthcare from hospitals into our homes and daily life requiring preventive and patient centric care

#### 2.3.2.1. Vision

Increasingly present-day patient functions are moving out of the hospital. In the end, only treatments and diagnoses that need large equipment and/or the near presence of specialised medical personnel will remain in hospitals that will transform into treatment and/or diagnosis centres. Enabling mobile diagnoses and treatment systems means that specific procedures can move out of the hospital towards general practitioners or patient homes. In the meantime, the focus of healthcare (time spent and cost) is on embedding diagnosis and treatment in the hospital with home-based prevention, monitoring and chronic disease management.

Patients are becoming healthcare customers. They and their relatives are engaged in the prevention and care, and they are empowered to participate. This is supported by widespread connected care, integrating home-based systems, and professional healthcare systems and information repositories.

Monitoring and alert systems are widely used to support prevention, diagnosis and aftercare. They are sensors and actuators to ensure precise and timely analysis and medical decision support.

Healthcare providers need to be proactive and address care customers, intervening before they notice their health condition is affected. Diagnosis and treatment are not bound to fixed places, but can occur near any place where the care customer is. Many chronic disorders will be treated at home with active implantable medical devices, which may be enhanced by body sensor networks. In addition to electronics, advanced biocompatible materials may be used as stimulators.

During treatment, the information gathering accelerates and delivers in real time the precise information needed to guide the (image guided) treatment and involvement of higher care.

#### 2.3.2.2. Scope and ambition

Just products, or point solutions, are not sufficient anymore. Care solutions need to be holistic and integrated services, combining information across all phases of the continuum of care from many sources, preventing, preparing and providing care based on the person specific characteristics, taking co-morbidities into account. Predictive and preventive care is based on information originating from massive and continuous data collection and analysis of individuals and populations.

Given the ageing of the population, the incidence of co-morbidity is growing rapidly. To make electronic treatment with Active Implantable

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[15] *EU industry here means the full Large Industry + SME + RTO + University eco-system*

Medical Devices (AIMD's) viable, these AIMD's will have to coexist with each other within a single patient. Furthermore, there will be a coexistence between main stream diagnostic and therapy systems in hospitals and implantable devices.

An important aspect is to deal with the many different formats in which data are and will be collected. Because of the large variety in bandwidth and information range, and also the differences in age of the equipment, it is unrealistic to assume that all devices and sensors will use the same protocol. Therefore, analysis and decision support will be based on incoming information in many protocols.

#### 2.3.2.3. High priority R&D&I areas

- From products to integrated solutions and services
- Improved biomedical models of the health situation of healthcare customers, taking heterogeneous, longitudinal (image) data, context and population information into account
- Use large heterogeneous data from many sources to obtain precise information
- Ensure low-latency analysis and reasoning involving 2D, 3D and 4D images, and prompt delivery of precise results, also in situations with partial and imperfect data
- Longitudinal monitoring and data analysis of many patients applying AI techniques, leading to precise alarms only when needed
- Remote diagnosis and treatment delivery based on advanced user interaction models and collaboration models involving the healthcare customer and the healthcare practitioners
- Development of smart catheters used in (image guided) treatment and specialised operating theatres (e.g. Cathlabs)
- Development of active or passive implantable medical devices for disorders currently not treated or treated by life-long pharmacy (e.g. stimulators for spinal cord disorders, depression, obesity, hypertension)
- Development of surgical robots
- Development of novel regenerative medicine solutions
- Mutual coexistence between implants and mainstream diagnostic systems is a high priority research area stretching from basic electromagnetic compatibility aspects to communication protocols and harmonised cloud analysis interfacing.
- Diagnostic imaging equipment with sufficient accuracy for active/passive implantable medical devices placement, preventing trial-and-error approach.

#### 2.3.2.4. Competitive situation

The current AIMD market is mainly governed by US companies Medtronic, Abbot and Boston Scientific. Nevertheless, in Europe a variety of start-ups, SMEs, large enterprises and the presence of two major healthcare diagnostic players, Siemens and Philips, are leading to promising market expectations.

For regenerative medicine, there are no big players yet, but there is a large number of start-up companies active that are being closely watched by the established industry.

Start-ups, SMEs are the most active players for introducing disruptive innovations in healthcare and wellbeing. Their innovation is industrialised and commercialised worldwide by large companies. The close collaboration between start-ups, SMEs and large companies is essential to strengthening the ecosystem.

#### 2.3.2.5. Expected achievements

- Integrated solutions and services for specific disease groups, for customer groups, and for populations, covering parts of the care cycle
- Applicable biomedical models for specific disease groups, for customer groups, and for populations, covering parts of the care cycle, taking heterogeneous data involving history, context or population information into account
- Low-latency (large image) data analysis and reasoning and dependable delivery of results
- Long-term monitoring and data analysis of patients with chronic diseases, leading to decision support with a low level of false alarms
- Effective remote diagnosis and (image guided) treatment delivery involving collaboration between the healthcare customer and the healthcare practitioners
- High quality of life for patients with damaged of dysfunctional body parts, reducing lifetime costs
- More accurate (higher precision) diagnostic imaging

### 2.3.3. Restructuring healthcare delivery systems, from supply-driven to patient-oriented

#### 2.3.3.1. Vision

Today healthcare costs are mainly based on demanding fixed prices for fixed, predefined, treatments at moments when the health problem unavoidably disturbs the life of the patient. Large amounts of images will be combined with other sensor data and biomedical models to get precise, quantified information about the person's health condition. Low–latency, massive image processing is the main information source for AI based automation, visualisation and decision support within the whole care cycle. Precise quantified imaging is needed at many levels: from molecular imaging up to whole body imaging. Additionally, imaging will be improved to become less harmful and less expensive.

For chronic patients, the costs are determined by long-term pharmaceutical prescriptions and irregular treatments, when the disease gets severe. However, patient centric healthcare demands prevention, early diagnosis before suffering, and continuous care in the case of (multiple) chronic diseases. Outcome based healthcare will predict the outcome of a disorder and its treatment for a patient much faster. At its core is maximising value for patients: that is, achieving the best outcomes at the lowest cost[16]. Not the number of treatments but the optimal value for the patients will become the driver of care. In addition, care centres will not be organised according to general hospitals that serve any disease. Instead, they will specialise to specified disease

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[16] https://hbr.org/2013/10/the-strategy-that-will-fix-health-care

types, to improve the total outcome. These centres will act not only for visiting patients but, increasingly, through remote access, for patients anywhere in the world.

#### 2.3.3.2. Scope and ambition

The goal of outcome based healthcare is to improve value for patients, without increasing the costs, and preferably lowering the costs. This demands that reimbursement schemes have to be changed, allowing more cost-effective care involving prevention, early detection and treatment, and continuous monitoring of chronically ill patients. Outcome based healthcare will learn and adopt optimisation practices common in industry. The ambition is that outcome based healthcare will improve the predictability of diagnosis and treatment.

#### 2.3.3.3. High priority R&D&I areas

- Holistic healthcare involving all imbalanced health situations of the patient
- Use of the (growing) whole body of medical knowledge during diagnosis, (image guided) treatment and monitoring
- EHR involving patient health models supporting precise communication between different care givers
- EHR involving health models that exactly describe the outcome heath values for the patients, both short and long term
- Transform large healthcare systems to optimise hospital workflow, automatically optimise diagnostic imaging and tracking of therapy results, enable preventive maintenance and generation of requirements and test cases for new generations of systems
- Predictable and repeatable outcome of diagnostic imaging. Current diagnostic imaging is often of a qualitative nature, meaning that comparison over time or with other patient cases is impossible
- Apply generic standards (e.g. industry 4.0) to diagnostic and therapy systems and use of big data principles to reduce cost of ownership
- Create and apply biomedical models for AI based automation, visualisation and decision support, to get precise, quantified information of the person's health condition. This needs large amounts of images and other sensor data at many levels: from molecular imaging up to whole body imaging
- Less harmful and less expensive imaging modalities at several levels: from molecular imaging up to whole body imaging, in the prevention, diagnosis, therapy and monitoring phases
- Humanoid robots applying interpreted human body language and emotion in care delivery
- Robotics to improve treatments either in the operating room, minimal invasively inside the body, at general practitioners or at home
- 3D Printing and CNC (Computerised Numerical Control machining): printing implants and prosthetics for individuals, create patient-specific anatomical models, e.g. create powered exoskeleton to help paraplegics to walk again

#### 2.3.3.4. Competitive situation

Two of the three major diagnostic imaging and image guided intervention companies (Philips and Siemens) are based in Europe. Competition from China (e.g. United Imaging) and Korea (Samsung) is emerging, driving the need for faster innovation at lower cost in Europe.

#### 2.3.3.5. Expected achievements

- Healthcare delivery for patients with co-morbidities
- Preventive and early warnings for (combine) diseases
- Image analysis and decision support for diagnosis, treatment and monitoring, using large medical knowledge bases
- Quantitative, less harmful and less expensive imaging for diagnosis and therapy
- Patient health models on complex heath conditions
- Outcome based treatment, diagnosis and monitoring health models
- Healthcare systems, IoT with big data learning for optimising workflow, usage, capabilities and maintenance
- Repeatable and quantifiable outcome of diagnosis (including the use of biomarkers) and treatment

### 2.3.4. Engaging individuals more actively in their own health and wellbeing

#### 2.3.4.1. Vision

In 2030, digitalisation will be common in our society, and will bring healthcare from clinical centres into the everyday life of the citizen, in health and vitality promotion as much as for healthcare and disease prevention. Highly motivated individuals will improve their vitality by using wearables and connected software, thus enabling adjustment of personalised models that make them increasingly aware about the impact of body movement, food and nutrition on their health. The development of digital health ecosystems (comprising digital health platforms, health monitoring wearables and devices, mobile applications and online services) will empower individuals to monitor against a norm, manage, track and improve their own health. This will open new markets of solutions and services directly targeted at both healthy and patient individuals, and positively impact the effect of preventive practices as well as on the application of treatments earlier.

#### 2.3.4.2. Scope and ambition

A motivated and educated population will take preventive measures. Collection of long-term data will contribute to early capture of a disease or disorder, which will increase probability of fast and successful treatment.

The ecosystem of healthcare solutions targeted at individuals is growing fast. The competition is pushing the improvement of features provided and quality of service as well as the specialisation. Smart algorithms for different purposes will be developed and specialised marketplaces will emerge; the demand and supply of data analytics will push the creation and sharing of data sources; precision medicine will follow the two previous building blocks.

#### 2.3.4.3. High priority R&D&I areas

- Wearables or minimally invasive implants, Internet of Things, simple analysers for home use; reliable data collection and analysis – focus on input data quality assessment (we need to know whether we evaluate useful data or noise and artefacts); standardisation of calibration, process interoperability
- Devices or systems for utilising/extracting/sharing new knowledge in the most informative and efficient manner (e.g. vitality data, molecular profiling, biotechnology, diagnostics, ICT tools) in the most appropriate personalised setting (e.g. healthcare system, at home)
- Devices or systems for protecting and enforcing individual health-related information: ownership

and secure storage of health data, data sharing with healthcare providers, and rendering real-time anonymity for wider data analytics Devices or systems improving security for executing transactions in healthcare and wellbeing, like blockchains to improve health or personal records exchanges and interact with stakeholders

- Devices or systems for integration of health and prevention ICT solutions in national health systems.

#### 2.3.4.4. Competitive situation

- A major development is the rapid development in the wearable technology and devices market. According to a research report conducted by Transparency Market Research, the wearable devices market, or the remote patient monitoring devices market, is anticipated to reach USD 0.98 billion by the end of 2020. This represents 14.2% CAGR. Top players are Biotricity Inc., Abbott Laboratories, Apple, Alphabet, Business Machines Corp.
- Three groups are fighting a war for control of the “healthcare value chain”.
- One group comprises “traditional innovators”—pharmaceutical firms, hospitals and medical-technology companies such as GE Healthcare, Siemens, Medtronic and Philips.
- A second category is made up of “incumbent players”, which include health insurers, pharmacy-benefit managers (which buy drugs in bulk), and single-payer healthcare systems such as UK NHS.
- The third group are the technology “insurgents”, including Google, Apple, Amazon and a host of hungry entrepreneurs that are creating apps, predictive-diagnostics systems and new devices. These firms may well profit most handsomely from the shift to digital.

#### 2.3.4.5. Expected achievements

- Repeatable and quantifiable outcome of vitality and prevention.
- Early diagnostics based on assessment of longitudinal patient data.
- New models of person-centred health delivery, also integrating health and social care and considering the environment and community setting of the individual. Transition to a decentralised model, from traditional healthcare venues like hospitals to integrated care models (e.g. transfer of records to patients);
- Empowerment of the individual to manage his data: individuals taking greater ownership of his/her state of health, especially for those with chronic conditions.

### 2.3.5. Ensuring affordable healthcare for the growing amount of chronic, lifestyle related diseases and an ageing population

#### 2.3.5.1. Vision

Most of the chronic and lifestyle related diseases and elderly diseases need long-term monitoring of the patient’s state and rehabilitation support. Current rehabilitation and physiotherapy are labour-intensive, thus the machine supported rehabilitation and physiotherapy could contribute to higher efficiency of the work.

According to several foresight studies[17], in 2030 priorities will lie with promoting healthy lifestyles, preventing illness and prompt cure while supporting vulnerable people and enabling social participation.

### 2.3.5.2. Scope and ambition

Modular rehabilitation devices with intelligent real-time feedback to the user can enhance the efficiency of treatment. Gamification of the interaction may contribute to motivation of the user. Modularity of the devices allows for personalisation of the treatment. Basic components will be built on Industry 4.0 principles.

### 2.3.5.3. High priority R&D&I areas

- Wearables or minimally invasive implants, including new sensor systems for easier and more efficient measurement of physiological parameters, incl. posture, sitting position, physical activity, dynamics of walking, etc
- Devices or systems using biomedical models for better diagnostics, therapy and feedback to the patient for several chronic diseases e.g. musculoskeletal system and simulation of activity of muscle groups, joints, etc.
- Devices or systems using predictive models to anticipate the appearance of co-morbidities because of the evolution of chronic diseases
- Real-time location services with badges that can track patients, staff and medical devices, Environmental monitoring — for example, checking hand hygiene compliance. Mobile apps will replace traditional physician visits

### 2.3.5.4. Competitive situation

Few companies exist that focus on development of precise models, e.g. Dassault systems. In the area of rehabilitation there are companies producing exoskeletons, e.g. ReWalk, Cyberdyne, Ekso Bionics Holdings.

### 2.3.5.5. Expected achievements

- Focus on wellbeing and prevention to identify trends towards ill health and so strive to keep people away from unnecessary care and to encourage them to be proactive
- Person-oriented approaches for the treatment of patients with multiple chronic diseases, situations of frailty and/or of loss of functionalities in a multi-cultural context
- Individuals taking greater ownership of his/her state of health, especially for those with chronic conditions
- Modular systems adjustable to individuals´ needs. Gamification will increase motivation of the patients

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[17] *National Institute for Public Health and the Environment (2014) A healthier Netherlands: Key findings from the Dutch 2014 Public Health Status and Foresight Report. RIVM, Netherlands.*

## 2.3.6. Developing platforms for wearables/implants, data analytics, artificial intelligence for precision medicine and personalised healthcare and wellbeing

### 2.3.6.1. Vision

In 2030, technologies such as wearable devices, remote diagnostics, tele-medicine and personalised medicine will be successfully developed to reduce inefficiencies and improve access to healthcare, with apps providing innovative platforms. These devices will generate enormous volumes of data. The role of digital health platforms, wearables or minimally invasive implants and mobile devices will evolve beyond remote health monitoring and reporting towards smarter tools able to make early decisions, both for medical professionals and the customer and his/her relatives, especially in cases where quick action is needed (e.g. brain stroke prevention). This will enable new approaches to early disease detection, prevention and treatment, paving the way for personalised treatments.

Furthermore, professional data, data originating from a person's wearables or minimally invasive implants, and environmental sensors will be integrated into relevant information about that person's health condition. This information will become the main source of decision support that alerts caregivers and the persons themselves about situations that endanger heath. Health measurements will combine both cheap retail products, sensors and certified healthcare measuring devices. Dependent on the person's condition, more or fewer certified products will be used.

### 2.3.6.2. Scope and ambition

Mobile devices and wearables will leverage advances in diagnostics, integrating sensor scanning, data recording and data analysis. New pharmaceuticals and treatments will be developed for personalised medicine settings by embedding connected devices and exploiting the potential of IoT and AI. AI (machine-learning, deep learning and related) will be the key differentiator for any smart health device. Smart algorithms and specialised predictive models will be developed, with specialised marketplaces emerging. Data analytics demand will push the creation and sharing of data sources, as well as the development of mechanisms (e.g. distributed ledgers) to protect the transmission of health data records across the healthcare value chain.

The aim is to deliver preventive and early care to everybody, wherever they may be, based on personalised models. Care is provided by combining many sensor inputs, personal historical information and analysing it according to their healthcare merits.

### 2.3.6.3. High priority R&D&I areas

- Smart, robust, secure and easy to use devices or systems (wearable or implantable and autonomous) for detection, diagnostic, therapy, through big data, artificial intelligence, machine learning, deep learning person-centred
- Multi-modal data fusion devices or systems: the generation of enormous amounts of data from different sources (e.g. vital signs from mobile apps, home monitoring, real-time sensors, imaging, genomic data, pharmaceutical data, and behavioural markers) brings valuable information to improve clinical decisions and to reveal entirely new approaches to treating diseases. But the fusion of multi-modal data poses several technical challenges related to modelling, data mining, interoperability, data share keeping privacy
- Scalable platforms able to support the automatic deployment and maintenance of applications for digital health, guaranteeing Service Level Agreements and Security for data
- Energy efficiency for medical wearables/implants: Improvement of energy consumption and battery life at device levels. Ability to deliver connected devices (wearable/implants) that are self-

sustainable from an energy point of view for the full duration of a medical treatment (weeks, months or years)

- Sustainable, renewable or harvested long-term highly integrated energy sources or devices
- Upgradability of medical wearables/implants: A wearable/implant must be able to adapt to several configurations in the function of the evolution of a disease and improvements in its treatment. The upgrade/downgrade must not imply obsolescence of the wearable/implant. Therefore, a supporting wearable infrastructure should support the possibility of running virtual devices that complement the processing power and storage embedded in wearables/implants
- Highly dependable (reliable, secure, safe, privacy supporting, easy to use, ...) IoT platforms
- Devices or systems data with low-latency analysis performed with deterministic algorithms or deep learning that are able to deal with known levels of trust (both high and low) for precise presentation of the results to medical professionals and non-professionals
- Devices or systems based on cognitive computers providing support to professionals or non-professionals for healthcare or wellbeing

#### 2.3.6.4. Competitive situation

The digital health market is fragmented geographically, with large companies, local small players and start-ups competing together in different regions. Globally, North America is expected to retain the highest market share (the US being the dominant market in this region), followed by Western Europe (Germany) and Asia (China)[18]. Major global players include European companies (Philips, Siemens, Lifewatch, Bosch Healthcare, SAP), although US companies dominate the global landscape (GE Healthcare, Qualcomm, McKesson Corporation, AT&T, IBM, Cerner Corp., Cisco, eClinicalWorks, athenahealth), followed by emerging competitors from China (iHealthLabs, Alibaba Health Information Technology, Tencent, Baidu). Major IT technology players are also positioning in the market, with solutions leveraging data analytics: IBM, Microsoft, Google, Apple and Amazon.

#### 2.3.6.5. Expected achievements

- Better understanding of treatment response and prognostic heterogeneity. More refined, patient tailored approaches to disease detection, prevention and treatment
- Better integration and analysis of multi-modal data, providing new tools for clinical decision-making and precision medicine. Development of dynamic healthcare systems that learn in real-time from every result

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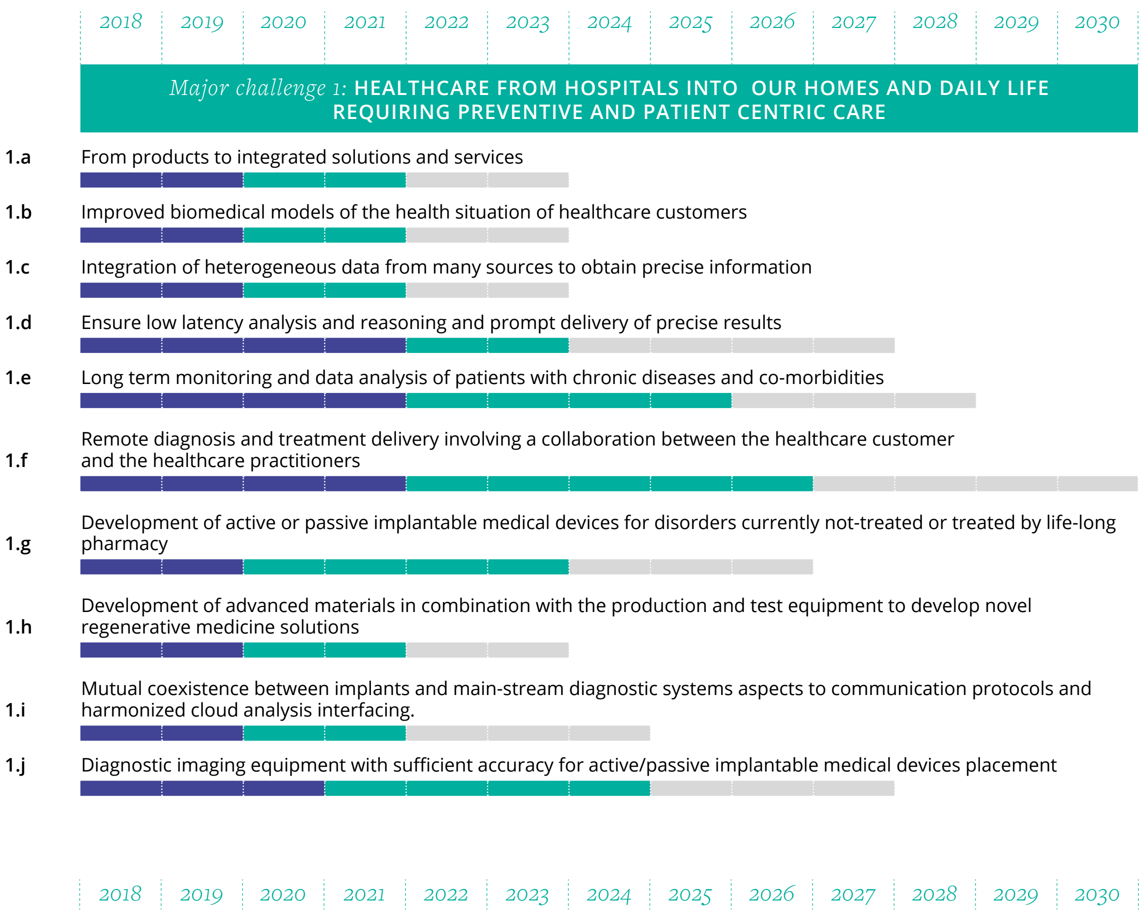
18 *Global Market Insights: Digital Health Market forecasts 2016-2024. November 2016.*

- New technologies for early diagnostics, personalised medicine and potential curative technologies (e.g. regenerative medicine, immunotherapy for cancer). Development of a wider European market offer of wearable and mobile devices for healthcare
- Repeatable and quantifiable outcome of diagnosis and treatment. Adjustment of treatment based on intermediate/continuous data evaluation.
- Dependable IoT platforms
- Models for levels of trust of sensor data and data quality
- Low latency analysis algorithms that are able to deal with known levels of trust (both high and low) of sensor data
- Presentation of analysis results to medical professionals and healthcare customers

## 2.4.
## TIMEFRAMES



2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030

## *Major challenge 2:* A MORE INDUSTRIAL APPROACH TO HEALTHCARE OR WELLBEING

**2.a** Holistic health care involving all imbalanced health situations of the patient

**2.b** Use of the (growing) whole body of medical knowledge during diagnosis, treatment and monitoring

**2.c** EHR involving patient health models supporting precise communication between different care givers

**2.d** EHR involving health models that exactly describe the outcome heath values for the patients, both short term and long term

**2.e** Transform large healthcare systems to optimize hospital workflow, automatically optimize diagnostic imaging and tracking of therapy results

**2.f** Predictable and repeatable outcome of diagnostic imaging. Current diagnostic imaging is often of qualitative nature

**2.g** Less harmful and less expensive imaging modalities (like ultrasound) at three levels: molecular imaging, whole organ imaging, whole body imaging)

**2.h** Humanoid robots for interpretation of  human body language, care delivery and to improve treatments in the operating room, inside the body  or at home

**2.i** 3 D Printing and Computerized Numerical Control machining: Printing implants and prosthetics for individuals, create patient-specific anatomical models

**2.j** Implantable organs on chip or implantable organs in package

## *Major challenge 3:* NEW SOLUTIONS FOR ENGAGING INDIVIDUALS  MORE ACTIVELY IN THEIR OWN HEALTH AND WELLBEING

**3.a** Wearables or minimal invasive implants, simple analyzers for home use;  input data quality assessment;

**3.b** Devices or systems for utilizing/extracting/sharing new knowledge in the most informative and efficient manner in the most appropriate personalized setting.

**3.c** Devices or systems for protecting and enforcing individual health-related information

**3.d** Devices or systems for integration of health and prevention ICT solutions in national health systems.

**3.e** Devices or systems improving security for executing transactions in healthcare and wellbeing, like blockchains

2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028 | 2029 | 2030


**F.19** *Timeframe 2018-2030*

# 2.5. SYNERGIES WITH OTHER THEMES

In the chapters **Transport & Smart Mobility** and **Digital Industry** new industrial processes are explored to optimise industrial processes, a cooperation between these domains and the Health and Wellbeing domain can be useful to support the major challenge "Restructuring Healthcare Delivery Systems".

Digitisation is a main driver in **Transport & Smart Mobility** and **Digital Life** and challenges related to the use of data, trust, safety and security are shared with the other domains.

Challenges on **Connectivity and Interoperability** and **Safety, Security and Reliability** are shared with most of the application domains especially relevant for the Health and Wellbeing chapter with the emerging Internet of Things (IoT) entering the hospital.

# 3

# *Energy*

# 3.1. EXECUTIVE SUMMARY

The energy world is in transition: different energy sources are linked to achieve high efficiency, reliability and affordability. The growth of renewable energy sources such as solar and wind power is changing the nature of the world's power grids. The increasing distribution of power generation leads from today's unidirectional to a distributed and bi-directional power flow. This situation requires intelligence and security features at each level of the grid and interfaces. Micro- and nano-electronics, integrated into power electronic modules and systems, are essential for an efficient, reliable and secure management of power generation, transmission, storage and consumption through smart grids, safe and secure system applications and devices.

All stakeholders of the European ECS industry, including nano-electronics, electronic device manufacturers and systems integrators (OEMs), together with the research institutes, contribute with innovative solutions, based on long-term continuous research on all Technology Readiness Levels (TRLs), to achieve the targets jointly agreed by the Industry and the European Commission.

Significant reduction of primary energy consumption along with the reduced carbon dioxide emissions is the key objective of the Energy chapter. ECS are key enablers for higher efficiencies and intelligent use of energy along the whole energy value chain, from generation to distribution and consumption. Enhancing efficiency in the generation, reducing energy consumption and carbon footprint are the driving forces for the research in nano-/micro-electronics and in embedded and integrated systems to secure the balance between sustainability, cost efficiency and security of supply in all energy applications.

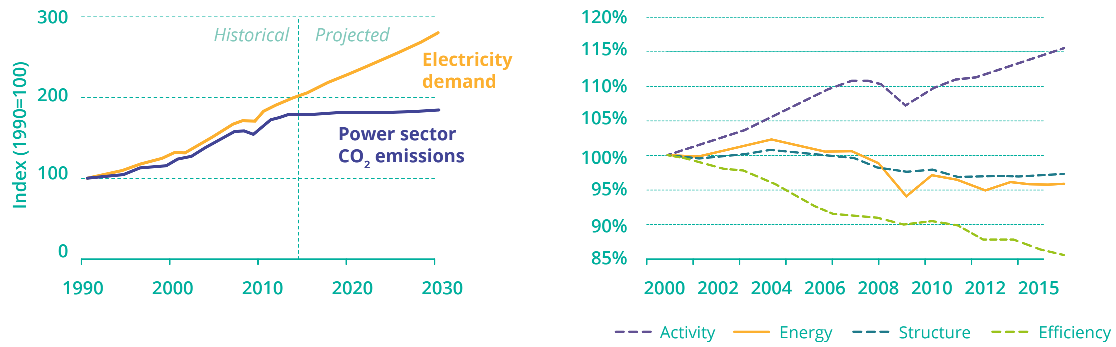
# 3.2. RELEVANCE

### 3.2.1. Competitive value

In the last years, it has become apparent that semiconductor-based innovative technologies have enabled more savings of electrical energy than the growth of demand has been in the same period. The core of the European competitive advantage is within the system knowledge and provision of holistic system solutions. Saving energy is equivalent to reducing the costs and being more competitive. Energy efficiency levels in IEA member countries improved, on average, by 14% between 2000 and 2015. This generated energy savings of 19 exajoules (EJ) or 450 million tonnes of oil equivalent (Mtoe) in 2015. These savings also reduced total energy expenditure by USD 540 billion in 2015, mostly in buildings and industry. While GDP grew by 2% in IEA countries, the efficiency gains led to flattening of the growth in the primary energy demand. In parallel, the global $CO_2$ emissions stalled since 2013 with only 2% growth, in 2014 with 1.1% and in 2015 with -0.1%.

Energy saving is also an opportunity. In fact, by reducing power dissipation and corresponding heat production, energy is available for other uses and equipment.

**GROWTH IN WORLD ELECTRICITY DEMAND AND RELATED $CO_2$ EMISSIONS**




*Source: World Energy Outlook Special Briefing for COP21 (2015)*

*Source: adapted from IEA Energy efficiency market report, 2016, based on IEA energy efficiency indicators database*

**F.20** *Growth in world electricity demand and related $CO_2$ emissions 2018-2030*

According to IEA, the analysis of factors driving energy consumption trends for IEA member countries indicates that in IEA the decoupling was mainly due to efficiency improvements (figure upper right). Structural changes (mostly shift to less intensive industries and services) also assisted efficiency improvements in reducing the total energy consumption. Cumulative savings over the period 2000 – 2015 were 159 EJ, equivalent to more than one year of final energy consumption in Europe, China and India altogether[19].

Examples of the most important ECS applications having high impact on the efficient use or generation of energy are power inverters – the steadily growing market (USD 65 bn. forecasted for inverters in 2020[20]).

Another example of ECS market contributing to the efficient use of energy is the wireless infrastructure RF power device market, with around USD1 billion TAM. The share of GaN based devices is expected to increase from 10% in 2015 to 40% in 2022 (source ABIresearch, 2017), which demonstrates how fast new techniques can be deployed if the added business value is achieved. Driven by new developments, such as the electro mobility and Industry 4.0, new energy supply chains and consumption patterns are emerging. Powering the electro mobility is a major challenge in the coming years with the implementation of a reliable and sustainable charging infrastructure.

[19] *Energy efficiency indicators by OECD/IEA – Highlights 2016*

[20] *Power Integrated Circuit 2017 - Quarterly Update – Yole Développement*

*Industrial 4.0 example*

**F.21**

The potential of the emerging industrial era 4.0 is based on the combination of two novel technologies: Cyber-Physical Systems (CPS) and the Internet of Things (IoT). Higher efficiency at all levels in power usage is one enabler for Smart Industry: Power conversion & energy harvesting, Power Management, Power storage & Motor Control (see figure above).

European ECS companies are amongst the leaders in smart energy related markets, which is largely driven by political decisions as well as by the move to renewing energies and to added costs on carbon dioxide emissions. Leading market positions are achieved for electrical drives, grid technology and decentralised renewable energy sources. This position will be strengthened and further employment secured by innovative research on a European level. Competitive advantages can be gained by research in the following areas:

1. significant reduction and recovery of losses (application and SoA related);
2. power density increase and decreased size of the systems by miniaturisation and integration, on system and power electronics level;
3. increased functionality, reliability and lifetime (incl. sensors & actuators, ECS HW/SW, monitoring systems,...);
4. manufacturing and supply of energy relevant components, modules and systems;
5. the game change to renewable energy sources and decentralised networks, including intermediate storage;
6. energy supply infrastructure for e-mobility, digital live and industry 4.0;
7. “plug and play integration” of ECS into self-organised grids and multi-modal systems;
8. safety and security issues of self-organised grids and multi-modal systems;
9. optimisation of applications and exploitation of achieved technology advances in all areas where electrical energy is consumed.
10. ECS for storage solutions.

### 3.2.2. Societal benefits

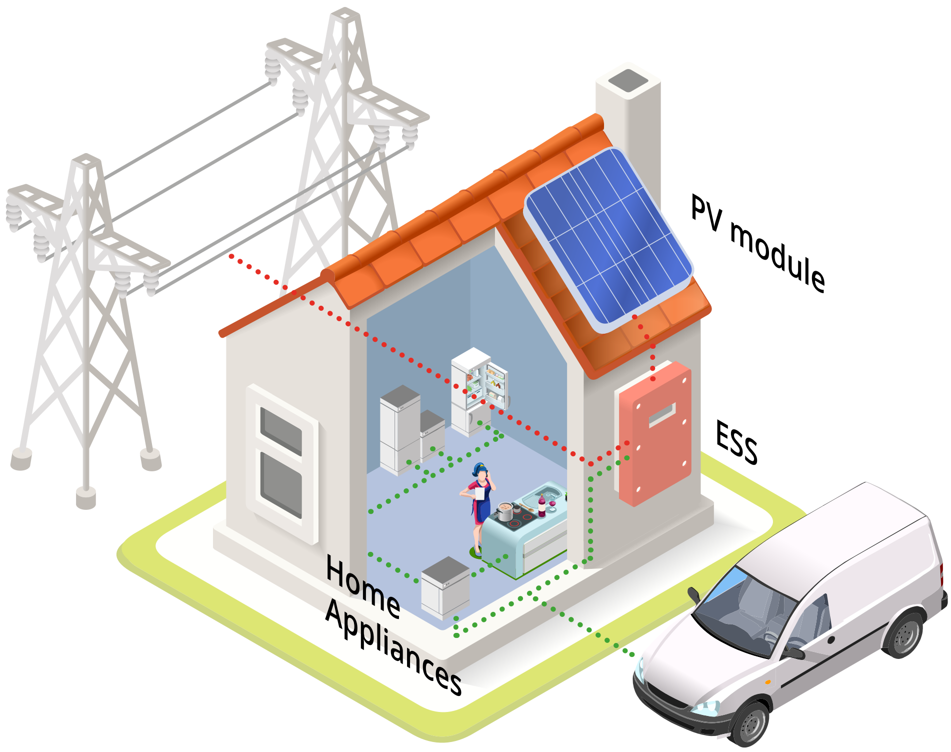
The ECS for energy (incl. components, modules, CPS, service solutions), which supports the EU and national energy targets, will have a huge impact on job generation and education if based on the complete supply chain and fully developed in Europe. The key will be the capability to maintain complete systems understanding and competence for small-scale solutions up to balanced energy supply solutions for regions. It is mandatory to have plug-and-play components that are enabled by broad research contributions from SMEs and service providers including EU champions in the energy domain. Thanks to the expected wider proliferation of energy storage devices in the smart city context, new distributed forms of energy storages will become available, to be exploited by smart control systems.

Societal benefits include access to knowledge, development of modern lifestyle and availability of energy all the time everywhere – with a minimum of wasted energy and a minimum of greenhouse gas emissions. Applications having a huge energy demand and therefore a large saving potential are in the areas of High Performance Data centres serving the mobile connected world, the implementation of Smart Cities and the future implementation of e-mobility with widely distributed charging stations, demanding a higher density of energy distribution points with, as a key feature, local intermediate storage systems.

[21] http://www.ecsel-ju.eu/web/downloads/documents/ecsel_gb_2015_46_-_masp_2016.pdf

**F.22** *Smart Energy landscape – from centralised to distributed (PV, wind, biogas, ...) generation and conversion, consisting of High/Medium Voltage grid (orange), Low Voltage grid (yellow) including Communication Network (aquamarine) linking producers and consumers down to regional and community level (source ECSEL MASP 2016 [21]).*

The smart grid delivers smart energy from suppliers to consumers using digital technology to control appliances at consumer's homes to save energy, reduce cost and increase reliability and transparency.




*The Prosumer concept. The Power transmission goes from one-way to two-way lines.* **F.23**

Highly innovative technologies guarantee high-value employment. With more than one million jobs in the field of renewable energies and the indirectly involved technologies, a significant factor for economic and societal stability is visible.

# 3.3. MAJOR CHALLENGES

## 3.3.1. SWOT analysis

The table below presents a SWOT analysis on the current European position in Energy. These points are addressed in the paragraphs about the individual major challenges and expected results.

| | POSITIVE FACTORS | NEGATIVE FACTORS |
|---|---|---|
| Internal factors<br>To the EU ECS industry[22] | **Strengths:**<br>Europe has a leading position. Four European based power semiconductor suppliers amongst the top 12 having together a market share of over 24% in 2014. Three power modules suppliers in the top ten with a market share of over 33%.<br>The overall share of European suppliers is increasing in this growing market underlining their competitiveness. | **Weaknesses:**<br>Ability to follow very fast changing environment<br>Speed of introduction of regulations.<br>"100 years old" established infrastructure to be converted into a highly flexible and dynamic energy supply infrastructure. |
| External factors<br>To the EU ECS industry | **Opportunities:**<br>Affordable energy conversion efficiencies (93% - 99% or more) allowing better use of renewable energy resources, exploiting new materials, new device architectures, innovative new circuit topologies, architectures and algorithms lowering the total system cost.<br>New infrastructure for EV charging is required<br>Energy highway through Europe has to be implemented.<br>Emission-free cities require electric approaches.<br>Decentralised smart storage.<br>Distributed DC network & grid technology<br>Efficient management of data and data storage. | **Threats:**<br>Availability of renewable energies in sufficient amount.<br>Oversupply and peak supply challenges for variable energy sources.<br>Availability of batteries and their installation.<br>Distribution grid – complexity of current setup and missing acceptance of new HV and DC grid connection.<br>Missing investments into DC voltage infrastructure since very long lasting decisions have to be taken in a fast changing environment.<br>Environmental changes.<br>Fragmented legislation. |

**F.24** *SWOT analysis of the position of the European ECS industry for energy*

## 3.3.2. Major Challenge 1: Ensuring sustainable power generation and energy conversion

### 3.3.2.1. Vision

The ultimate vision is and will be loss-free energy conversion and generation. A feasible vision is to reach ~99% efficiency by 2020.

[22] *EU industry here means the full Large Industry + SME + RTO + University eco-system*

#### 3.3.2.2. Scope and ambition

Historically, the topic of Energy Generation can be divided into two main fields: traditional energy generation (e.g. fossil or nuclear power plants) and energy generation based on renewable sources (e.g. wind, solar, hydropower, geo-thermal). In both cases, "raw energy" is produced in a form that cannot be transmitted or used without conversion. A new emerging application in the field of EV is the need for new batteries for energy storage to manage overcapacities and undersupply. Examples are non-continuous energy sources like windmills and solar cells. Using old-fashioned electronics for rectifying, transforming or converting (AC/DC or DC/AC) the currents, only about half of the energy can be used. New, much more dedicated and efficient components have to be used, partially based on new materials. In general, everything must be done to reduce the lifetime capital and operational expenses (CAPEX and OPEX) of renewable energy generation below those of the traditional energy generation.

#### 3.3.2.3. Competitive situation and game changers

The need for energy is a fact in modern society. The question is how to provide the energy in a resource efficient way and at a cost accepted by the society. Nano-electronics is playing an important role in the generation of renewable energies. Highly efficient conversion leads to fewer investments and therefore lower cost for the renewable energies. CAPEX and OPEX reduction per generated power unit is the only way to compete with traditional energy sources.

In terms of power semiconductors, which are the fuel for energy efficient systems, Europe has a leading position with four European based suppliers amongst the top 12 having together a market share of over 24% in 2014 for power semiconductors and three in the top ten with a market share of over 33% for power modules. Overall, the increasing share of European suppliers in this growing market underlines their competitiveness.

#### 3.3.2.4. High priority R&D&I areas

- Affordable energy conversion efficiencies of 93% to 99% or more allowing better use of renewable energy resources, exploiting new materials, new devices architectures, innovative new circuit topologies, architectures and algorithms lowering the total system cost.
- Enhanced device and system lifetime and reliability with effective thermal management ensuring life expectancy for renewable energy systems of 20 to 30 years.
- Developing semiconductors-based solar energy technologies including photovoltaic technologies and integrating them with solid-state lighting applications.
- Reduced physical size and weight of individual transformer stations with equivalent power ratings by the development of solid-state transformers. These actuators will provide new functions for the operation of power systems and avoid infrastructure extensions caused by increasing share of distributed generation.
- Innovative devices exploiting new materials to dramatically increase their power density capabilities to be used in efficient converters, supported by passive elements, new interconnect technologies and packaging techniques to achieve further miniaturisation and further reduce losses.
- New nanomaterials, devices and systems for improving energy efficiency of the growing worldwide renewable energy technologies, such as photovoltaic, wind and hydropower.
- System EMI research to cope with higher switching frequencies and further miniaturisation.
- System reliability enhancement with focus on thermo-mechanical and thermo-electro-mechanical reliability.
- Resilient control strategies, and self-healing systems technologies that enable better use of renewable energy sources, their real-time monitoring, performance prediction, proactive coordination and integration with smart urban systems.

- Smart sensor networks able to measure all internal and external physical parameters that influence energy conversion efficiency and thus help to enable an efficient smart energy landscape. This also includes sensors that support intelligent predictive maintenance concepts resulting in reduced maintenance costs and increased lifetime for equipment and infrastructure.
- Self-powering systems for small IoT nodes have to be developed. The target is that local energy harvesting will substitute battery powered devices and eliminate the high demand of energy for the battery manufacturing and distribution logistics.

#### 3.3.2.5. Expected achievements

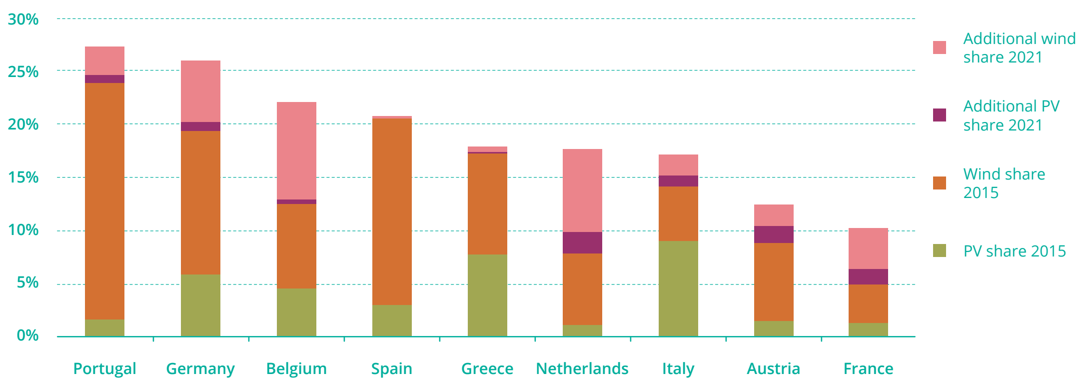
It can be expected that new highly efficient technologies (e.g. wide band gap materials, disruptive innovations based on new processing approaches and architectures) will be introduced and new competitive solutions will lead to further market share in the supply of power semiconductors. On the system level, European suppliers are expected to be established in the field of resilient control strategies that enable better use of renewable energy sources, their real-time monitoring, performance prediction, proactive coordination and integration with smart urban systems. For the energy supply of the IoT nodes, harvesters and intermediate storages have to be developed to substitute and minimise batteries.

### 3.3.3. **Major Challenge 2:** Achieving efficient community energy management

#### 3.3.3.1. Vision

The decentralisation of energy sources, opportunities with networked systems, limitations in peak electricity supply, oversupply times, new demand for electric energy supply for the urban mobility and the introduction of storage systems will lead to new challenges in energy management and distribution for communities and cities.

PV and wind energy examples are given to illustrate the change and challenges in the distribution of energy. Over the last 6 years, electricity demand in the UCTE countries' grids have slowly decreased from 2,600 to 2,500 TWh. In the same period, wind and solar PV production has increased by 79% and 338% respectively, reaching 226 TWh and 94 TWh in 2015. This development has led to variable renewable energy (VRE) accounting for 12.8% of total electricity production in 2015. The share of VRE for 2015 and projected for 2021 is shown in the following figure of selected **UCTE countries**[23]:




**F.25** *Share of VRE generation in 2015 and 2021 for selected UCTE countries* *Source: Adapted from IEA (2016a), Medium Term Renewable Energy Market Report*

### 3.3.3.2. Scope and ambition

Through the supported technologies the scope and ambition is to reach the highest efficiency and most economic energy supply and management solutions for communities and smart cities, including the distribution of energy to them.

### 3.3.3.3. Competitive situation and game changers

Advanced control and monitoring systems are already deployed at the transmission network level (high DC voltage). Broad inclusion of small and medium sized renewable energy sources into the grid and their coordination requires the adoption of control and monitoring systems at medium voltage levels as well. In the medium voltage grids, where small and medium size energy sources represent a significant part of the installed energy production potential, real-time monitoring of energy flows is needed to enable demand/response management (DRM).

### 3.3.3.4. High priority R&D&I areas

- Smart Grid applications that exploit demand/response technology in a robust and secure way, negotiating the trade-off between different levels of urgency in energy need with a varying price of that energy at any given time and accommodating variable renewable electricity;
- Self-organising grids and multi-modal energy systems;
- Improved grid visibility through advanced grid monitoring, including medium and low voltage levels;
- A highly resilient power grid through the introduction of proactive control algorithms (that go beyond demand/response), significantly improving the grid's self-healing and self-protection capabilities;
- Full implementation of Smart Grid technologies, resulting in the massive deployment of the necessary control options for the complete realisation of the Agile Fractal Grid also including smart agriculture (e.g. greenhouse energy efficiency);
- Smart E-Mobility grid for optimised charging, storage and distribution of electric power for light, medium and heavy vehicle transportation;
- Technological solutions for efficient and smart buildings (indoor) and outdoor subsystems including heating, ventilation, air conditioning and lighting, as well as traffic access, to achieve optimal energy-efficient performance, connectivity and adaptive intelligent management while ensuring scalability and security;
- Fog / cloud computing to offer sufficient and cost-effective processing power and to ease maintenance and update of control software with edge computing to support low-latency applications, such as real-time grid control.

[23] *Large Scale Electricity Interconnection 2016, IEA*

#### 3.3.3.5. Expected achievements

Medium voltage level management (DRM) helps to adjust consumption to the production (presently the production is adjusted to match the consumption), promotes the dynamic pricing tariffs that are needed to increase market share of small energy producers and, at the same time, enables the reduction of energy losses by better matching of production and consumption. Improved energy management at the MV level enables risk-free integration of additional renewable energy sources into the grid without any negative impacts on grid stability of the MV an LV micro-grids. Real-time monitoring at the MV level enables the deployment of self-healing MV grid strategies.

The growing impact of e-mobility on the energy infrastructure and management will help to create market success for demand technologies such as for the decentralisation of energy & energy storage and fast-charging infrastructure with >20kW power supply.

### 3.3.4. Major Challenge 3: Reducing energy consumption

#### 3.3.4.1. Vision

The vision for 2030 is to achieve the current EU policy targeted of 30% savings potential by utilising innovative nano-electronics based solutions.

#### 3.3.4.2. Scope and ambition

Three prominent and fast growing areas are addressed:

- the reduction of power consumption by the electronic components and systems themselves;
- the systems built upon them; and
- the application level in several areas.

**Electronic components examples:**

- One of the most challenging issues in High-Performance Computing is energy consumption. It is a well-known fact that the energy consumption of HPC data centres will grow by a significant factor in the next four to five years. Hence the costs of associated cooling infrastructures (with 50%-70% of the overall power dedicated to the cooling task of the current generation data centres) already exceed the costs of the HPC systems themselves. Therefore, reduction of energy consumption is becoming mandatory. Otherwise the consumption of exaflop systems will reach up to the 100 mega-watt range.
- The demand for mobile electronic equipment: the scaling is tremendous since billions of mobile electronic devices are deployed and connected to the grid each year. Even low-percentage improvements have a high impact on energy consumption.
- The demands for communication networks: increasing data volumes (1000 fold increase in mobile data volume), always-on availability, instant messaging – they all demand a permanently active infrastructure avoiding any inefficient operation. In order to avoid explosion of energy consumption of the communication networks, energy per transmitted data unit needs to be cut drastically. In the 5G development, the target is set to limit the energy per transmitted bit to 1/10$^{th}$ of today's level. To reach the target several measures needs be applied, e.g., electronic beam-forming techniques, efficient communication algorithms and highest efficiency components.

**System configurations:**

The energy efficiency of the system is achieved by using sensors, actuators, drives, controls and innovative components where the loss of energy can be reduced by innovative or even destructive approaches. The ambition is to reach a wider implementation of adaptive and controlled systems to meet the needs through monitoring and the ability to reduce energy losses. For example, intelligent building management systems can guarantee minimal energy use for heating and lighting (also providing safety and security).

**Application level:**

MEPS minimum energy performance standards[24].

Under the EU Ecodesign Directive, the European Commission sets MEPS for 23 categories of products sold in Europe. The Commission is currently considering revising or developing standards for the following product groups: air heating products, cooling products and process chillers, enterprise servers and data storage products, machine tools and welding equipment, smart appliances, taps and showers, lighting products, household refrigeration, household washing machines and dishwashers, computers, standby power consumption, water heaters, pumps and vacuum cleaners. Furthermore, under the Energy Performance of Building Directive, there is a continuous tightening of national minimum energy performance requirements in line with the optimum cost methodology.

The growing number of computing components within the hardware architecture of both HPC and embedded systems requires greater efforts for the parallelisation of algorithms. In fact, the optimisation of parallel applications still lags far behind the possibilities offered by today's HPC hardware, resulting in sub-optimal system exploitation and hence a significant waste of energy consumption.

#### 3.3.4.3. Competitive situation and game changers

Having the whole value chain represented and with leading positions worldwide, Europe has a rather good chance to build up a healthy "green industry" around tools and goods to reduce energy consumption. European companies have acknowledged strengths in power electronics and in nearly every related application. Market studies show leading positions of Europe in the field of power electronics and advanced LED lighting and even dominance in power semiconductor modules for renewable energies. Activities inspired, founded and led by European stakeholders such as the GreenTouch® initiative or a number of ETSI and ITU standardisation initiatives and focus groups exert worldwide influence. By employing the latest micro-/nano-electronic technologies and most advanced system concepts, European companies have defined and set new standards, raising the bars in performance and energy efficiency. Related R&D is also very active in all of those domains.

→

24 *ENERGY EFFICIENCY Market Report 2016 – International Energy Agency*

### 3.3.4.4. High priority R&D&I areas

- Intelligent drive control: technology, components and miniaturised (sub) systems, new system architectures and circuit designs, innovative module, interconnect and assembly techniques addressing the challenges at system, sub-system and device level for efficiently controlled engines and electrical actuation in industrial applications;
- Technologies and control systems to improve energy performance of lighting system;
- Highly efficient and controlled power trains for e-mobility and transportation;
- Efficient (in-situ) power supplies and power management solutions supported by efficient voltage conversion and ultra-low power standby, based on new system architectures, innovative circuit and packaging concepts, specific power components for lighting and industrial equipment serving portable computers and mobile phones, and standby switches for TVs, recorders and computers. Power management solutions in industrial, municipal and private facilities;
- Low-weight/low-power electronics, with advanced thermal management solutions, based on novel materials and innovative devices particularly benefiting, among other areas, medical applications, where improved energy management is one of the keys to cost-effective solutions (for example, medical imaging equipment);
- Immediate issue to be solved on the way towards exascale computing is power consumption. The root cause of this impending crisis is that the needs for ever increasing performances require larger amount of devices (and associated memory) while the chip power efficiency is no longer improving at previous rates. Therefore, improvements in system architecture (e.g. clock switching, etc.) and computing technologies (i.e. usage of low-power processors and accelerators like GPU, FPGA, etc.) are mandatory to progress further;
- Related issue of heat dissipation in computing system requires sophisticated air or liquid cooling units (e.g. chilled water doors, refrigerated racks, heat exchangers, etc.) further adding to the costs;
- Together with computing technologies (CPU, GPU, DSP, etc.) interconnect technologies add their own energy consumption, thus requiring further efforts to optimize routing strategies and switching policies in order to minimize the traffic. Usage of 3D nano-electronics based integrated devices and photonics can be envisioned for such improvement;
- Energy-efficient sensor networks, including hardware and software application layers;
- Optimal parallelisation of traditional sequential algorithms and efficient mapping on parallel and heterogeneous architectures will not only provide necessary performance but help to reduce energy consumption;
- Energy-efficient communication networks with highest efficient ECS, beam-forming and embedded algorithms;
- Efficient adaptive power management for 5G wireless network.

### 3.3.4.5. Expected achievements

The expected achievements are directly linked to the R&D priorities. It is worth highlighting that in several applications a huge price pressure, neglecting the benefits via reduced operational costs over the lifetime, demands significant achievements in reducing the cost of technologies. The achievement of exascale high-performance computing capability by 2020 requires a reduction by at least a factor of 5 of the current consumption in order to stay in the domain of technical and economic feasibility.

The following list of potential implementations supports the objective of energy consumption reduction: added increased share of intelligent drive control, electrical actuators for robotics, enterprise servers and data storage products, lighting products, household refrigeration, washing machines and dishwashers, computers, standby power consumption overall, water heaters, pumps and vacuum cleaners. Further potential is seen in highly efficient Industry 4.0 improvements based on sensor data and new control for actuators.

## 3.4. MAKE IT HAPPEN

The conditions for success are threefold: regulation and standards; technology availability, reliability and seamless integration; acceptance by the users. Standard interfaces and policies for the use and implementation of renewables, grids, farming approaches and others will anchor successful implementations.

## 3.5. TIMEFRAMES

| ENERGY: | SHORT TERM | MEDIUM TERM | LONG TERM |
|---|---|---|---|
| Overall – Embedded in EU strategy | EU targets for 2020 supported (20/20/20)<br><br>20% reduction in greenhouse gas levels<br><br>increased share of renewable to 20%<br><br>20% reduction in energy consumption<br><br>Projection regarding the targets in 2020: 24/21/17 | ECS to recover unmatched targets in 2020 and preparation for 2030 targets<br><br>Secured supply of ECS by European manufacturing | EU targets for 2030 supported by ECS from European suppliers: share of renewable energy in the electricity sector would increase from 21%<br><br>today to at least 45% in 2030[25] |

*Energy summary roadmap*

**F.26**

[25] *COM (2014) 15 final – A policy framework for climate and energy in the period from 2020 to 2030, Brussels January 2014 – The so called 20-20-20 targets- page 6*

2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028

## 1 - ENSURING SUSTAINABLE POWER GENERATION AND ENERGY CONVERSION

### 1.1 - ENERGY SUPPLY LANDSCAPE

**1.1.a** 1st order decentralized simple connected local systems – higher efficiency and first integration approaches including power system services

**1.1.b** 2nd order decentralized – regional area balanced energy supply (villages and cities up to 100.000 users)

**1.1.c** ECS capable for efficient fast reaction oversupply and peak load management (e.g. low latency, real time, connected, secure, ...)

**1.1.d** 3rd order decentralized – on country level balanced energy supply

### 1.2 GENERATION & CONVERSION

**1.2.a** Highest efficient and reliable ECS for all kind of electrical energy generation – de-centralized to large power plants, cross link to processes and mater.

**1.2.b** smart and micro inverter reference architecture with integrated control

**1.2.c** new power electronic actuators for DC and AC grids

**1.2.d** inverter on a chip or integrated modules

## 2 - ACHIEVING EFFICIENT COMMUNITY ENERGY MANAGEMENT

### 2.1 - ENERGY MANAGEMENT IN COMMUNITIES

**2.1.a** monitoring of energy infrastructure and cross domain services (e.g. maintenance, planning) Decreased integration costs in self-organizing grids.

**2.1.b** smart systems enabling optimized heat / cold and el. power supply

**2.1.c** ECS support for standalone grids and therefore decreasing demand for “big” power plants.

**2.1.d** New energy market design. E.g. self-coordinated energy supply in local grids

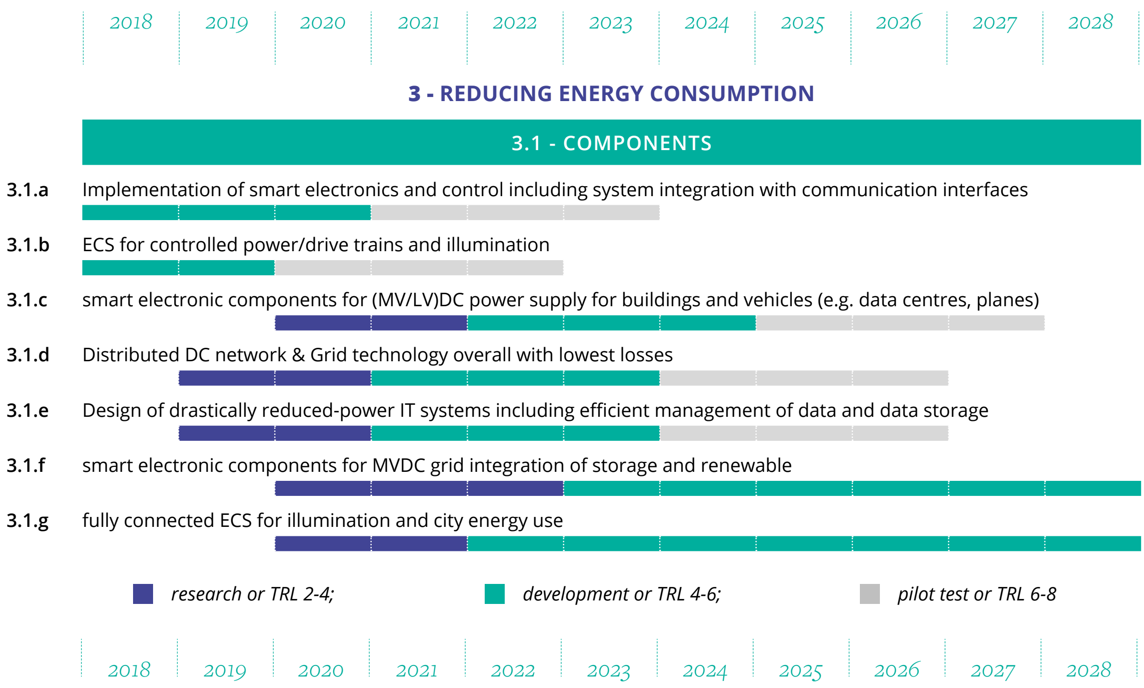
**2.1.e** Black Out safe energy distribution

**2.1.f** Management of Distribution with new capabilities (connected, data prediction, secure, ...) and high variability of sources and consumers

**2.1.g** Microgrid installations with local decentralized smart storage & redistribution including demand prediction capabilities

**2.1.h** Sharing of assets (sensors, consumption, demand, ...) with other application areas (transport, industry, digital life, ...)

2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028




*Energy roadmap* **F.27**

## 3.6 SYNERGIES WITH OTHER THEMES

Synergies can be found with all other chapters in terms of energy efficiency that enables new approaches in automotive, society or production.

The bases are the technologies, both power semiconductors and efficient μC, and all actuators such as sensors and actuators for energy-efficient measurements.On the other hand, the physical and functional integration technologies for the realisation of the systems are built with the components in accordance with the criteria of durability and reliability.

Security aspects related to Energy are considered in chapters Transport and Smart Mobility, Connectivity and Interoperability, Dependability and Trustability, Computing & Storage.

With reference to the Transport and Smart Mobility chapter, as the new concepts of automotive powertrain will be battery powered vehicles, fuel cell vehicles and hybrid engines, there is a need for new technologies with greater efficiency and robustness, so there is a strong connection with high priority R & D & I areas defined in Chapter 3 Energy.

# 4

# *Digital Industry*

# 4.1. EXECUTIVE SUMMARY

Digital Industry will require new applications and methods to make current factories work at the maximum flexibility and efficiency, and to optimise production level. As there will be fewer workers, they will have to handle more information. The only way to support that information flow is to use new innovations and integrate them in the normal work flow. This means that the user should have access to information as he/she needs it. This kind of easy access still requires security and a lot of back-end server capacity to process information ready to be used. An optimal system will set itself up according to the designed and installed system. This means we should have self-organising intelligence at the factory level.

Disruption can happen as wireless sensors and new field connectivity solutions are needed with industrial internet. Cloud-based network and integration will change the value chain. One challenge is to use this kind of network in a fast and dynamic way.

# 4.2. RELEVANCE

### 4.2.1. Competitive value

The Digitisation of industries has already advanced to a high international level, and European factories, as well as factories globally that are built by European companies, have high level of automation and digitisation. Many of the leading end-user companies of the domain are European based, and we also have a number of significant system and machine building, engineering and contracting companies in Europe who have drawn their competitive edges from automation and digitisation. The business environment has also been changing, i.e., we tend to specialise by new or niche end products, production is becoming more demand-driven or agile, production is more and more geographically distributed, outsourcing of auxiliary business functions, such as condition monitoring and maintenance, is gaining popularity leading to highly networked businesses. There are many opportunities for energy, waste, material, recycling optimisation, etc., over the value chains and across company boundaries. Such advantages are only realised by having a significantly more extensive digitisation in place.

The process of digitisation as such is again changing and advancing. Internet has become a backbone for many kinds of global and local, near process and enterprise level, open and confidential - process and business management functions. Internet offers, in principle, integration, interoperability, remote operations that are offered today as so-called cloud services. Data, or big data, has become an asset for many kinds of situational awareness, predictive analytics, deep learning, wide optimisation and, in general, new artificial intelligence applications. Modelling and simulation, virtualisation offers versatile opportunities for both factory design and operative factory management. European industrial policies now emphasise building a digital single market for European industries. To achieve this, industrial applications need much more capable internet than what traditional internet alone can offer. On top of internet, we need so-called industrial internet whose functionality and form is now developing under the title Industrie4.0. Industrie4.0 is expected to contain all the elements that are needed to realise the heavily software and automation managed global, distributed and flexible businesses, across value chains, across company and geographical borders, from process to business function levels. A new 'digitalisation' is being emphasised as we now enter an era of novel products calling for new processes, new business models, etc.

As in all digitalisation, cybersecurity becomes a necessity that has to be solved. New generation digitalisation needs secure exchange of data. If not solved properly, cybersecurity issues may become showstoppers. In networked businesses hesitations about trust exist: how can companies in an open-like digital environment trust each other in a constructive way. The whole world is now poised to create the needs of new business culture, contract bases, legislations, market places, business models, i.e., new conditions for growth and success.

Sustainable production must be optimised and accurate. It must be energy-efficient and use raw materials in an effective and even clever way. Raw materials can and must be reused or circulated to maximum effect, and minimise the amount of waste or discharge. Industrial Internet solutions can monitor and report these, and also provide the basis for many kinds of decision-making, both operative and design or building time. As in the case of Amazon, which sells a lot of consumer goods, this kind of trading needs far more efficient logistics, which may have tremendous effects on production at the same time. The whole value chain is becoming more end-customer driven, agile and faster. 3D printing could be one solution for faster delivery and requires lighter logistics.

Consumer electronics for AR/VR/MR emerging from gaming industry are very attractive for industrial use. These devices are becoming technically more viable, cheaper and providing new possibilities for users at the factories. At the same time, cognitive services using speech interfaces are becoming "intelligent" or applicable. Several such devices are about to become available. In the same way, there are reasonably priced AR/VR/MR kits from the gaming industry with good frameworks. They will enable fast prototyping. The recent commercial release of, e.g., Google Glass 2.0 for business use reflects the current trend.

There should be industrial grade devices attached, e.g., to safety helmets that meet other environmental requirements. Machine learning, AI and chatbots are providing new effective assistants to workers in the field. As digital twin and simulation-based models are built, they can provide effective ways to get real benefits.

Actual chip design that will support this is going to provide deep neural network acceleration inside CPU. Intel has developed the HPU (Holographic Processing Unit) and now the next version will contain the deep neural network (DNN). In the same way NVIDIA is providing new graphics processing units (GPUs) for cloud machine learning.

Wireless sensors and Ethernet-based field connectivity will change the cost of measurements. Different kind of low-cost versatile chips will differentiate and move connectivity towards Industrial Internet. This is one clear value that European industry should note.

### 4.2.2. Societal benefits

Digital Industry deals to a large extent with existing production facilities. There are thousands of systems in use that could be more effective and reduce maintenance costs and shorten downtimes. The hardest part of the work is to make it dynamic and self-learning. This way it will be cost-efficient to set up and maintain.

The actual value chain will come from the existing installations, whereas new factories are built seldom. As new, fast and secure communication protocols will provide easy connectivity and interoperability across systems, this will enable all integration possibilities. Easy access to a secure internal network will provide all the existing information to users at the plant. But more interesting features could be provided with cloud or edge-based intelligence but this requires new hardware to be added to the plant installations with more processing power that can handle large amounts of data.

As for building these kinds of systems on top of existing installations, there should be reasonable ways to integrate existing legacy systems at the design and communication level. There are existing protocols and architectures to implement this but it should be more effective. New gateways and frameworks should be experimented with and then productised so that a new Industry 4.0-based can be built that makes it possible to integrate new services.

New services should be attractive to customers so that they will create value. A service can provide predictive maintenance information or help in troubleshooting. Value comes to the end customer from the savings in the maintenance and fewer downtimes / more production. In the same way, a service can optimise energy or material usage resulting in more profitable production.

Knowledge from machine learning and artificial intelligence can be used by service personnel. Users are more valuable and they must learn little bit more about analysis. The use of intelligent services will become more practical and usable for engineers.

The carbon footprint can be minimised with new Industrial Internet-based solutions. Service people and other personnel may avoid travelling in many cases. New solutions can provide dashboards and remote support though connections over Internet. Experts can work from home instead of flying (this can even account for 70% of time).

### Servitisation, business models based on machine data

Digital infrastructure and micro services will change business models more towards selling added value as a service. Investment in projects creates network and connections between vendors and providers that the end user (mill or factory) wants to use. For example, maintenance or some other service and condition monitoring needs to get real data from the factory and devices. This kind of value chain contains heterogeneous systems that should be a single channel for the end customer. One dashboard view with background systems will perhaps be integrated to whole factory information and the value of the data will become a key element for the new business; a value chain that integrates multiple sources to one single interface. The next steps are to create actual event notification between other factory systems like ERP, etc.

In modern machine vendor to end-customer or B2B relationships, recent and ongoing R&D or industrial pilots are aiming at delivering many kinds of after-sales services to the end customers. Most typically, such services include condition monitoring, operations support, spare parts and maintenance services, help desks, troubleshooting and operator guidance, performance reporting as well as increasingly required advanced big data analytics and prognostics-based decision support. The actual markets for this service is still in its infancy. Many end customers are still hesitant to outsource their condition monitoring business processes but, at the same time, significant joint benefits have been demonstrated by organising such business processes as commercial services and allowing the end users to pay more attention to their core businesses.

Industrial services often represent 50% or more of the industrial business volume, and the share is steadily growing. The share of services is generally higher in high-income countries than in low-income countries. The importance of service businesses in the future is evident as service businesses enable continued revenue also after the traditional product sales and, more importantly, the service business is typically many times more profitable than the product sale itself. The service business market is becoming more and more challenging, while the high-income countries are focusing on high-skilled pre-production and after sales life-cycle stages. Fortunately, in the global service business market, Europe can differentiate itself by using its strengths: highly skilled workforce, deep technology knowledge and proven ICT capabilities, but the success needs new innovations and industry level changes.

# 4.3. MAJOR CHALLENGES

### 4.3.1. Major Challenge 1: Developing digital twins, simulation models for the evaluation of industrial assets at all factory levels and over system or product life-cycles

A digital twin is a dynamic digital representation of an industrial asset that enables companies to better understand and predict the performance of their machines and to find new revenue streams, and to change the way their business behave. Nowadays, machine intelligence and connectivity to cloud allow us an unprecedented potential for large-scale implementation of digital twin technology for companies of various industries. A physical asset can have a virtual copy running in the cloud, getting richer along with every second of operational data.

Simulation capability is currently a key element to European machine tool industry to increase competitiveness. According to Industry 4.0, modelling plays a key role in managing the increasing complexity of technological systems. A holistic engineering approach is required to span the different technical disciplines and prove end-to-end engineering across the entire value chain.

The manufacturing industry can take advantage of digital twin and simulations from different perspectives. Focusing on virtual commissioning with the digital twin, manufacturers and their suppliers can efficiently tackle the pressures of competition: changing customer demands, ever shorter product lifecycles, the increasing number of product variants, the reduced product launch times and the increasing pressure of earnings. At the same time, and to address these pressures, ever more flexible production machines and production systems are introduced, with sophisticated tooling, mechanised automation, robots, transfer lines and safety equipment.

Commissioning is the phase when deliveries from mechanical, electrical and control engineering come together for the first time to form the production machine or system. Until now, such integration had only been possible on the shop floor, which meant that every realised change or revision at that stage generated delays, increased costs, threatened loss of reputation, and potentially reduced market share, undoubtedly if such changes adversely affected machine delivery or production launch. Virtual Commissioning allows engineers to connect the digital twin to the PLC to test, refine and optimise mechanical, electrical and logical designs, and the integration between them, well before hardware is assembled on the shop floor, without the need to delay delivery or stop production.

Virtual Commissioning provides:

- A common virtual space for mechanical, electrical, control and systems engineers to collaborate and develop simultaneously, rather than serially, at an early stage.
- An environment to perform early testing of control-driven mechanical behaviour, early testing of control logic through observation of machine or system reaction to PLC output, and PLC reaction to machine or system input.
- In-depth simulation of the entire production plant with all its components, allowing ramp up or reconfiguration with minimal production stoppages.
- Shifting of commissioning off the production floor, reducing on-site personnel during the final commissioning phase from several weeks to a few days, cutting costs significantly.
- A realistic validation of a machine or system allowing for identification and resolution of errors, as well as optimisation of the logic programmed into the PLC, by visualising such things as improper material flow or an incorrect sequence of events.

Virtual commissioning scenarios can be composed of virtual **robotic assembly systems** (assembly lines, material handling systems, and machines with integrated robotics), virtual **conveyance-centric material flow systems** (conveyors and devices, whereby the devices are attached to or perform in concert with the conveyors) and virtual **machine tools** (PLC and CNC controls whereby the behavioural physics of parts, such as gravity, force, torque, and load profiles used for sizing drives, becomes increasingly important).

Moreover, in a complementary approach, a digital twin can be employed in **machining process simulation**. Machining process performance is related to the combination of the different phenomena (machine tool kinematic and dynamic behaviour, machining process, tool path, work item dynamics, etc.), and it is necessary to integrate the most important effects in a common simulation environment in which the machine tool, the process and other aspects are simultaneously analysed. A holistic approach based on improved simulation models of energy efficiency or maintenance optimisation can provide more accurate estimations. It is also important to remark that machine monitoring data combined with the model-based estimations will allow an improved performance of the manufacturing process by controlling component degradation and optimising maintenance actions, increasing energy efficiency, modifying process parameters to increase efficiency or even easing operations to protect a degraded component from failure until the next planned maintenance stop, etc.

All indications seem to predict we are on the cusp of a digital twin technology explosion that enhances the necessary collaboration between machine tool builders and part manufacturers in order to improve the productivity of the manufacturing processes.

Besides virtual commissioning, modelling and simulation responds, to a wider extent, to many kinds of digitalisation challenges:

- understanding, explaining, and visualisation of physical or real-world phenomena of products, production, businesses, markets, etc.
- helping designers to perform their core tasks, i.e., studying alternative designs, optimising solutions, ascertaining safety, providing a test-bench for automation and IoT solutions.
- the effects of changes can be safely and more comprehensively experimented in advance in a virtual domain than using real plants, equipment or even mock-ups.
- simulators offer versatile environments for user or operator training
- it is evident that former CAD driven digitalisation is moving the focus towards simulation-based design.

Simulators may be used online and parallel with its real counterpart to predict future behaviour and performance, to give early warnings, to outline alternative scenarios for decision-making, etc. In spite of years of research, such tracking simulators are still in their infancy, at least in industrial use.

#### 4.3.1.1. Scope and ambition

The digital twin does not only mean simulation and modelling but also documentation and design exist as digital. They are constantly updated as there are changes in production and/or process. There is need to have digital platforms that will provide an infrastructure that can be used to automate the required background processes.

#### 4.3.1.2. Competitive situation and game changers

Siemens has already adopted the term "digital twin" though the term has been in popular use generally and earlier, too. Siemens is providing the Comos platform that enables application life-cycle management. MindSphere brings IoT platform as a commercial solution. GE has similar products and initiatives.
There are multiple digital platforms of this kind that are focused on a digital single market. Commercial providers are becoming dominant in the market, whereas, research solutions provide only practical examples and proof-of-concept studies.

#### 4.3.1.3. High priority R&D&I areas

- Virtual commissioning
- Interoperability is one major challenge. Applications cannot yet be used across platforms. Heterogeneous systems are and remain a challenge.
- Having all relevant engineering disciplines (processes, assembly, electronics and electrical, information systems, etc.) evolving together and properly connected over the life-cycle phases. Multisimulation.
- Tracking mode simulation. Model adaption based on measurements.
- Generating simulators automatically from other design documentation, measurements, etc.
- Simulator-based design.

#### 4.3.1.4. Expected achievements

In an ideal world, interoperability runs on a communication level, but in terms of applications, there are ontological and semantic challenges. There is a possibility to create a standard to define applications and digital twins that could communicate together.

### 4.3.2. Major Challenge 2: Implementing AI and machine learning to detect anomalies or similarities and to optimise parameters

There are several machine learning systems provided by major internet players like Google, Microsoft Azure and IBM Watson. These are using different kinds of implementation from the deep learning or other algorithms. Deep learning usually needs a large amount of carefully selected training data to be accurate. There is a need for time series data handling to detect similarity or anomaly with an easy set up. This is one basic principle that is required to get successful implementation to industry. As there are not so many data scientists for every company or domain, a solution suitable for normal automation engineers should be developed.

Even though we have large libraries using a variety of programming languages, this is not enough since engineers with a common PLC/DCS background cannot use them. This will require software or framework that can be configured and connected easily to system. Existing runtime systems are not even capable of running algorithms fast enough. Again, this will require a personal edge computing device (perhaps with GPU) to run analysis to provide result in reasonable time.

Another interesting aspect is cognitive services. As some high-end systems will understand speech and run actions or use background services, they are providing new natural language understanding (NLU). One problem with these services is how to integrate them into the production unit without access to Internet. It will require some security and DMZ set-up to use it in safe way. Or another implementation could be a personal hybrid cloud solution. Nevertheless, this new AR/MR application can be a real game changer for user interfaces. Maintenance people can talk and walk and get instant information from the devices and systems nearby.

#### 4.3.2.1. Scope and ambition

How to use and get applications for domain users defines the scope. Intelligent services will provide knowledge and information to the user in a normal and transparent way. Digital industry results should be used by a normal engineer. He/she does not have to be a skilled specialist in programming or data science.

Since industry has been digital in many ways for decades and in growing proportions, it has also developed its own system engineering concepts, tools, languages, platforms and standards. Examples include PLCs, DCSs, alarm systems, CAD. Today, this technology basis is drastically expanding to the variety of concepts and technologies, grouped conveniently under the title cyber-physical systems or industrial internet. Machine learning, big data, deep learning and artificial intelligence are significant examples. What is still striking is that bringing these technologies into industry tends to depend on research initiatives, pilot experiments, proofs of concept, or in making real applications tailored, brittle, non-transparent and difficult to understand and manage. In other words, they are expensive or untrustworthy, or too low-level to be practical. Yesterday's technologies are engineered in place, which is very beneficial and practical; there is no need for experimenting or science. Reference architectures, design languages, application generators, design automation and respective standardisation are obviously constituents of such engineerable new solutions.

#### 4.3.2.2. Competitive situation and game changers

The main players are coming from the US. They are dominating cloud-based solutions.

Local edge-based intelligence is one European opportunity.

The biggest AI and machine learning acquisitions will continue with the acquisition by Facebook of Ozlo, Google of Kaggle and Halli Labs as well as of AIMatter, Microsoft of Maluuba, Apple of Realface and Lattice, Amazon of Harvest.ai and Spotify of Niland.

| | POSITIVE FACTORS | NEGATIVE FACTORS |
|---|---|---|
| Internal factors<br>To the EU ECS industry [26] | **Strengths:**<br>Presence of strong industrial players in EU<br>(Bosch, Schneider, Siemens, ABB, Beckhoff etc.)<br>Much creativity in EU<br>Great design capabilities in EU<br>... | **Weaknesses:**<br>Fragmented market across countries<br>Limited start-up / VC culture<br>Few social media companies in EU<br>Personalised cloud providers from US<br>... |
| External factors<br>To the EU ECS industry | **Opportunities:**<br>Ubiquitous availability of smart phones<br>Low-cost availability of accurate sensors<br>Advent of IoT, 5G and AI/Deep Learning<br>Advent of VR, AR, BCI, Robotics, ...<br>Advent of self-parking car, ...<br>Disruption: collaborative business models | **Threats:**<br>Big players: Google, AWS, IBM, MS<br>Providing platforms & Machine learning<br>... |

**F.28** *SWOT analysis of Digital Industry in Europe*

- Collaboration between industry and research is one key activator to combine research and practical implementations.
- More advanced SOC for Edge computing (Intel & NVIDIA). Study level where this can be used.
- AR/VR/MR display technologies and camera use cases.
- Edge computing and chatbot / ML / AI use cases locally (inside factory). How to use cloud-based intelligent services without Internet connection?
- ERP / MESH system API to get benefits from ML/AI results. Uncertain / KPI data from fleet. How to use this data in upper level?

[26] *EU industry here means the full Large Industry + SME + RTO + University eco-system*

### 4.3.2.3. Expected achievements

- Capabilities to build digital industry with outperforming business.
- IoT chips for wireless and Ethernet-based connectivity.
- Tools for engineers to use and get information and knowledge at all levels of personnel.

### 4.3.3. Major challenge 3: Generalising condition monitoring, to pre-damage warning on-line decision-making support

Condition monitoring techniques can be applied to many types of industrial components and systems, however, often at an additional cost. To determine which level condition monitoring machinery warrants, a criticality index method can be utilised, categorising machinery into Critical, Essential and General purpose, which takes into account factors such as downtime cost, spares proximity, redundancy, environmental impact and safety. Commonly, the business value required from condition monitoring comprises higher availability of equipment and, for production processes, information provision to be able to plan and act on maintenance proactively instead of reactively, decreased cost and improved on-time delivery. Other business values that may be of interest are safety and optimal dimensioning/distribution of spare parts and maintenance staff. Thus, serious breakdowns and unplanned stops in production processes can be avoided to a large extent using condition monitoring.

It is possible to combine quantitative approaches and methods (e.g. using machine learning, historical data/ Big Data) with qualitative approaches and methods in order to achieve a higher level of prediction accuracy and find more types of problems/issues. Regarding qualitative approaches and methods, they require a deeper understanding of the equipment or process and the application/area to be able to model the data and find relationships based on sometimes more than 3-5 parameters that together may characterise the issues. Furthermore, (on-line) condition monitoring can be combined with other aspects in order to reveal additional issues/problems that otherwise would not have been indicated or discovered based on condition monitoring alone. An example of such is continuous quality control that checks firstly that the input is within accepted ranges, secondly that the process parameters are OK, and thirdly that the output produced meets the expected requirements, etc. Thus, if output problems are detected and all the others look OK, it is an indication that the equipment needs maintenance or that the process needs to be adjusted.

To be able to achieve advanced condition monitoring, it is important that this is already considered during the design so that necessary sensors are included, data can be extracted at the rates needed, and it is possible to add additional sensors later on if needed. Otherwise, it will be hard to successfully and economically perform condition monitoring that resultsd in the required business value. In addition, using thye results of the condition monitoring in re-designs or designs of new models/versions is encouraged as a lot of future problems can be avoided then (as well as achieving a higher reliability and potentially also a better maintainability if components or sub-systems which are error-prone are made easy to service and change parts).

#### 4.3.3.1. Scope and ambition

- Continuous/online/real-time monitoring of industrial equipment.
- Fleet management, i.e., managing fleets of machinery, local and remote, benefiting from larger sets of similar components, etc., distributing experience, understanding common or similar characteristics and context specific characteristics.
- Modelling and integration of process and equipment
- Benefiting from or taking into account online condition in other applications of digital twin, i.e., MES, ERP, automation.
- Hybrid/linked simulation and analysis
- Flexibility and robustness of production process, enabled by monitoring and predictions
- Adopting of 5G to condition monitoring. May become a game changer

#### 4.3.3.2. Competitive situation and game changers

The interest is very high and many realise the potential benefits that can be obtained with condition monitoring. On the 'use'-side, it is foreseen that those who use condition monitoring will be more competitive and profitable than those not using it. Furthermore, on the provider side, large companies are showing an increasing interest in condition monitoring systems and investing in the market. Larger provider players include IBM, Schneider Electric, Microsoft, SKF and Bosch.

#### 4.3.3.3. High priority R&D&I areas

- Target KPIs and sustainability/environmental parameters
- Modelling and analytics tools
- Automated modelling and analytics
- Multivariate- and multi- objective simulation and optimisation
- Information management, data storage, digital preservation

#### 4.3.3.4 Expected achievements

The expected achievements are improved overall equipment efficiency and profitability through increased efficiency, flexibility and robustness of the production process. This is enabled by improved risk management using condition monitoring and predictive ability.

### 4.3.4. **Major challenge 4:** Developing digital platforms, application development frameworks that integrate sensors and systems

The role of IoT is becoming more prominent in enabling access to devices and machines, which used to be hidden in well-designed silos in manufacturing systems. This evolution will allow IT to penetrate digitised manufacturing systems further.

Industrial IoT applications are using the available data, business analytics, cloud services, enterprise mobility and many others to improve the industrial processes. The future IoT developments integrated into the digital economy will address highly distributed IoT applications involving a high degree of distribution and processing at the edge of the network by using platforms that provide computing, storage and networking services between edge devices and computing data centres.

Most companies are now experiencing difficult times justifying risky, expensive and uncertain investments for smart manufacturing across company borders and factory levels. Changes in the structure, organisation and culture of manufacturing occur slowly, which hinders technology integration.

There are many initiatives around Digital Manufacturing and IoT Platforms, thanks to the widespread research and innovation in the EU (C2Net, CREMA, FIWARE, FITMAN, ARROWHEAD,...). However, those IoT driven platforms have not yet led to a successful and effective digitisation of all the aspects and resources of manufacturing industry. This is mainly due to the heterogeneity of the IT supply side and of the heterogeneity of the domains to be addressed and transformed in the industry demand side.

Questions to be solved:

- Are the digital platforms meant for manufacturing business processes also suitable for real time execution?
- Have performance and security issues been solved?
- Are the proposed platforms reasonable for low tech SMEs?
- Can we define a Meta-Platform that acts as the translator between the different digital platforms?
- Can we define something similar to AUTOSAR, a standard way to communicate the different parts and platforms for the Intelligent Manufacturing ecosystem? Something to solve the interoperability problem? Each of the actors in an Intelligent Manufacturing ecosystem is using their own solution. Having a standard way to connect and have interoperability of those different digital platforms and different devices located at different levels of the factory will provide a competitive position to the European intelligent manufacturing ecosystem.

To resolve this last question, the Industrial Internet Consortium (IIC) has defined the so-called Connectivity Framework. Connectivity refers to the infrastructure enabling communication between participants. Communication refers to the exchange of information between them. Without connectivity, there is no communication. Communication is the basis for interoperable systems and, to be meaningful, requires some context. The more context the connectivity infrastructure can maintain, the more meaningful the communication. The Industrial Internet Connectivity Framework (IICF) defines the role of a connectivity framework as providing syntactic interoperability for communicating between disparate Industrial Internet of Things (IIoT) systems and components developed by different parties at different times. The IICF is a comprehensive resource for understanding connectivity considerations in IIoT. It builds on the foundation established by the Industrial Internet Reference Architecture and Industrial Internet Security Framework by explaining how connectivity fits within the business of industrial operations, and its foundational role in providing system and component interoperability when building IIoT systems. (http://www.iiconsortium.org/IICF.htm)

EFFRA: The diversity of approaches and implementations of digital manufacturing platforms prompt the need for the creation of Meta-Platforms to connect existing platforms, including abstraction layers for interface, protocol and data mapping to provide interoperability as a service. There is a need for holistic interoperability solutions spanning all communication channels and interfaces (M2M, HMI, machine to service) in the factories and supply chains.

In addition, new players are arriving from the IT sector:

- Hadoop
- Kafka
- Apache STORM
- IBM (Bluemix)
- Microsoft Azure
- Digital Enterprise Suite (SIEMENS), MindSphere (Siemens, open IoT operating system, turn data into knowledge, and knowledge into measured business success.)

How can they be considered in the intelligent manufacturing ecosystem? How can these tools be integrated into the digital platforms? How can the IPR issues of the data and knowledge created by those tools be solved?

### 4.3.4.1. Scope and ambition

Study for meta-platform that can communicate with different platforms and integrate tools.
Managing complexities with AI-based design, self-configuration and with many kinds of autonomous adaptation. "How to connect intelligence!"

### 4.3.4.2. Competitive situation and game changers

There are actually several benchmarking studies about digital platforms, either in progress or very recently completed. In the same way, companies are carrying out their own respective surveys. A general remark is that there are several digital platforms emerging, as research project outcomes, or actually as the result of several consecutive projects, both national and EU. Certain standardisation is under way, most notably by Industrie4.0 (or RAMI) and IIC. Since the realms of respective applications are huge and, therefore, technologies as well, the standard actually consists of many standards that have been known and used for some time already; though there are needs to create new (sub)standards. The commercial digital platforms are also emerging, most notably Siemens MindSphere and GE Predix. At the time of writing, it is not clear which platform perhaps will win, or how the market positions will evolve. The situation very much resembles with the early stages of evolving operating systems of personal computers or mobile phones, or rather the early situation of industrial fieldbuses. As we well know, in some domains there have been clear global winners, but for instance with fieldbuses, several strong players seem to prevail. Due to the emergence of Industry4.0, rectification of initiatives is apparently taking place.

The research origin platforms may be more versatile than the current commercial offerings. At the end of the day, application industries may start choosing more and more commercially supported platforms but, as we have seen in recent history of ICT, open source platforms may keep their strong position.

Digital platforms are clearly becoming ever more state-of-the-art technologies, i.e., they are pushed somewhat in the background as we have operating systems of PCs today. The applications have been dominating engineering, in the past and in the future. As is clearly recognised in industry, applications in all life-cycle stages and on all system levels, both in digital and physical realms, are most valuable. The digital assets themselves are important, as well as, the connectivity of ever more elaborate and diverse applications.

### 4.3.4.3. High priority R&D&I areas

Move focus on the industrial or engineering applications. It is important to win the global platform game on various application sectors (which are strong today) and in building effectively and on high-level outperforming applications and systems, for the actual industrial and business needs.

Prepare for the era of 5G in communication technology, and especially its manufacturing and engineering dimension.

Solve the cyber-security problems. Only safe, secure, and trusted platforms survive in industry.

### 4.3.4.4. Expected achievements

- Meta-platform could be used with other platforms, systems and tools.
- Easier, more comprehensive and tools supported integration of compound applications, on top of digital platforms.
- Automated design features
- Technologies to connect intelligence

# 4.4. MAKE IT HAPPEN

Some initial ideas on how to get involvement from industry to test research ideas. Participate and get in-field experience.

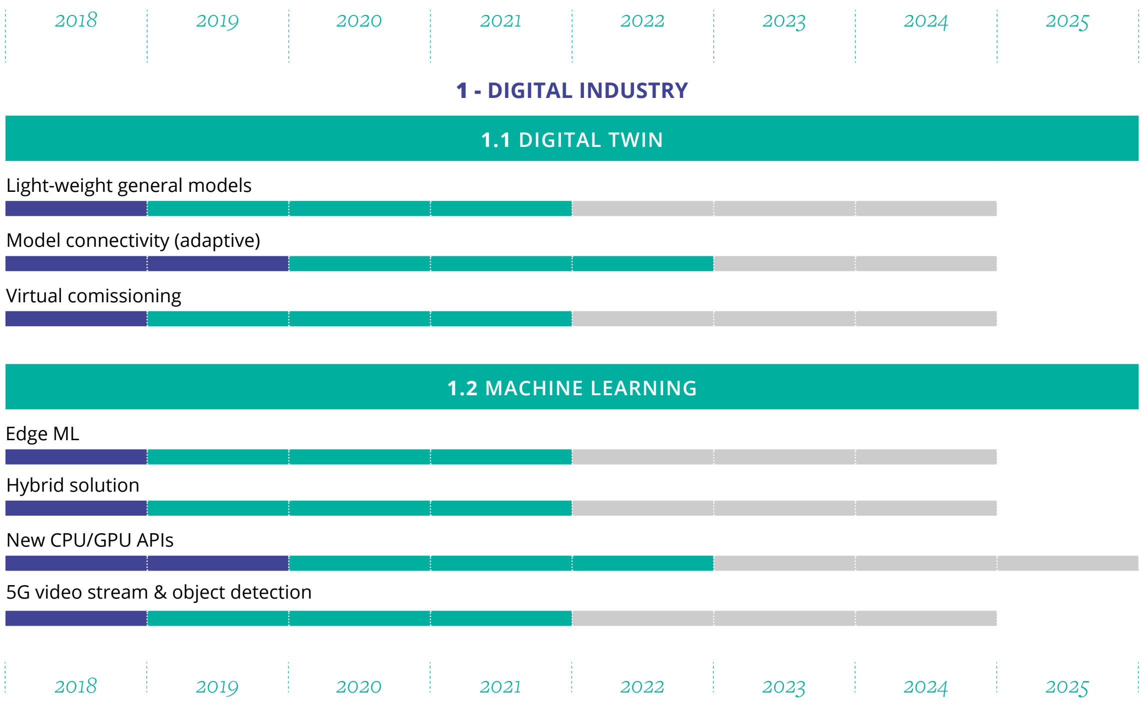
Gartner / ARC studies about 50 billion IoT sensors => communication + storage => applications needed that will create actual information and value from the data.

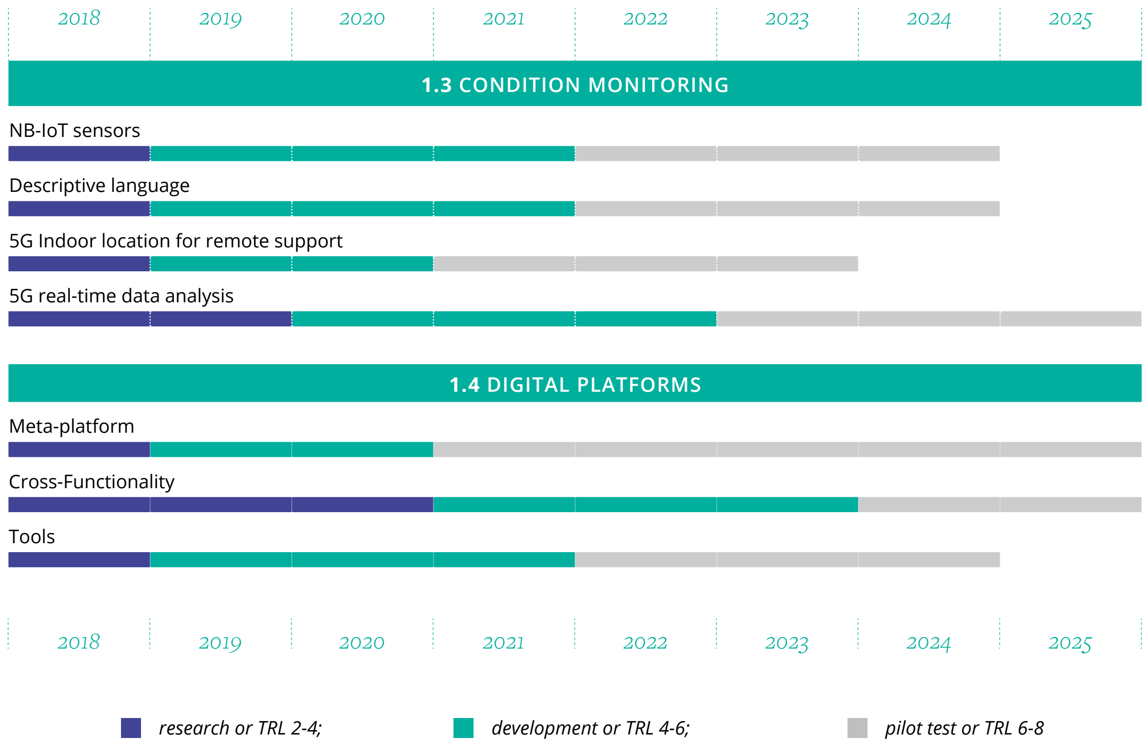
Sensor price / unit + storage capacity + application execution = investment price
Existing standards can be used and there are a lot more applications based on standards.

Development cycle from chip provider to system designer and then to application can be shorter. E.g. actual framework and faster design flow create stakeholder value.

# 4.5. TIMEFRAMES

The timeframe below contains some pre-steps to make actual targets feasible.






**F.29** *Digital Industry roadmap*

# 4.6. SYNERGIES WITH OTHER THEMES

Connectivity & interoperability is one key factor for Digital Industry that it will work.

- Connectivity: 5G in industry for
  - Fast communication
  - Indoor location
  - Interoperability
- Computing & storage:
  - Machine learning API for hybrid CPU&GPU
  - Storage for training data (wearable, low power & fast)

# 5

# Digital Life

# 5.1.
# EXECUTIVE SUMMARY

Increasingly, digital services are part of almost everything we do, be it at work or during our free time. In all cases we want to have a safe, comfortable and fulfilling life in the right social context. The Digital Life chapter covers the intelligent (and preferably anticipating) applications that support our lives wherever we are and whatever we are doing.

Due to political, demographics and climate trends, Europe is facing major challenges across those spaces, for security, safety, privacy, mobility, efficient energy consumption, etc... The ubiquitous availability of smart devices and the advent of new technologies like IoT (Internet of Things), 5G, AI (Artificial Intelligence) with DL (Deep Learning), VR (Virtual Reality) and AR (Augmented Reality), BCI, Robotics and the like will shape new ways of how people interact with the world and with each other. The 24/7 always-online culture resulting from the ubiquitous connectedness has empowered citizens, they have evolved from consumer to prosumer (such as on YouTube), maker communities have emerged (enabled by the advent of 3D-printing) and simple initiatives as Neighbourhood Watch groups (based on WhatsApp) allow citizens to enhance their own security. More intelligent, secure and user-centred solutions are necessary to meet Europe's challenges, while keeping up with societal needs in a sustainable way, guaranteeing citizens' privacy and reaching broad acceptance in the public.

Four Major Challenges have been defined to ensure safe, secure, healthy, comfortable, anticipating and sustainable spaces, in the personal, private, professional and public context.

# 5.2.
# INTRODUCTION

The Digital Life is at the heart of a modern smart society and hence tightly related to the overall need of "liveability", which implies all Maslow's hierarchy of needs: physiological (sufficient housing, food, energy, etc.), safety (individual protection from external threads), love and belongingness (social inclusion and recognition) and self-fulfilment (artistic expression). Given the state of the planet, there is also an underlying requirement of sustainability. In this context, importance of rights in the digital life domain brings new challenges related to technology implementation, Internet access for all, trust, security, safety, privacy, surveillance and encryption, awareness, protection and realisation of needs and rights.

### Major Challenges

The Major Challenges aim to improve our Digital Life and are associated to the spaces we live in:

1. Ensuring safe and secure spaces
2. Ensuring healthy and comfortable spaces
3. Ensuring anticipating spaces
4. Ensuring sustainable spaces

Nowadays, and certainly in the next few years, we need to drastically improve our safety and security requirements to live comfortably to enjoy many healthy years of life. Furthermore, comfort and acceptance of application can be further enhanced through anticipation. And above and beyond this, sustainability is a key prerequisite.

The table below shows the different Major Challenges that address the needs of people in the four different spaces identified [27]. This results in the following sixteen innovation areas (examples given):

| IDENTIFIED SPACES: | PUBLIC SPACE | PROFESSIONAL SPACE | PRIVATE SPACE | PERSONAL SPACE |
|---|---|---|---|---|
| *Characteristics:*<br>*Major Challenges:* | *in a public environment, with anyone* | *in the work environment, with your colleagues* | *in the home environment, with your family* | *with yourself* |
| **Safety & security** | Public safety<br>Emergency and crowd management | Access control | Anti-burglary | e-Wallet<br>Biometrics |
| **Healthy & Comfortable** | (indoor) navigation | Healthy office<br>Productivity | Home Assistant | Personal assistant<br>Quantified self<br>Media content consumption |
| **Anticipating** | Traffic management<br>Asset tracking | Adaptive work space | e-Butler | Coaching wearables |
| **Sustainable** | Energy saving<br>Water saving<br>Air-pollution | Carbon neutral offices | Off-grid living<br>Micro housing | Sharing rather than owning |

**F.30** *Major Challenges*

These imply ample business opportunities for Europe in related application areas, for example:

- Anti-burglary solutions and comfortable domotics at the Smart Home
- Energy saving and productivity enhancers in Smart Buildings
- Public safety and crowd management in Smart Cities

Innovative solutions and services called for in this context may either be completely new (e.g. hologram based 3D-video communication) or based on existing systems that are extended, bridged or merged (e.g. integrating autonomous service vehicles and fleets of surveillance drones to assist on massive gatherings in urban management solutions and/or disaster recovery).

[27] *The model with the four spaces in varying levels of trust and intimacy does not explicitly mention the domain between the personal and the public spaces which includes friends, sport mates, neighbours, etc*

## 5.2.1. Vision

### 5.2.1.1. Safety & security

In our daily lives we expect our environment to be safe, meaning that it is designed and managed to cause no harm, and to be secure, meaning that is difficult to be attacked by external agents. These requirements are applicable in all our living areas, at home, while walking in our city, attending an event, exercising, working or travelling. Safety and security are always moving targets since, beside the known threats, new forms of cyber-crime and terrorism are constantly emerging. Moreover, as we rely more and more on digital services to be available, unavailability may have drastic consequences and should also been regarded as a safety concern.

New systems that are deployed should at least not reduce the level of safety. With more digital devices connected to the Internet of Things, safety and availability of these connected systems cannot be taken for granted and so careful planning is required. New opportunities are also provided for cities to enable active participation by its citizens, like neighbourhood watch groups.

Digital Life brings a paradigm shift for the concept of trust as an element with multiple dimensions, combining, for example, privacy, security reliability, availability and integrity with human and machine behaviour. In this context, there is a need for greater understanding of how individuals interact with machines and how machines/things interact with other machines/things with respect to the extension of trust to assure a safe and secure environment that combines elements of physical, digital and virtual worlds.

The vision is to provide products and solutions that help to ensure high levels of security and safety wherever we are, while at the same time ensuring an adequate level of data protection to ensure privacy.

New surveillance systems based on AI could help in the early detection of threats or alarm conditions of all sorts (from accidents, burglary, vandalism or terrorist attacks), while other technologies (like augmented reality and advanced robotics) will help to bridge the gap between the virtual and the real world offering new ways for the users to access the services.

Given the ever-increasing dependency on digital products and online services much attention must be paid to address the demand for a permanent uptime and the vulnerability in case of failure. This also implies an increasing need to have a high data rate communications infrastructure that can offer continuous secure and reliable communications.

### 5.2.1.2. Health & comfort

The pervasiveness and the increasing proliferation of digitisation in different application domains is an enabler for innovative environments. The ever-smarter environments in which people will live are characterised by a high degree of heterogeneous interaction, seamlessly providing services to ever better support of our habits and actions for health, comfort and leisure.

We want to foster these smart spaces, envisaging the expected benefits they can provide, also on health, comfort and leisure:

- At **personal space**: improving the awareness of our body condition, to external or internal stimuli. Smart systems can provide support for disabilities or a personal coach and trainer to identify behaviour to be avoided (wrong body position, bad habits) and possible future injury or disorders.
- Smart systems can also offer an immersive experience, on vision, gaming and sensory interaction though VR or AR. Consumers can be offered the Immediacy, Individualisation, Interactivity, and Immersion they expect for media content consumption.

- At **private space** with healthier and more comfortable environment based on personal preferences (on temperature, humidity, air flux) in the context of running activities and clothing: adapting lighting and acoustic quality to one's own sense of wellbeing. Providing capability to comfortably communicate and interact remotely with people, institutions and sellers, possibly without leaving home.
- At **office space**, remote connections and large interoperability enable office operations and business opportunities around the world. AR vision and AI will assist operators and workers. Work is made more comfortable and personalised to the actual workers' condition and age.
- At **public space**, a smart guidance system will interact with the public showing relevant information on promotion, on opening hours, or tourist info. Augmented reality can extend what we see in meaningful way and provide new experiences while visiting a city and/or a museum. Also, social media can help to increase safety in public spaces. For instance, alignment of the time and place of "walking the dog" with others in the neighbourhood.

These are just a few examples for the implementation of the Digital Life. New products and solutions will make our everyday life healthier and more comfortable and should enhance social cohesion through digital inclusion.

#### 5.2.1.3. Anticipation

The increasing awareness of the smart environment allows observations of behaviour to be extrapolated into profile-based predictions of human intent. Such predictions can be used to anticipate events and offer an appropriate service at just the right moment (before asking) which includes user-friendliness, usability and usefulness and calls for contributions from the social sciences.

- In a **personal space**: anticipation can be provided through a digital watch or other personal coaching device (serving as a kind of "digital twin"), including cradle-to-cradle and circular economy aspects. remarks for self-improvement activities such as fitness, diet, set goals.
- In a **private space** with trusted people: anticipation can imply the e-butler functionality by providing suggestions for recipes and meals, or entertainment/gaming in-house or external, based on the proclivities of the individuals in the group.
- In an **office space** with colleagues: anticipation can be based on asset tracking, organiing activities under consideration of availabilities, absence and replacement.
- In a **public space**: anticipation can be provided through smart traffic management and/or asset tracking, considering empirical values derived from analysis of historical data. This is also true for retail environments, both physical and virtual.

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[28] *The future of mobility: What's next? https://dupress.deloitte.com/content/dam/dup-us-en/articles/3367_Future-of-mobility-whats-next/DUP_Future-of-mobility-whats-next.pdf*

#### 5.2.1.4. Sustainability

Based on the motto of "Towards a sustainable Digital Life" the vision for this Major Challenge is to introduce new digital products that contribute to a sustainable lifestyle in all areas of human life, including cradle-to-cradle and circular economy aspects. Energy consumption has increased year over year. Smart products and IoT devices for a Digital Life will help to reverse this trend. In particular, we are addressing the following spaces:

- Sustainable **personal spaces**: Optimised energy consumption with feedback / reminders / coaching / guidance to users about usage and waste of resources as part of the "quantified self" (incl. efficient charging of smart device and wearables) …
- Sustainable **private spaces**: Comprehensive assessment of resource usage to identify largest areas of consumption. Offer solutions for lighting, heating, computing with reduced usage of energy and other resources. Also, home-grown vegetables and city farming systems.
- Sustainable **professional spaces**: Providing IoT/smart systems that support the digital business life with the minimum amount of resources (energy, water, paper, …) ensuring a highly efficient, productive and sustainable working environment. Furthermore, the reduction of (food) waste in supermarkets and restaurants.
- Sustainable **public spaces**: Traffic management for efficient use of energy supporting different types of mobility. Smart water management to protect resources. Intelligent management of energy at public places such as football stadiums and railway stations, including smart street lighting. Promoting green areas in the cities and enable citizens to provide their own sustainable solutions.

#### 5.2.1.5. Game changers

Europe is in the middle of a changing world with an ageing population that is living more and more in urban environments. This is challenging the preservation of natural resources, air quality, clean and efficient transportation, new infrastructures, and the like, all in relation to the quality of life. Together with a climate change in progress this poses major challenges.

Apart from technological advancements, important driving forces for futures changes are the general desire for access to any information and the adaption to rapidly changing circumstances. Moreover, the increasing possibilities to take control as (a group of) citizens without authority involvement can have far reaching consequences (e.g. bitcoin, twitter, maker communities, …).

The general trend in which the services providers are becoming ever more the mere carrier of demand and response of services without requiring the ownership of the resources themselves potentially impacts everyone's life and habits. Additionally, instruments provided by the pervasive digitalisation and extended interconnection reinforce the convergence between traditionally "institutional" and/or "professional" service providers and less "professional" and possibly "occasional" or "temporary" providers. The obvious examples concern B&B and taxi services, but it is also in the concept of prosumers within a smart grid. The mobile digital payment trend, triggered by EU regulation PSD2 (2015/2366/UE), is further stimulating this.

The in-vehicle transit / on-the-move experience will increasingly be a defining feature of the future of mobility. As shared and autonomous mobility proliferate, a tremendous opportunity arises for companies seeking to sell content, entertain and generally enhance the time spent in-transit. "Experience enablers" — content providers, in-vehicle service providers, data and analytics companies, advertisers, entertainment equipment providers and social media companies — will clamour to make the in-transit experience whatever we want it to be: relaxing, productive or entertaining [28].

Many anticipating devices will be wearables. In the US there used to be a demographic divide among the users, mainly in the age bracket between 25 and 54 and encompassing the fittest users. Recently the market has grown and opened up to younger consumers and those doing moderate or no exercise[29]. The smart phone as the only connection to cloud and internet will be complemented and partially replaced by wearables. These, in turn, will become the most personal devices. They will replace items such as watches, GPS, glucose and blood pressure monitoring, identification documents and will support the user in relevant situations.

| | POSITIVE FACTORS | NEGATIVE FACTORS |
|---|---|---|
| Internal factors<br>To the EU ECS industry[30] | **Strengths:**<br>Presence of strong industrial players in EU<br>Citizen protection by EU through privacy regulations<br>Much creativity in EU<br>Great design capabilities in EU<br>Experience in embedded systems | **Weaknesses:**<br>Fragmented market across countries<br>Limited start-up / VC culture<br>Few social media companies in EU<br>Personalised cloud providers from US<br>… |
| External factors<br>To the EU ECS industry | **Opportunities:**<br>Ubiquitous availability of smart phones<br>Low-cost availability of accurate sensors<br>Advent of IoT, 5G and AI/DL<br>Advent of VR, AR, BCI, Robotics, …<br>Advent of self-parking car, … | **Threats:**<br>Ageing population<br>Rural-urban migration<br>Climate change<br>Competition from other continents<br>… |

**F.31** *SWOT analysis / game changers*

### 5.2.1.6. Competitive situation

There are many different market segments involved. Most of them are dominated by US companies, but with strong competition from the EU and Japan. In a recent study, five of the top ten global suppliers for smart cities are American, three European and two Japanese.

However, there are some markets where the situation is quite the opposite, like the professional mobile radio whose market leader is a European company, or the surveillance segment where US and European companies account for one third of the market share each.

- The United States tends to compete in the field of sustainability through corporate-driven R&D&I, science and technology. For instance, large companies such as Google and Apple invest in home automation (e.g. Nest and HomeKit), expecting benefits for the consumer primarily in convenience and home security but at the same time unlocking a huge energy-saving potential if properly used.
- China has a mixed open/controlled model of central government-driven science, technology and corporate RDI aiming at sustainable growth. It will spend USD 361 bn on renewable energy by 2020 and USD 146 bn on semiconductors in "Made in China 2025". These gigantic programmes will enable smart systems that support sustainability according to China's positioning as world's climate leader and they will flood the world market just as smart phones are doing this today.

- The Japanese science and technology agency JST aims to realise a sustainable society by developing game-changing technologies for a low-carbon society and solving food and water issues. IoTs are used in Smart City projects in Japan initially as smart meters. Gradually the system will be linked to household appliances and individual as well as public transport to create sustainability via big data
- In China IoT has been announced as one of the strategic industries by China's State Council. Focal areas include Smart Cities, Environment and Sustainable Development and Big Data also in the MC2025 programme. Surveys (https://www.ericsson.com/en/networked-society/trends-and-insights/consumerlab/consumer-insights/reports/wearable-technology-and-the-internet-of-things) in major markets worldwide show that the purchase intention for wearables such as fitness trackers, allergy alert scarfs, emotions sensing tattoos is highest among Chinese consumers [31].
- Japan has a long tradition in robotics research to compensate the effects of demographic development. The latest items are exoskeletons controlled by bio-electric signals from the user to lift heavy loads. Vision of smart home.
- Taiwan's government supports academic edge AI chip development project. See http://www.design-reuse-embedded.com/news/201708054#.WlhpOpOdXAx
- Qualcomm boosts machine learning capability by buying Scyfer (same link as above)
- AI Sees New Apps, Chips, says Qualcomm (same link)
- (Leisure) Creative Industries are a major player in the EU economy: the industry provides 7.7 million jobs in 2.2 million companies of which 85% are SMEs creating yearly revenue of EUR 625 billion [32]. The aggregate revenues for all media technology products and services providers in 2016 were USD 50.97 billion, where Europe and the Middle East together accounted for 43.3%, the Americas for 37.6% and Asia Pacific for 19.1% [33].

←

[29] *Wearable technology and the IoT, Ericsson*

[30] *EU industry here means the full Large Industry + SME + RTO + University eco-system*

→

[31] *Wearable technology and the IoT, Ericsson*

[32] *New challenges in media, content, and creativity sectors in Europe, by Albert Gauthier, Policy Officer Data Applications & Creativity, DG CONNECT, 2016 https://nem-initiative.org/wp-content/uploads/2016/11/ec.pdf*

[33] *2017 IABM DC Global Market Valuation Report*

# 5.3. MAJOR CHALLENGES

## 5.3.1. Major Challenge 1: Ensuring safe and secure spaces

First and foremost, the spaces we live in must be safe and secure, both physically and virtually. Moreover, the digital services that we rely on must indeed be available.

### 5.3.1.1. Scope and ambition

The **scope** of this chapter covers many different locations:

- At **personal space**: Personal data and privacy should be should be protected by developing and deploying the proper security and private mechanisms to avoid malicious tracking and attacks in the personal devices such as wearables, tablets and new other devices.
- At **private space**: Although we usually feel safe at home, statistics show that a high number of physical accidents happens at home, falls, poisoning and drowning being the main cause. Extra attention should be paid to the higher-risk groups of young children and elderly people. In the virtual domain, own control over personal data storage is necessary for privacy, where people are the owner of their data and decide for themselves whom to give access.
- At **professional space**: Activities related to smart manufacturing and healthcare are outside of the scope of this chapter, however safety and security in all other work environments are within the scope, covering office environments, agriculture and farming, construction sites, etc.
- At **public spaces**: Except for transportation, all other activities in public areas in a city are within the scope of this Major challenge.

The **ambition** of this MC is to provide systems and technologies that help avoid dangerous or harmful situations in any of the above-mentioned environments, while ensuring early detection and fast management of the incidents when they occur. The objective is to reduce the number of incidents and their impact while maintaining a low number of false alarms. These incidents include all that is caused by fortuitous accidents and by malicious acts. A critical aspect of the challenge is to ensure an adequate level of privacy for the users.

### 5.3.1.2. High priority R&D&I areas

- Emergency management and evacuation systems
- Real-time dynamic malware avoidance and detection systems
- Mission- and safety-critical, feature-rich communication systems for law enforcement
- Autonomous, dynamic user authentication, authorisation and trusted relations
- Distributed AI, cognitive learning and distributed security (based on blockchain technology or other concepts) and,
- Surveillance systems for both indoor private use and outdoor public use employing advanced video pattern recognition to allow large numbers of resulting video streams to be automatically monitored
- New concepts and architectures for increasing the trustworthiness and high availability of digital services and platforms, addressing ways to perform trade-offs between safety, security and availability

#### 5.3.1.3. Expected achievements

Reduction of the number of incidents with respect to the current baseline, and mitigation of their impact through the usage of the new technologies, integrated in an emergency management system that enables adequate, well-coordinated response in time.

### 5.3.2. Major Challenge 2: Ensuring healthy and comfortable spaces

All spaces must support a healthy life, while providing comfort.

#### 5.3.2.1. Scope and ambition

Exploiting Smart System Integration capabilities with Cyber Physical System approaches and integrating them into efficient IoT systems is required to provide the right collection of data for a true exploitation of digital analysis and to implement innovative services and appropriate physical actuation. Hence, there is interest in:

- SSI: sensors, actuations, harvesting, power management, miniaturisation, embedded computing, communication. etc.…
- CPS: systems of systems, communication protocols and architectures, devices virtualisation, networking and ICT, edge computing, etc.…
- Smart data analytics: systems virtualisation, digital twin, learning methodologies, taking into consideration that the things belonging to the IoT infrastructure can establish social relationships in an autonomous manner with respect to their owners, which derives from the integration of social networking concepts into IoT, virtual spaces and AR.

The ambition is to raise the awareness of the potential and the (social) impact of smart solutions for their adoption in critical situations and their essence in normal life. For example, providing a vehicle that is responsive to the driver’s physiological status (fatigue, alcohol rate…) is part of assisted driving and a safety issue from the point of view of the vehicle’s occupants as well as other drivers and pedestrians nearby; these smart solutions make their trip more comfortable and safe. Research and development should address the future implementation of Digital Life ensuring a right, safe and confidential environment in which to improve our quality of life.

The quality of life is also determined by the way consumers spend their leisure time, at home and on the move. Mobile technology is transforming the way people around the world consume media content, and will continue to drive the expansion in overall media consumption. More technological advances will make it possible to place audiences in the middle of the action and to offer them *Immediacy, Individualisation, Interaction and Immersion*.

#### 5.3.2.2. High priority R&D&I areas

- Development of sensor devices to measure and digitise physical quantities through low-cost, energy-efficient, highly accurate implementations i.e. inertial and micro-nano-bio systems, air sensors, water quality sensors and more generally resource quality and environmental variables measurements, monitoring of infrastructures, skin and tactile sensors, utility smart metering, etc.
- Compact, energy-efficient actuators to allow better physical activation using new mechatronic technologies, robotic concepts, self-navigating features and haptic interaction.
- Sensor and actuator data fusion technology and application of methodologies like machine learning and adaptive solutions in order to improve the quality of the information derived from the data and the interaction with the users.

- Innovative solutions that allow a larger diffusion of the physical edge nodes, making them more effective in terms of communication, data elaboration and power management, so to not require any wire connections to install
- Improvement on interoperability among different domains to make the awareness of each context appropriately available (privacy, security and safety) to the other. Multi-protocol hardware and software platforms, standardisation,
- Improvement on wireless networking capability (on throughput, on consumptions, reliability, etc.) from Personal Area Network and Local Area Network up to Wide Area Network and promote the reuse and conversion of replaced telecommunication network for sensing/actuating, metering and IoT applications.
- For media content creation the move to IP, use of virtualised, software-based environments, UHD, and Virtual Reality will continue to alter the landscape of media. Humans and machines are becoming more interchangeable in many areas as data-driven automation increases. Data-driven automation will enable increased efficiency in live productions and new business models for multi-platform content delivery.

#### 5.3.2.3. Expected achievements

Development of future solutions that contribute to healthy and comfortable life:

- Human-centric, open interaction platforms including wearables and portables, integrating personal IoT devices and smart spaces (personal, office, public) to provide new kinds of services and personal experience
- A large diffusion and adoption of IoT devices for smart home, smart building, smart office, smart grid, smart manufacturing ("SmartX"), favoured by improvement on wireless communication and on power harvesting capabilities
- Collaborative robots ("cobots") and cooperation with other machines and humans
- Integration of physical things/objects with augmented reality and virtual spaces
- Distributed AI, AR vision and virtual spaces
- Smart media content generation and multi-platform content delivery
- Automatic adaptation to operator conditions and operator age
- Advanced sensors for autonomous vehicles, distributed augmented reality

### 5.3.3. Major Challenge 3: Ensuring anticipating spaces

Additional added value can be provided through anticipation mechanisms that provide the *service* before it is explicitly required.

#### 5.3.3.1. Scope and ambition

The scope of ensuring anticipating spaces is formed by smart systems such as personal devices and robots that facilitate daily routines in all aspects of the digital life. These range from smart phones for personal organisation, robots at home, and large-scale systems to organising life at work and in the city. The ambition is to provide systems that pro-actively support individuals (and society) in their daily affairs. Anticipating systems and services will have a sense of what is desired and required.

#### 5.3.3.2. High priority R&D&I areas

- **Personal space**: the smart phone can provide personal anticipation at the personal level.
- **Private space**: robotics in care and smart assisted living environments, enabling elderly people to lead a self-determined life. Imminent needs for support can be predicted through observation of habits, regular events, and daily routines.
- **Office space**: anticipate and prepare events incl. reservation of meeting rooms, catering, travel booking providing of necessary elements, etc.
- **Public space**:
  - Providing navigation tips to avoid congestions, indication of free parking space, self-parking, street lighting on demand/need, etc.
  - Identification of the emergence of potential dangerous situations, technologies that use VR and AR to provide education of security measures / crowd management (situation awareness, pedestrian circulation, ...)
- Further development of data analytics (performed at edge computing and machine learning capabilities) to realise the anticipation functionality.

### 5.3.4. **Major Challenge 4:** Ensuring sustainable spaces

The state of the planet implies extra requirements to ensure survival in the long run. These include not only carbon neutrality, but also the managed use of scarce water resources and the availability of affordable housing in large megacities.

#### 5.3.4.1. Scope and ambition

- The scope of the research and development efforts cover electronic components and systems to support smart energy, smart lighting, smart water management, and other "green" facilities in smart cities, smart buildings and smart homes.
- One important goal is to create a wide acceptance for energy saving products and services by ease of use and transparency of functionality in all aspects of the digital life.

#### 5.3.4.2. High priority R&D&I areas

These are priorities for the R&D&I on technologies which are enabling the applications:

- Multi-modal traffic and parking management in congested areas (up to 40% of traffic in these areas is created by searching for parking spaces)
- Multi-modal (intermodal) traffic in sparsely populated areas (e.g. autonomous vehicles called on demand to/from the stations of the backbone railway line, since frequent public bus transport does not pay off, etc.), "Tram (small train units) on demand" etc.
- Overall transport automation in European regions (automated "robot taxis" vehicles complementing high speed railway lines, last-mile freight transport by automated vehicles or by small autonomous train units, etc.)
- Solutions addressing circular economy concepts to identify and separate recyclable material over the life-cycle of a product
- Smart sensor evaluation to reduce communication power (in sensor, smart hub/gateway, edge processing or cloud)
- Monitor life-cycle of materials as part of circular economy to save resources
- Concepts for smart street lighting (reducing energy usage while enhancing safety)

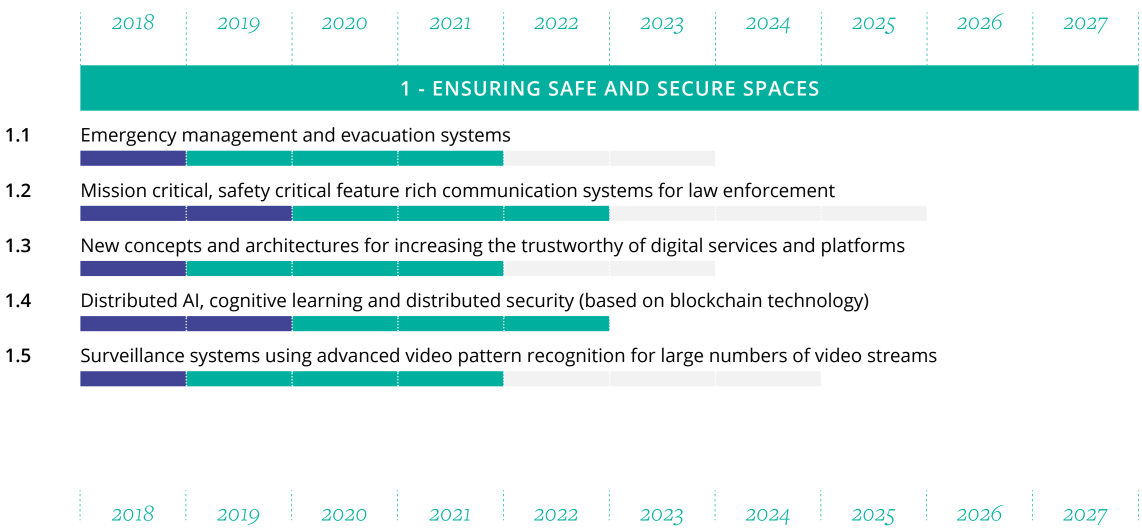
- Embedded air quality monitoring (particles/gas) solutions for efficient energy usage e.g. ventilation of buildings
- Integrated sensors to detect leakage in ageing infrastructure
- Systems solutions for sustainable agri-food industry preserving natural resources, reducing production waste, minimize the use of pesticide and/or facilitate the use of organic products to shift more and more to organic production.
- Energy-efficient horticulture lighting and animal-friendly poultry lighting
- Serious gaming and gamification for educational purposes
- Context awareness for energy reduction and improved living
- Smart sleep mode for smart devices: wake-up functionality to conserve energy
- Assessment tools for energy-saving technologies: well-to-wheel, total energy consumption including production phase as support for decision-making

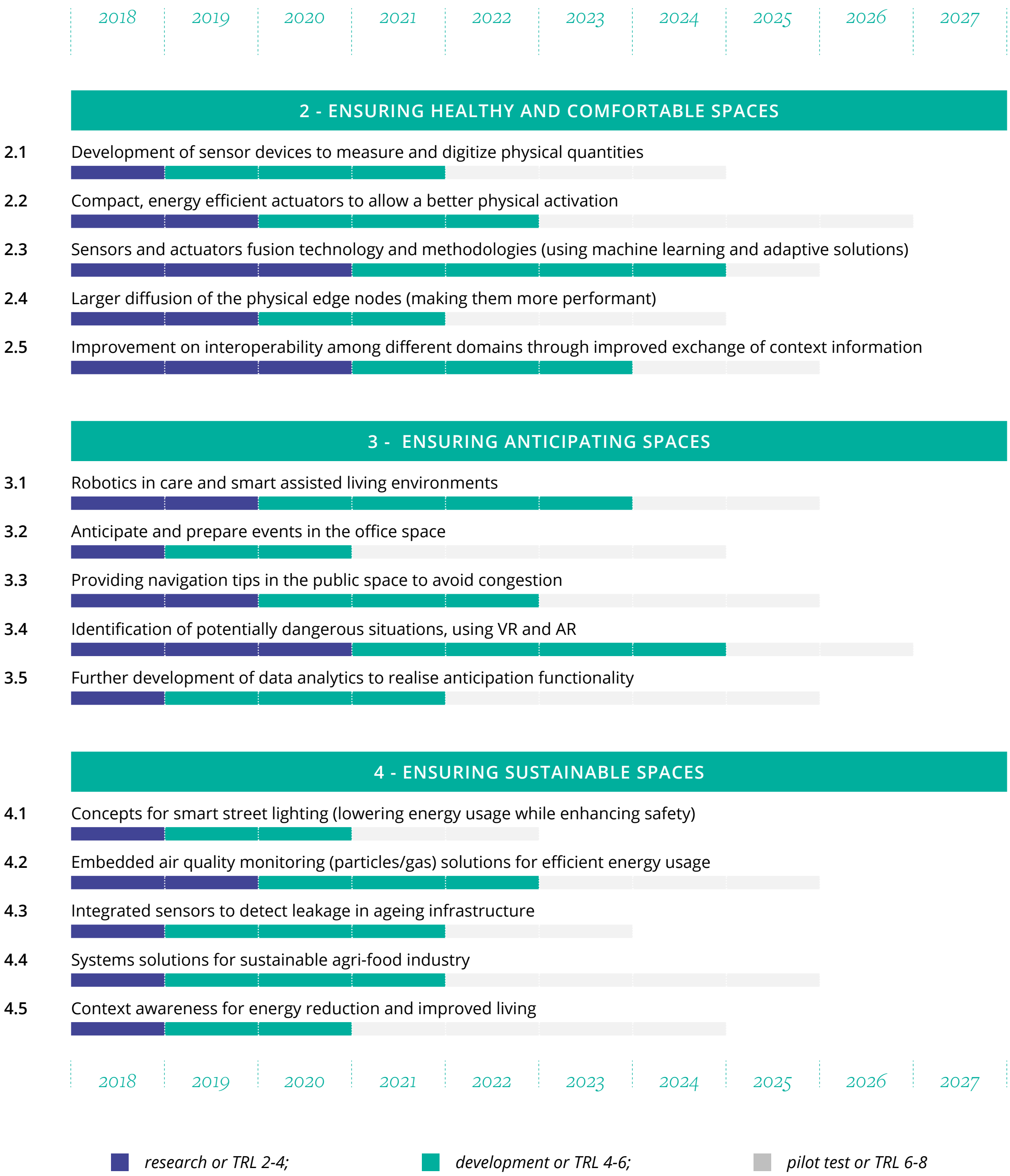
### 5.3.3.4. Expected achievements

Development of future solutions that contribute to sustainability and preserve natural resources

1. Smart energy monitoring by IoT devices embedded within Distributed Energy Resources
2. Extended battery life by ultra-low-power techniques
3. Creating frontrunners for sustainable Digital Life, i.e. projects in selected cities
4. Energy-efficient smart parking management systems, reducing traffic congestion
5. Energy efficient public safety systems, including alarming and evacuation of crowds (in a station or stadium) through personalised digital services

## 5.4. TIMEFRAMES



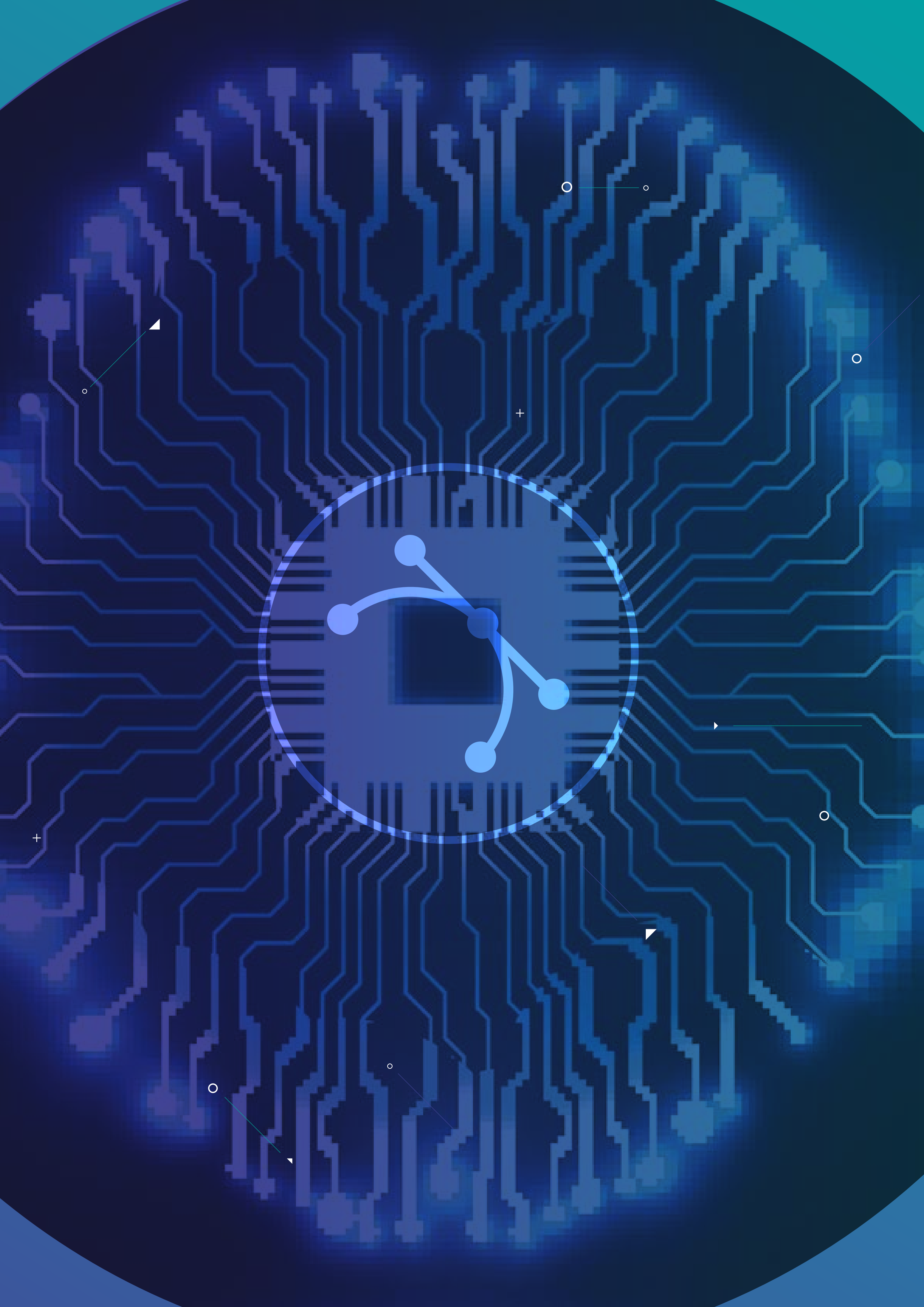



*Digital Life roadmap* **F.32**

# SYNERGIES

With three other ECS SRA chapters there is some synergy, which has been delineated as follows:

- **Health & wellbeing**: Where Healthcare aims to cure people of diseases, wellbeing implies measures to keep healthy people healthy. The Major Challenge "Ensuring healthy and comfortable spaces" will contribute to the aim to keep healthy people healthy by Digital Life supportive products and services.
- **Multimodal transportation / Mobility**: Where the transportation chapter will mainly address infrastructure related aspects, Digital Life implies "being on the move" from time to time. The aspects address by the Major Challenges for Digital Life also apply when being on the move.
- **Energy**: Electrical Energy is a pre-requisite of a Digital Life, as smart devices live from it. Although in general energy generation and distribution is a different area, energy scavenging of IoT sensors and actuators, energy storage and wireless charging of smart phones and other wearables can be an essential element of a Digital Life.



# 6

# *Systems and Components: Architecture, Design and Integration*

# 6.1.
# EXECUTIVE SUMMARY

Effective design technologies and (smart) systems integration, supported by efficient and effective architectures, are the ways in which ideas and requirements are predictively transformed into innovative, high-quality and testable products, at whatever level of the value chain, shown in figure 33.


*On every level of the value chain, the top-level artefact to be developed is usually called "the system", even if it is used as a component on higher levels of the chain*

F.33

These aforementioned technologies aim at increasing productivity, reducing development costs and time-to-market ensuring the level of targeted requirements such as new functionalities, quality, system level performance, cost, energy efficiency, safety, security and reliability.

**Design Technologies** include methodologies involving hardware and software components, design flows, development processes, tools, libraries, models, specification and design languages, IPs, manufacturing and process characterisation. Mastering design technologies and extending them to cope with the new requirements imposed by modern and future Electronic Components and Systems (ECS) are highly important capabilities of European industries to ensure their leading position in ECS engineering. To ensure this leading position, the creation of efficient, modular **architectures** and digital platforms is needed to enable the system's intended functionality at the required quality, and support efficient, cost-effective validation and test methods.

**Physical and Functional Systems Integration** (PFSI) is one of the essential capabilities that are required to maintain and to improve the competitiveness of European industry in the application domains of ECS. Although, in practice, PFSI is often geared towards specific applications, the materials, technologies, manufacturing and development processes that form part of this domain are generic. PFSI is hence an enabling technology in the area of ECS that needs to be further addressed by research, development and innovation (R&D&I), filling the value chain, the gap between technology and application, and moving innovations into products, services, and markets.

The objective of the proposed R&D&I activities is to leverage progress in **Systems and Components Architecture, Design and Integration Technologies** for innovations on the application level.

## 6.2. RELEVANCE

Effective architectures, design methods, development approaches, tools and technologies are essential to transform ideas and concepts into innovative, producible and testable ECS, and products and services based on them. They provide the link between the ever-increasing technology push (More Moore (MM) and More-than-Moore (MtM), increased connectivity and its potential,...) and the demand for new innovative products and services of ever-increasing complexity that are needed to fulfil societal needs. At the same time, they aim at increasing productivity, reducing development costs and time-to-market, and ensure the level of targeted requirements such as on quality, performance, cost, energy and resource efficiency, safety, security and reliability.

Design technologies enable the specification, concept engineering, architecture exploration and design, implementation and verification of ECS. In addition to design flows and related tools, design technologies also embrace libraries, IPs, process characteristics and methodologies including those to describe the system environment and use cases as well as Reference Architectures, Digital Platforms and other (semi-) standardised building blocks. Design Technologies involve both hardware and software components, including their interaction and the interaction with the system environment, covering also integration into (cloud-based) services and ecosystems.

Moreover, the importance of software in ECS is increasing since the current trend includes the shift of features from the hardware to the software. This trend aims at standardising more the hardware (reducing the costs) and creating more advanced and customisable features in software (allowing also easier updates and improvements). This shift is required to meet the needs of the market that requires not only safety and security but also short time-to-market and development cycles. Systems architectures, design technologies and especially validation and testing processes have to follow this shift to enable European industry to meet the continuous changes of the market.

Future smart systems will feature new applications, higher levels of integration, decreased size, and decreased cost. Miniaturisation, functional integration and high-volume manufacturing will make it possible to install sensors in even the smallest devices. Given the low cost of sensors and the large demand for process optimisation in manufacturing, very high adoption rates are possible; in fact, perhaps around 80–100% of all manufacturing could be using IoT-based applications by 2025. Improved integration technologies and miniaturisation will enable patient monitoring devices for a broad range of conditions. Cost-efficient manufacturing will increase the market penetration of advanced driver assistance systems and help reduce traffic mortality.

Components are versatile in terms of design (size, flexibility), material or composition, and thus the network of stakeholders involved in a production process of smart systems is equally complex. If one keeps in mind that Europe's supply chain towards smart systems production consists of more than 6,000 large companies and SMEs, new models for more efficient production processes that can react instantly to sudden market developments need to be developed.

Looking at how the internet, communications and the required technology have revolutionised the world in the last 10 years, it is obvious that the short lifecycle of products and fabrication on demand are just a few of the issues to be concerned about. In addition, the demand for smart technologies regarding size, performance, quality, durability, energy efficiency to comply with data security, integrity and safety will increase as time goes on. Last, but not least, issues regarding materials (from polymer parts to rare earth metals), as well as their appropriate disposal, recycling, climate and environmental effects, will gain further importance and be regulated progressively.

### 6.2.1. Game changers

While the objectives outlined above have been pursued even for the very first instances of electronic systems embedded into products, a number of new demands are coming from the increased complexity of ECS to be designed. Even more critical is the appearance of 'game changers' arising from the stepwise changes in system evolution. Among these 'game changers', many of the ones described in Section 0 apply for Architecture, Design and Integration Technology, too: Safety and Security (c.f. Sec. 0.2.3, and also Chapter 8) are overarching goals that we have to target. Increased connectivity of ECS, increased importance and capabilities of software, including the advent of Artificial Intelligence and learning systems (c.f. Section 0.2.1), all increase the complexity of the design and integration task and require new methods, processes and tools support their cost efficient design, development, integration, and verification and validation.

Among the 'game changers', the most critical will be:

- **Autonomous networked systems**: the introduction of IoT implies that ECS are becoming increasingly networked with each other as well as with 'cloud-based' services, creating machine-to-machine interactions without any human intervention in the control loop, for example in fully automated driving. Besides the need to be able to handle the added complexity of interfacing different subsystems adhering to different standards, the systems' rising complexity and increased automation implies increased severity of safety risks. New techniques are required, such as scenario and model based safety analysis, online safety assessment, re-certification, architectural support not only for the functionality but also for verification, and many similar.
- **Self-evolving systems**: ECS and especially Cyber-Physical Systems (CPS) exhibit an increasing level of automation (up to autonomy). Machine learning, neuromorphic architectures, Artificial Intelligence, now entering the field of the possible, coupled with decision-making capabilities and handling of uncertainty to match an evolving environment, are proposing an enormous challenge for safe design, Verification and Validation (V&V) technologies and testing.
- **Design for a larger world**: ECS span more than one application domain. Example domains include Embedded Systems and the Internet / Cloud, or consumer electronics and assistance systems in cars. Moreover, ECS based products in general have a long lifetime (up to several decades, e.g. for airplanes), during which they might encounter new situations in the environment in which they are meant to act, and new unforeseen requirements to their behaviour (e.g. changing regulations, etc.). The design therefore has to expand its scope including the full ECS system, its application environment and its evolution. The complete (foreseeable)lifecycle of the product must be covered, and potentially different lifecycles/lifetimes of its components must be taken into account.

Tough challenges are coming also from the trends already present in ECS evolution, including:

- **Human Machine Interaction**: ECS and especially CPS interact with each other and with human beings: Human Machine Interaction, Human Machine Cooperation and adaptation of machines to human needs thus are increasingly important topics in systems design.
- **Personalised functionalities and Variant Management**: ECS based products are often highly configurable to adapt to users' needs and requirements and thus product variability is increasing vastly. The challenge here is to adapt and enrich the Design Methodologies (including the Software Engineering ones) and have corresponding tools to support these changes.
- **Increasing importance of software**: Features are shifting from hardware to software to improve adaptability, upgradability and evolvability. Therefore, software engineering (approaches and tools) is of increasing importance and needs to be adapted to the specific requirements of ECS.
- **Increasing speed in development processes** –consumer electronics technologies used in industrial, infrastructure or automotive applications, for example, have much shorter development cycles and must therefore be updated/exchanged significantly more often than the core technologies in the other areas.

These game changers for developing modern and future ECS give rise to seven 'Major Challenges', that are detailed in Section 6.3.

### 6.2.2. Competitive value

Traditionally, European industry has a leading position in Systems Engineering, allowing it to build ECS based products that meet customer expectations in terms of functionality as well as quality. Design technologies – processes and methods for development, testing and ensuring qualities of the Hardware, the Software and the complete system, as well as efficient tools supporting these – are a key enabler for this strong position. Facing the new requirements and game changers explained above, it is of utmost importance for these industries to put significant resources into R&D&I activities to maintain and strengthen this leading position and to enable them to satisfy the needs of the different domains while reducing the development cycles and costs.

Europe also has very strong system houses producing complex innovative high-tech designs for products in the areas of aeronautics, automotive, industrial applications and manufacturing, healthcare, and communications. To maintain their world-leading positions, a continuously push for improved electronic systems at increasing levels of automation is essential while sustaining high quality in parallel. This means that system complexity is continuously increasing and the probability of design errors is growing.

Large EDA (Electronic Design Automation) companies currently provide mainly tools and methodologies for specific design domains (digital macros, analogue & RF macros, SW, package, PCB) which are only roughly linked and mostly not focused on European needs in design technology. Higher design levels are not well covered, even though some initiatives for the support of higher levels of abstraction do exist. Large system and semiconductor companies normally combine available (partial) solutions with (non standardized) in-house solutions. A comprehensive seamless open and extendable open design ecosystem across the whole value chain has thus to be created, especially for supporting heterogeneous applications. Yield, heat, and mechanical stress need to be addressed in more holistic way. This will become increasing critical as parts are further embedded into packages (e.g. SiP, SoC) and opportunities for re-work, inspection and repair diminish. Design for testability and manufacturability are critical for the same reasons with a need to model and simulate processes as well as product behaviour.

To compete with low labour-cost countries, it is of topmost importance for Europe to develop and offer, at the right time, sophisticated feature-rich innovative products with the superior performance and quality needed to justify a higher price tag. Time-to-market is of crucial importance, since even a one-month delay in market introduction can result in a significant loss of revenue in fast moving markets, or in the complete loss of seasonal consumer markets. Life cycle cost analysis is also critical to ensure that installation, operation, maintenance, re-configuration over project life, re-cycling, etc. are all taken into account. Europe's competitiveness in ECS offerings will be enhanced for many applications when such a holistic assessment is undertaken.

The Smart Systems sector in Europe covers nearly all required technologies and competencies. With more than 6,000 innovative companies in the EU, the sector employs approx. 827,600 people (2012), of which 8% or 66,200 are involved in R&D with a budget of EUR 9.6 bn per year. New R&D&I actions are expected to further strengthen the European leadership in Smart Systems technologies and to increase the global market share of European companies in the sector. New Smart System solutions will feature higher levels of integration, decreased size and decreased cost. Time to market for subsequent products will be reduced by new designs, building blocks, testing and self-diagnosis strategies, methods and tools capable of meeting the prospect use-case requirements on reliability, robustness, functional safety and security in harsh and/or not trusted environments.

Tackling the Major Challenges introduced in Section 3 will enable European Industry as a whole to benefit from the progress made in innovative electronic components and systems.

### 6.2.3. Societal benefits

Society wants high-end technologies on a large scale and at affordable cost. Within the global trends of becoming a world where everything is connected, everything is smart and everything is safe and secure, design technologies and physical and functional systems integration are two of the key enablers for this development. First, they enable modern and future ECS based products – Cyber-Physical Systems, components of 'Information and Communication Technology' and thus of the 'Internet of Things' (IoT), smart devices – with the required functionality and quality to be built at all. Second, they assure products that meet and exceed the required quality – i.e., products that are safe and secure, dependable and reliable, recyclable, serviceable, etc. – thus allowing these products to enter the market and increase user trust and confidence in using these products. Third, they enable cost-efficient production of these products, thus making them affordable. Last, but not least, they allow increasing 'smartness' of products and therefore market opportunities are huge. The design technology bottlenecks have to be removed to enable the design of all the ECS necessary to meet the societal needs of a growing population.

Within the global trends of becoming a world where everything is connected, everything is smart and everything is secure, Smart Systems Integration is at the core of the plethora of those smart devices. Smart Systems are the key enabler of the growing "Smartification" of applications. Together with the "Digitalisation" process, both allow disruptive improvements in each aspect of human life.

## 6.3. MAJOR CHALLENGES

Effective and efficient architectures, design and integration technologies are essential for predictively transforming ideas and requirements into innovative, high-quality, testable and deployable products on all levels of the value chain. These approaches, supported by valuable verification, validation and testing techniques, methods and tools, aim at increasing productivity, reducing development costs and time-to-market. They ensure the targeted requirements such as new functionalities, quality, system level performance, cost, energy efficiency, safety, security and reliability. As such, continued development of those technologies is a prerequisite to the realisation of the ever more complex systems required to meet Europe's societal challenges.

Major Challenges in Architecture, Design and Integration are:

- Managing critical, autonomous, cooperating, evolvable systems
- Managing complexity
- Managing diversity

- Managing multiple constraints
- Integrating miniaturised features of various technologies and materials into smart components
- Providing effective module integration for highly demanding environments
- Increasing compactness and capabilities by functional and physical systems integration

These challenges are not disjointed but strongly interdependent, for example diversity and also handling of multiple constraints (e.g. for a required minimum quality of the product) significant increase complexity. Nonetheless, these challenges emphasise the main obstacles that need to be overcome in order to realise the vision.

Furthermore, all challenges commonly face the demand of integrating design technology aspects into an ecosystem for processes, methods and tools for the cost-efficient design working along the whole value chain and lifecycle.

## 6.3.1. Major Challenge 1: Managing critical, autonomous, cooperating, evolvable systems

### 6.3.1.1. Vision

Many new and innovative ECS products exhibit an ever-increasing level of automation, an ever-increasing capability to cooperate with other technical systems and with humans, and an increasing level of (semi-) autonomous and context-aware decision-making capabilities in order to fulfil their intended functionality. In addition, they need the capability to evolve and adapt during run-time, e.g., by updates in the field and/ or by learning. Building these systems, and guaranteeing their safety, security and certification, requires innovative technologies in the areas of modelling (systems and their environment, humans as operators and cooperation partners of these systems, as well as use cases, scenarios, etc.), software engineering (quality of the process and the product, development approaches, etc.), model-based design, V&V technologies, and virtual engineering for high-quality, certifiable ECS that can be produced (cost-)effectively.

### 6.3.1.2. Scope and ambition

R&D&I activities in this challenge aim at enabling seamless and concurrent model-based development methods and tools for critical systems, with a strong focus on V&V and testing activities. Major topics are identified in the areas of models, model libraries and model-based design technologies, V&V and test methodologies and tools, and (virtual) engineering of ECS.

### 6.3.1.3. High priority R&D&I areas on critical, autonomous, cooperating, evolvable systems

The topics of Major Challenge 1 are collected into three categories (high priority R&D&I areas), which are described here. For each of the areas, the timelines in section 6.6 contain an elaborated list of the corresponding R&D&I topics, the full list for each area is given in section 12 of the document, “Appendix to Chapter 6”.

**Models, model libraries, and model-based design technologies**

Topics grouped under this heading include re-usable, validated and standardised models and model libraries for systems behaviour, systems’ context/environment and humans (as operators, users and cooperation partners). Additional important topics in this area are model-based design methods, including advanced modelling techniques for future ECS and extended specification capabilities, all supported by advanced modelling and specification tools.

#### Verification and Validation (V&V) and test for critical systems: Methods and tools

This area comprises model-based verification, validation and test methodologies and technologies as well as interoperable tool chains and platforms for critical systems, automated derivation of verification procedures and back annotation, V&V and test methods for the lifecycle and in-service phase, and V&V and test methods for adaptive, cognitive and learning systems and autonomous systems.

#### (Virtual) Engineering of Electronic Component and Systems (ECS)

Collaboration concepts and methods across groups, organisations, and disciplines for holistic (virtual) engineering of ECS over the whole value chain is the main topic in this R&D&I area. This includes methods and interoperable tools for virtual prototyping of complex ECS and appropriate engineering support (libraries, platforms, and interoperable tools for evolvable, adaptable Open World Systems, including cognitive and cooperative systems).

## 6.3.2. Major Challenge 2: Managing complexity

### 6.3.2.1. Vision

With the increasing role of electronics systems and especially under the influence of connected systems, e.g. in IoT, CPS, etc., the complexity of new and innovative ECS is increasing constantly. Better and new methods and tools are needed to handle this new complexity (also considering the increased amount of software used for many of the most complex features) and enable the development and design of such complex systems in order to fulfil all functional and non-functional requirements, and to get cost-effective solutions from high productivity. This challenge focuses on complexity reduction techniques in the design and analysis of such ECS, in order to increase design productivity, efficiency and reduce costs.

### 6.3.2.2. Scope and ambition

R&D&I activities in this area aim at developing solutions for managing the design of complex ECS in time at affordable costs. They focus on architecture principles and systems design topics to reduce complexity for the design, V&V and testing of such ECS systems, methods and tools to increase design efficiency and reduce the complexity of V&V and Test methods.

### 6.3.2.3. High priority R&D&I areas on managing complexity

Topics of Major Challenge 2 are grouped into four categories (high priority R&D&I areas) described here. For each of the areas, the timelines in section 6.6 contain an extensive list of the corresponding R&D&I topics, the full list for each area is given in section 12 of the document, “Appendix to Chapter 6”.

#### Systems architecture

This area groups extended methods for architectural design – support for systems with thousands of components, metrics for functional and non-functional properties, and early architectural exploration – and design methods and architectural principles, platforms and libraries supporting V&V, Test and Lifecycle Management of complex, networked ECS, including support for self-management, self-awareness and self-healing as well as cognitive and adaptive systems.

#### System design

Design and Analysis methods for Systems and Components are the focus of this area. This includes support for multi-/many-core systems, support for IP modelling, component-based HW/SW co-design approaches and methods and tools for virtual prototyping.

**Methods and tools to increase design efficiency**

Seamless and consistent design and tool chains for automated transfer (extraction, synthesis, …) of system design description into functional block, strong support of package, board and sensor/MEMS co-design, new methods and tools to support new design paradigms (like multi-/many cores, increased software content, GALS, neural architectures, etc.), new technologies (FD-SOI, graphene, etc…) and new approaches to handle analogue/mixed design are the main topics of this area.

**Complexity reduction for V&V and test**

Coping with the complexity of V&V and Test methods for modern ECS is the focus of this area. This includes techniques (and tools support) for (automatic) complexity reduction, methods and tools to support scenario-based V&V and Test, virtual platforms in the loop and similar, as well as prove techniques to assess the safeness and soundness of these complexity reduction techniques.

## 6.3.3. Major Challenge 3: Managing diversity

### 6.3.3.1. Vision

In the ECS context a wide range of applications has to be supported. With the growing diversity of today's heterogeneous systems/designs requiring integration of analogue-mixed signal, digital, sensors, MEMS, actuators/power devices, transducers, storage devices, domains of physics like mechanical, photonic and fluidic aspects that have to be considered at system level, and embedded software. This design diversity is enormous. It requires multi-objective optimisation of systems, components and products based on heterogeneous modelling and simulation tools. Last, but not least, a multi-layered connection of the digital and physical world is needed (for real-time as well as scenario investigations).

### 6.3.3.2. Scope and ambition

R&D&I activities in this area aims at the development of design technologies to enable the design of complex smart systems and services incorporating heterogeneous devices and functions, including V&V in mixed disciplines like electrical, mechanical, thermal, magnetic, chemical and/or optical.

### 6.3.3.3. High priority R&D&I areas on managing diversity

The main R&D&I activities for this challenge 3 are grouped into four categories (high priority R&D&I areas):

**Multi-objective optimisation of components and systems**

The area of Multi-objective optimisation of components and systems comprises integrated development processes for application-wide product engineering along the value chain including modelling, constraint management, multi-criteria, cross-domain optimisation and standardised interfaces. Furthermore, it deals with consistent and complete co-design and integrated simulation of IC, package and board in the application context and modular design of 2.5 and 3D integrated systems (reuse, 3D IPs, COTS and supply chain integration, multi-criteria design space exploration for performance, cost, power, reliability, etc…)

**Modelling and simulation of heterogeneous systems**

The area of modelling and simulation of heterogeneous systems comprises hierarchical Approaches for modelling on System Levels, modelling methods considering operating conditions, statistical scattering and system changes as well as methods and tools for the modelling and integration of heterogeneous subsystems. Furthermore, it deals with methods for HW/SW co-simulation of heterogeneous systems at different abstraction levels, different modelling paradigms, modelling methods and model libraries for learning, adaptive systems and models and model libraries for chemical and biological systems.

**Integration of analogue and digital design methods**

The area of integration of analogue and digital design methods comprises metrics for testability and diagnostic efficiency especially for AMS designs, harmonisation of methodological approaches and tooling environments for analogue, RF and digital design and automation of analogue and RF design.

**Connecting the digital and physical world**

The area of connecting digital and physical world comprises advanced simulation methods (environmental modelling, multi-modal simulation, simulation of (digital) functional and physical effects, emulation and coupling with real hardware, connection of virtual and physical world) and novel More than Moore design methods and tools.

## 6.3.4. Major Challenge 4: Managing multiple constraints

### 6.3.4.1. Vision

Beyond its pure functionality, different types of properties characterise IC designs. Non-functional properties especially tend to determine the market success or failure of a product. Since many of them originate in the physical realisation of the technology, these properties cannot be analysed or optimised in isolation. Hence, we need appropriate models, methods and tools to manage multiple constrains (e.g. design for yield, robustness, reliability, safety), functional and non-functional (e.g. low-power consumption, temperature, time, etc.) properties as well as constraints coming from the applications themselves. As a long-term vision, we aim at an integrated toolset for managing all relevant constraints.

To manage multiple constraints will require the standardisation and integration of methods, tools and flows for analysing and optimising multiple constrains in a single holistic approach. This includes ultra-low power design, monitoring and diagnosis methods and tools, building secure extendable or evolvable systems, assessing opportunities to harvest from ambient energy sources to replenish power sources, conditional monitoring of systems for anomalous behaviour of equipment and infrastructure, on-going dynamic functional adaptability to meet application needs, tackling of new technology nodes and efficient methodologies for reliability and robustness in highly complex systems including modelling, test and analysis, considering variability and degradation.

### 6.3.4.2. Scope and ambition

Aims at developing design technologies considering various constraints (e.g. design for yield, robustness, reliability, safety), functional and non-functional (e.g. power, temperature, time, etc.) properties as well as constraints coming from the applications themselves. The cross-propagation of constraints among the different domains, nowadays involved in systems and their application contexts, is an important issue to be considered for system design.

### 6.3.4.3. High priority R&D&I areas on managing multiple constraints

R&D&I activities in this challenge are grouped into three categories (high priority R&D&I areas)

**Ultra-low power design methods**

The area of Ultra-low power design methods comprises advanced methods for ultra-low power design, design methods for (autonomous) ultra-low-power systems considering application-specific requirements and methods for comprehensive assessment and optimisation of power management and power consumption including the inclusion of parasitic effects.

#### Efficient modelling, test and analysis for reliable, complex systems taking into account physical effects and constraints

The area of efficient modelling, test and analysis for reliable, complex systems taking into account physical effects and constraints comprises hierarchical modelling and early assessment of critical physical effects and properties from SoC down to system level, design and development of error-robust circuits and systems including adaptation strategies, intelligent redundancy concepts, adaptive algorithms. Furthermore, it deals with production-related design techniques, consistent methods and new approaches for (multi-level) modelling, analysis, verification and formalisation of ECS's operational reliability and service life taking into account the operating conditions and dependencies between hardware and software, detection and evaluation of complex fault failure probabilities. Additionally, the area is about a consistent design system able to model and optimise variability, operational reliability yield and system reliability taking into account dependencies and analysis techniques for new circuit concepts and special operating conditions. Last, but not least, it comprises advanced test methods, intelligent concepts for test termination, automated metrics/ tools for testability and diagnosis, extraction of diagnostic information and methods and tools for monitoring, diagnostics and error prediction for ECS.

#### Safe systems with structural variability

The area of safe systems with structural variability comprises architectures, components and design methods and tools for adaptive, expanding systems ((self-)monitoring, diagnostics, update mechanisms, strategies for maintaining functional and data security, life cycle management, adaptive safety and certification concepts, realisation of real-time requirements, high availability and functional and IT security, evaluation of non-functional properties, analysis of safety and resilience under variable operating conditions). Furthermore it is about novel simulation approaches for the rapid evaluation of function, safety and reliability and security concepts for adaptive, expanding systems (self-monitoring, environmental analysis, ageing-resistant chip identification techniques, ensuring functional safety through robustness guarantee).

## 6.3.5. Major Challenge 5: Integrating miniaturised features of various technologies and materials into smart components

### 6.3.5.1. Vision

Smart systems will combine sets of components utilising features based on nanoelectronics, micro-electro-mechanic, magnetic, photonic, micro-fluidic, acoustic, bio- and chemical principles, radiation and RF as well as completely new technologies in an unprecedented variety. The components will interact with each other as well as with the outside world. The systems will need to be reliable, robust and secure, miniaturised, networked, predictive, able to learn and often autonomous. Physical fabrication and integration of the components will require a multitude of materials and processes from silicon and non-silicon micro-nano, printing, laminate and other joining and assembling technologies as well as hybrid combinations of them. The technologies for smart systems, as they are understood here, are fundamental to the properties and capabilities of these components and to the system as a whole. Despite the complexity, manufacturing will flexibly support large-scale fabrication for the sake of appropriate unit costs.

### 6.3.5.2. Scope and ambition

The SSI industry produces a number of underlying smart technologies (components) such as sensors, actuators, semiconductor technologies, energy generators, storage devices, micro-nano-bio systems (MNBS), MEMS and LAE. After product design and subsequent testing, the orchestra of underlying process technologies leads finally to the integration of smart systems into smart products for enabling smart and sustainable functionalities and services. The components for these integrated smart systems already represent a fusion of functionalities enabled by a set of materials, structural elements, parts or subsystems. The total complexity and diversity exceeds that of the microelectronics components substantially necessitating a tremendous increase in scope and efficiency also of the methods, processes and schemes to be utilised in the production, assembly and testing of these various components.

#### 6.3.5.3. High priority R&D&I areas on component level integration

Three high priority R&D&I areas have been identified to master the challenges by improving: i) Functional Features, ii) Materials, and iii) Integration Technologies and Manufacturing

- Further massive increase in the level of complexity and heterogeneity within systems in package (SiP) e.g., by stacking layers of micro-fluidics, MEMS, electronics. communication, and other features, respectively, to form one packaged component
- Artefact-free sensors are necessary and are focused on error compensation at the place of origin with innovative solutions (e.g. multi-sensors).
- Innovative solutions are necessary regarding the long-term stability of the relevant components. The calibration effort has to be reduced drastically, especially in cases where the new generation of sensors is located inside the monitored processes and where the access by service/maintenance is too cost-intensive.
- Coping with the dramatically higher requirements in functional safety and system availability of safety-relevant components for the new solutions (automated car, industrial automation, smart energy systems) while keeping the systems affordable for a broader public by integrating micro- and nano-scale detectors for self-monitoring of essential integration features like interfaces (prone to delamination) and joints (risk of cracks).
- Highest volume production of smart power components at minimum cost for the new consumer and industrial products by further advancement of miniaturisation. This brings the sensors and signal processing for health monitoring and performance control in very close vicinity to WBG power devices, which can be operated at high temperatures.

For each of these areas, specific actions are noted and incorporated in their respective "Timeframes" section while their full text is found in section 12 of the document, "Appendix to Chapter 6".

### 6.3.6. **Major Challenge 6: Providing effective module integration for highly demanding environments**

#### 6.3.6.1. Vision

Progress in performance and miniaturisation makes electronic systems increasingly attractive and suitable for a direct integration into all fields of applications (chapters 1-5), in which form factor, material behaviour or cost of the existing solutions have prevented their use so far. For example, motors can be improved in smart drives, which actively adapt to the various use conditions, machine tools can gain precision, efficiency and versatility, automotive systems can take over duties of the human driver, energy or other infrastructure can flexibly adjust to the actual needs, perhaps even by changing from receiver to supplier, exo- and endoskeletons can interact with the patient proactively etc. with the help of smart electronic systems to be added. In summary, human life will be eased and societal challenges met by the new electronic systems.

#### 6.3.6.2. Scope and ambition

In many of the new applications, the electronic systems will be exposed to very demanding conditions. At the same time, the dependence of human life on the safe functioning of these electronic systems will increase dramatically with these new applications. Hence, the future structures of electronics modules will not just show a strong increase in functional and structural complexity but also in diversity. They will show yet higher compactness with more features and materials integrated within a given volume. The new structural and fabrication design concepts to be developed will make this possible but need to be able to reliably suppress any unwanted interactions and parasitic effects that may threaten the safe and dependable functioning of the new modules.

#### 6.3.6.3. High priority R&D&I areas on board / module level integration

The high priority R&D&I areas identified for the mastering of the challenges in module integration are: i) Functional Features, ii) Materials, and iii) Integration Technologies and Manufacturing.

- Fabrication of direct embedding of electronic components and SiPs into substrates/PCBs or even structural components (e.g., motor housing, machine tools like drills, bits, sawing blade, nozzles, …)
- Heat removal from complex and ultra-dense modules comprising power and signal electronics at minimum form factor
- Harsh environment modules operating between -40°C and 300…500°C exposed to vibration and chemicals (moisture, salt dust, gases, oil, …) in addition
- Long-term stable and bio-compatible / implantable micro-fluidics modules
- Fabrication of low-volume customised electronic modules at the process efficiency of high-volume production by implementing new manufacturing technologies based on 3D printing, role-to-role, stamping, injection moulding etc.

The specific actions are noted and incorporated in their respective "Timeframes" section while their full text can be found in section 12 of the document, "Appendix to Chapter 6" to this chapter.

### 6.3.7. Major Challenge 7: Increasing compactness and capabilities by functional and physical systems integration

#### 6.3.7.1. Vision

Smart electronic systems will exhibit an increasing level of various kinds of "smartness" - useful in many application fields like healthy living, automotive, communication, energy, water quality, smart textiles, forestry and food. The IoT smart systems will be integrated with existing equipment and infrastructure - often by retrofit. Enabling factors will be: interoperability with existing systems, self- and re-configurability, scalability, ease of deployment, sustainability (e.g. batteries as power source replenished by energy harvesting instead of replacement) and reliability, e.g., by self-repair capabilities. Systems of systems, upgradable and automatically configurable suits of sensors may share computer power or – alternatively - will be customised to the application scenario (sparse, slim and ubiquitous). The smart systems will help industries to cope with the growing variety of production processes and, at the same time, will facilitate better living for individual end users.

#### 6.3.7.2. Scope and ambition

Many of the new ECS benefit from the same transversal technologies. Advanced driver assistance systems and minimally invasive surgery devices both require the heterogeneous (3D) integration of different building blocks. Similarly, intraocular measurement devices and environmental sensors for dangerous substances both rely on wireless communication for data exchange. Also, there is the general trend for sensors and actuators to get much closer to the actual scene in order to measure data in-situ. Hence, harsh environments with high temperatures, humidity, vibration, electrical fields must often be endured for 15 to 30 years, with zero defects and error-free. In the case of human health monitoring (hyperpiesia, diabetes, stroke, infarct), the much smarter sensor solutions will increasingly need to be based on non-invasive principles. In all cases, the highest quality raw sensor signals with high reproducibility need to be provided by the next generation of extremely miniaturised innovative sensors, with lowest power consumption and at mass production levels. Moreover, smart systems for collaborative environments as well as driver assistance systems require autonomous decision-making capabilities to enable efficient interaction.

For the sake of European R&D&I efficiency, these common challenges will be addressed by application-independent developments of system and application level integration technologies

### 6.3.7.3. High priority R&D&I areas on system & application level integration

Again, the main R&D&I activities identified are: i) Functional Features, ii) Materials and iii) Integration Technologies and Manufacturing; detailed actions are listed under "Timeframes" and in section 12 of the document, "Appendix to Chapter 6".

- Manage highly compact heterogeneous architectures for new smart electronic systems in safety relevant applications and various demanding environments (harsh, in vivo, …)
- Master the HW + SW integration & testing for the systems of much higher complexity at that level of comprehensiveness and efficiency at the same time, which is needed for high-volume consumer and industrial products (automated car, production robots, …)
- Coping with the high requirements on functional safety and availability of the new applications for complex systems comprising several modules with heterogeneously integrated components, i.e., implementing efficient and safe health monitoring for systems with many different critical elements and a multitude of similarly probable failure modes.

## 6.4. EXPECTED ACHIEVEMENTS

Overcoming the challenges in section 3 will enable European Industry to maintain and increase its leading position in developing, producing and selling future Electronic Components and Systems that meet societal needs in a way that is cost-efficient, yet yields products of highest quality. Especially, expected achievements are:

- the creation and extension of modelling and specification techniques and languages matching the new properties of and requirements for critical, autonomous, cooperating and evolvable systems, developing and standardising architectural measures to ease their validation and testing, appropriate V&V and Test methodologies to ensure their expected and needed qualities.
- the establishment of standard languages and ontologies and associated tools and methods to develop system models that can be shared across the system design value chain.
- the establishment of standard languages, plus associated tools and methods, to build integrated design flows and platforms targeting heterogeneous SoC and SiP.
- the establishment of common platforms and libraries of parts/components that enable modular development, reusable IP, standardised software and middleware solutions, etc.

- enabling systematic reuse of (models of) components, environments, contexts, etc.
- a drastic increase in the scalability of methods to match the increased complexity of systems.
- improved capabilities to develop, validate and optimise system properties and qualities (from power consumption, functional and non-functional systems properties like safety, security, reliability, real time).
- methods and tools to facilitate online monitoring and diagnostics with embedded context awareness.

The general strategic actions required are:

- Demand – individual manufacturing, personalised (medicine, smart home, smart transportation und smart environments)
- Shortening the time-to-market – from research and testing until production
- Automation of fabrication processes for smart devices
- Creating open-innovation platforms to enable easier stakeholder cooperation
- Securing R&D&I financing in a complex ecosystem (regarding SMEs)
- 'Deploy and forget' retrofitability – self-sustaining IoT devices requiring no maintenance

## 6.5. MAKE IT HAPPEN

**Design Ecosystem:** The key success factor of this roadmap is the actual adoption by European Industry of the new methodologies in Systems and Component Engineering. This implies not only traditional technology transfer but also changes in the way of working in industry towards a much more comprehensive structured approach. This means that cooperation with and between the leading industries in Europe is very important.

Many of the R&D&I topics described in the previous sections cannot be solved by a single company or organisation. Most noteworthy, this includes all standardisation and pre-standardisation activities, but also

- the development of a common design and validation methodology applicable along the value chain, that is
    - accepted by public authorities, especially by certification authorities
    - accepted by the general public in terms of yielding trustworthy products
    - based upon a V&V and Test methodology using standardised catalogues of system contexts/ scenarios as test cases
    - enabling cost-efficient processes and allowing reuse and re-certification.
- support for validation of methodologies in industrial practice
- support for industry in the process of adopting new methodologies
- support for heterogeneous applications addressing yield, heat and mechanical stress in a more holistic way.

Therefore, a seamless, open, sustainable and extendable design ecosystem for processes, methods and tools for cost-efficient design is needed, focusing on design technologies based on standards. It has to start at system level and has to contain flexible, seamless design flows for all design domains and heterogeneous subsystems to (co-)design ECS with and for sophisticated feature-rich innovative products of superior performance and quality.

The creation of such an ecosystem, involving all stakeholders along the value chain, is a key success factor for European industry to maintain its leading role in Engineering ECS.

**PFSI Technologies and Production Processes**: The ambition is to find optimal models to enable effortless processes for the production of smart devices, while taking into account the overall spectrum of relevant aspects and the entire palette of stakeholders – from manufacturers and users to decision-makers, regulators, product and service providers and researchers and developers.

When speaking about the smart systems ecosystem in Europe, which, as described, is versatile in many respects, it is essential to develop new forms of stakeholder cooperation on market-ready products, thereby creating a special impact on SMEs and start-ups to maintain or increase their presence and competitiveness in international markets through their innovation, autonomy and agility capabilities. Besides, companies that are not yet visible on the smart systems radar should be motivated to join and enrich the community with their innovations and expertise. In particular, recognising that the rapid growth of the IoT, or simply various trends that are creating new challenges for Europe's smart system community, the proposed strategy will contribute to meeting such challenges in a more prepared way.

## 6.6. TIMEFRAMES

The timeframes given in this section denote for each R&D&I activity (topic) in each high priority R&D&I area the foreseen development lines. Each timeline is divided in three parts, for producing results of TRL2-4, 4-6, and 6-8 respectively. The concrete meaning of this section is that we envisage in a given year projects producing results of this TRL level or higher to be started (c.f. Section 0.6.2).

The Topics (actions) are abbreviated if necessary and therefore also listed, with a full description, in section 12 of the document, "Appendix to Chapter 6".

## *Major Challenge 1:* MANAGING CRITICAL, HIGHLY AUTONOMOUS, COOPERATING, EVOLVABLE SYSTEMS

2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027

### 1. MODELS, MODEL LIBRARIES, AND MODEL BASED DESIGN TECHNOLOGIES

1.a Re-usable, validated and standardized models and libraries for (a) systems contexts, (b) environment and (c ) humans

1.b Re-usable, validated and standardized models and libraries for systems behavior, including environment/situation perception, interpretation and prediction, self-X and handling of uncertainty

1.c Advanced modelling techniques for future ECS

1.d Model based design methods and interoperable tool chains for critical systems, supporting constraint driven requirements and (incremental) certification and homologation

1. e Extended specification capabilities to enable executable and consistent specifications of all design aspects

### 2. V&V AND TEST METHODOLOGY AND TOOLS FOR CRITICAL, HIGHLY AUTONOMOUS, COOPERATING, EVOLVABLE SYSTEM

2.a Model based verification, validation and test methodology and interoperable tool chains and platforms for critical systems

2.b Automated derivation of verification procedures and tools from requirements and models, back annotation of verification results, interface between requirement engineering and V&V environment

2.c V&V and test methods including tool support for Life-Cycle and in-service phase

2.d V&V and test methods including tool support for adaptive, cognitive and learning systems

2.e V&V and test methods including tool support for Human-Machine Interaction, collaborative decision making, cooperation strategies and activities

2.f V&V methods and analysis tools for autonomous systems including environment/situation perception, interpretation and prediction, handling of uncertainty, inaccuracy and faults

2.g Methods for the hierarchical verification of the whole system

2.h Concepts and procedures for the evaluation of functional safety, robustness and reliability

### 3. (VIRTUAL) ENGINEERING OF ECS

3.a Collaboration concepts and methods, platforms and interoperable tools for interdisciplinary, holistic virtual engineering of ECS covering the whole value chain, spanning organisations, engineering domains, and development activities

3.b Methods and interoperable tools for virtual prototyping of complex, networked systems

3.c Engineering support (libraries, platforms, interoperable tools) for evolvable and adaptable systems

3.d Engineering support (libraries, platforms, interoperable tools) for the design and operation of Open-World Systems

3.e Engineering support (libraries, platforms, interoperable tools) for the design and operation of cognitive, cooperating systems

2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027

## *Major Challenge 2:* MANAGING COMPLEXITY

2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027

### 1. SYSTEMS ARCHITECTURE (SYSTEMS AND COMPONENTS, HARDWARE AND SOFTWARE,...)

1.a Extended methods for architectural design (thousands of components, property metrics, early architectural exploration,...)

1.b Design methods and architectural principles, platforms and libraries supporting V&V, Test, and Life-Cycle-Management of complex, networked ECS: Modular Architectures and platforms

1.c Design methods and architectural principles, platforms and libraries supporting Self Management, Self-Awareness and Self-Healing

1.d Design methods and architectural principles, platforms and libraries supporting cognitive and adpative systems (artificial intelligence, machine learning, neuromorphic architecture ...)

1.e Model based system architecture, including models representing requirements and specifications in dynamic and executable architectures

### 2. SYSTEMS DESIGN

2.a Hierarchical Concepts and Standards for IP Modelling including coverage and error mode analysis

2.b Methods and Tools for component based HW/SW Co-Design for heterogeneous products in their (possibly unknown) environments

2.c Methods and Tools for Model Driven Engineering, supporting model creation and transformation (incl model extraction and model learning), model languages (incl. Domain Specific Languages), model management, and scalability of model based approaches

2.d Methods and Tools for efficient virtual prototyping, (incl. early SW integration and validation, adaptive, re-configurable real-time platforms and cognitive computing)

2.e Design and Analysis methods for multi-/many-core systems

### 3. METHODS AND TOOLS TO INCREASE DESIGN EFFICIENCY

3.a Seamless and consistent design tool chain for automated transfer of abstract (system level) descriptions into functional HW/SW blocks

3.b Strong support of package, board and sensor/MEMS (co-) design including die-embedding and 2.5/3D integration

3.c New methods and tools to support new design paradigms

3.d Support of new technologies: FD-SOI, graphene, naotubes,..., <7nm technology

3.e New approaches to handle analog/mixed signal design

### 4. V&V & TEST COMPLEXITY REDUCTION

4.a V&V methods to prove safeness and soundness of real-time complexity reduction in situation representation and situation prediction

4.b Hierarchical system verification using already verified components and verification process re-use

4.c Methods and tools to support scenario based V&V and Test,

4.d Virtual platform in the loop: Enabling the efficient combination of model-based design and virtual platform based verification and simulation

4.e Methods and tools for V&V and test automation and optimization including test system generation and handling of product variability

2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027

## *Major Challenge 3:* MANAGING DIVERSITY

| | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
|---|---|---|---|---|---|---|---|---|---|---|

| | |
|---|---|
| | **1. MULTI-CRITERIA OPITMIZATION OF COMPONENTS AND SYSTEMS** |
| **1.a** | Integrated development processes for application-spanning product engineering along the value chain |
| **1.b** | Consistent and complete Co-Design and integrated simulation of IC, package and board in the application context |
| **1.c** | Modular design of 2.5 and 3D integrated systems |
| | **2. MODELLING AND SIMULATION OF HETEROGENEOUS SYSTEMS** |
| **2.a** | Hierarchical Approaches for Modeling of heterogeneous systems on System Levels |
| **2.b** | Modeling methods to take account of operating conditions, statistical scattering and system changes |
| **2.c** | Methods and tools for the modeling and integration of heterogeneous subsystems |
| **2.d** | Methods for hardware software co-simulation of heterogeneous systems at different abstraction levels |
| **2.e** | Modeling methods and model libraries for learning, adaptive systems |
| **2.f** | Models and model libraries for chemical and biological systems |
| | **3. INTEGRATION OF ANALOG AND DIGITAL DESIGN METHODS** |
| **3.a** | Metrics for testability and diagnostic efficiency (including verification, validation and test), especially for AMS |
| **3.b** | Harmonization of methodological approaches and tooling environments for analog, RF and digital design |
| **3.c** | Automation of analog and RF design (high-level description, synthesis acceleration and physical design, modularization, use of standardized components) |
| | **4. CONNECTING DIGITAL AND PHYSICAL WORLD** |
| **4.a** | Advanced simulation methods considering the connection of virtual and physical world and its environment |
| **4.b** | Novel More than Moore design methods and tools |

| 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 |
|---|---|---|---|---|---|---|---|---|---|

## *Major Challenge 4:* MANAGING MULTIPLE CONSTRAINTS

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

### 1. ULTRA-LOW POWER DESIGN METHODS

**1.a** Advanced design methods for ultra-low-power design

**1.b** Design methods for (autonomous) ultra-low-power systems, taking into account application-specific requirements

**1.c** Method for comprehensive assessment and optimization of power management and power consumption

### 2. EFFICIENT MODELLING, TEST,AND ANALYSIS FOR RELIABLE, COMPLEX SYSTEMS CONSIDERING PHYSICAL EFFECTS AND CONSTRAINTS

**2.a** Hierarchical modeling and early assessment of critical physical effects and properties from SoC up to system level

**2.b** Design and development of error-robust circuits and systems including adaptation strategies and redundancy concepts

**2.c** Production-related design techniques

**2.d** Consistent methods and new approaches for (multi-level) modeling, analysis, verification and formalization of ECS's operational reliability and service life

**2.e** Consistent design system able to model and optimize variability, operational reliability, yield and system reliability, considering dependencies

**2.f** Analysis techniques for new circuit concepts and special operating conditions (Voltage Domain Check, especially for Start-Up, Floating Node Analysis …)

**2.g** Advanced test methods, intelligent concepts for test termination, automated metrics/tools for testability and Diagnosis, extraction of diagnostic information)

**2.h** Methods and tools for monitoring, diagnostics and error prediction for ECS (online and real-time monitoring and diagnostics, intelligent self-monitoring of safety-critical components, life expectancy)

### 3. SAFE SYSTEMS WITH STRUCTURAL VARIABILITY

**3.a** Architectures, components and methods for adaptive, expanding systems

**3.b** Design methods and tools for adaptive, expanding systems

**3.c** Novel simulation approaches for the rapid evaluation of function, safety and reliability

**3.d** Security concepts for adaptive, expanding systems

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

## *Major Challenge 5:* COMPONENT LEVEL INTEGRATION

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

### 1 - FUNCTIONAL FEATURES

1.a Selective gas (CO, CO2, NOx, VOC, etc.) sensing components

1.b Low power wireless architectures

1.c PMICs with high efficiency at very low power levels and over a wide range of input voltages (AC & DC)

1.d Selective detection of allergens, residues in food/water, atmospheric particles, etc

1.e Disease monitoring & diagnostics (at home, POC, animal health)

1.f Bio-sensors and bio-actuators

1.g MOEMS and micro-optics

1.h Various sensors and systems in package for autonomous cars, industrial robots, smart energy, health, environmental applications etc.

1.i Component-level features for self-diagnosis (PHM detectors)

1.j Harvesters and storage devices (e.g. microbatteries, supercapacitors), including 2D, 3D and solid-state for feeding low or zero power devices

1.k Hardware solutions for security and privacy

### 2 - MATERIALS

2.a Surface coatings for multi-functionality on the same base structures

2.b High efficiency photonic materials

2.c New / alternative organic and bio-compatible materials

2.d New materials and features for sensing (CNT, Graphene, Nitrogen voids, etc.)

2.e Low quiescent/leakage power material/devices for sensors

2.f Materials for low power, fast responding gas sensors and occupancy sensors

2.g Non-toxic, scalable, high density feature materials for energy harvesting sources and higher performing electrodes and electrolytes

2.h Rare earths replacement, e.g. for magnetics

2.i Heterogeneous integration of new materials, sensors, actuators for miniaturised chips (also for high temperature and photonics applications)

### 3 - INTEGRATION PROCESS TECHNOLOGIES AND MANUFACTURING

3.a 2D and 3D printing technologies (printing, etc.) for heterogeneous system integration and rapid manufacturing

3.b Robust integration of multi-component systems (sensors, actuators, electronics, communication, energy supply (incl. e.g. fluidics and photonics)

3.c Key technology areas (printing, etching, coating, etc.)

3.d Manufacturing & health monitoring tools (including tests, inspection and self-diagnosis) for components

3.e Quantum sensors and associated integration

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

## *Major Challenge 6:* BOARD / MODULE LEVEL INTEGRATION

2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027

### 1 - FUNCTIONAL FEATURES

1.a Board-level signal processing and control features for self-diagnosis and self-learning

1.b Smart power (mini-) modules for low-power sensing/actuation and efficient power transfer

1.c Low-power sensor nodes for real-time data processing

1.d High performance signal quality under harsh environmental conditions

1.e Protective housing and coating features (e.g., against chemicals)

1.f Photonics features like optical sources, pathes and connectors integrated into PCB

1.g Advanced and active cooling systems, thermal management

1.h EMI optimized boards

1.i 3D board & module design

1.j Board level high speed communication features

### 2 - MATERIALS

2.a Heterogeneous integration of new materials for miniaturised sensor & actuator modules

2.b Recycling and repair of modules

2.c Transducer materials (e.g. CMOS compatible piezo, e.g. flexible solar panels) that can be integrated into SiPs

2.d Materials for flexible devices

2.e Materials for coating, potting, and overmolding

2.f New thermal interface materials

2.g New substrate materials on board level

### 3 - INTEGRATION PROCESS TECHNOLOGIES AND MANUFACTURING

3.a Transfer printing of heterogeneous components on various substrates

3.b Heterogeneous 3D integration of sensors, actuators, electronics, communication, and energy supply features for miniaturised modules

3.c Highly miniaturised engineering and computer technologies with biochemical processes

3.d Bio-mimicking (bio-hybrids, fluidics)

3.e Manufacturing & health monitoring tools (including tests, inspection and self-diagnosis) for components

3.f Direct manufacturing and rapid prototyping

3.g Automation and customization ('towards I4.0') in module manufacturing

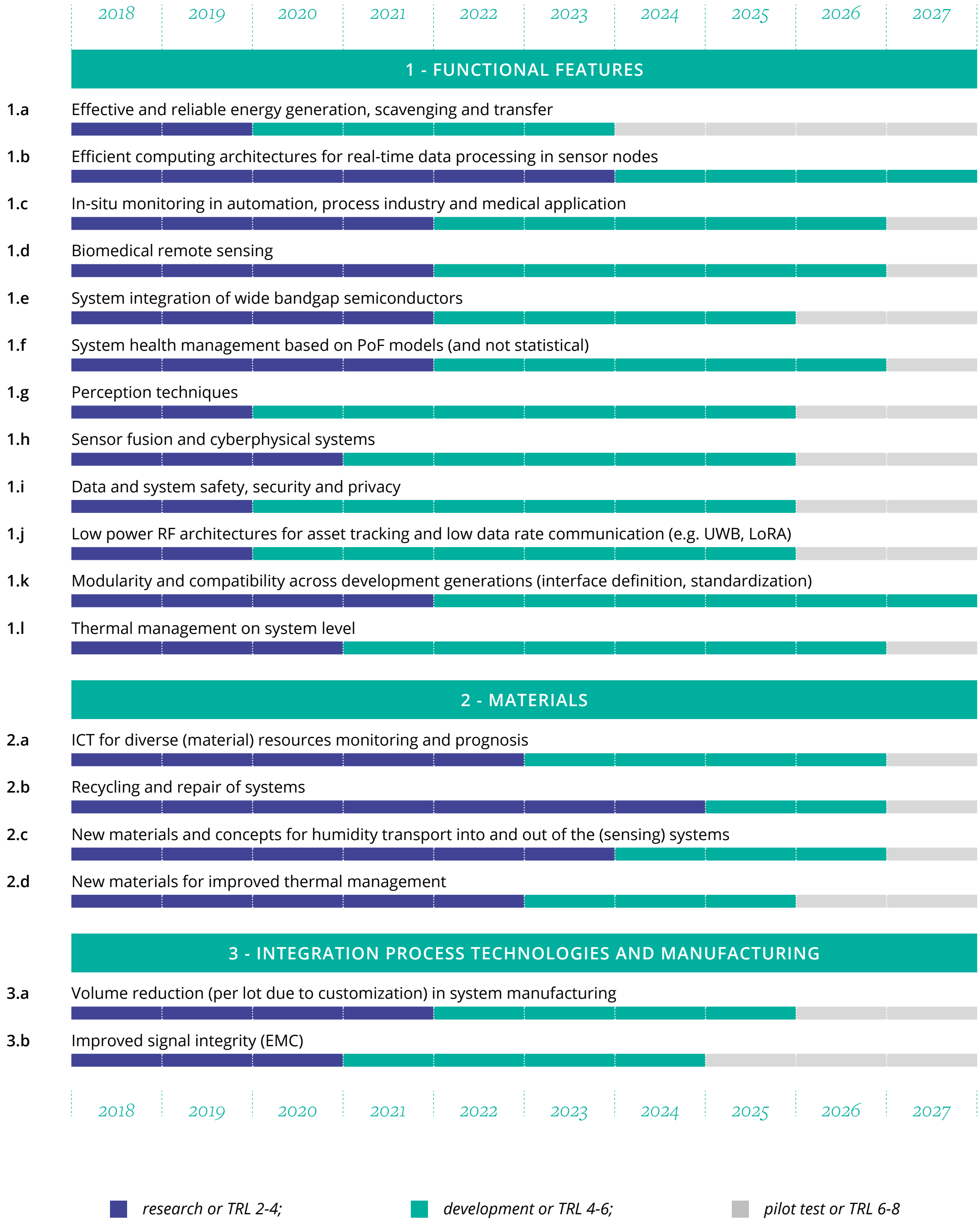
3.h Flexible and stretchable devices and substrates

3.i Chips, passives and packaged components embedded in board

3.j 3D printing of IC components on top of PCBs

2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027

## *Major Challenge 7:* SYSTEM & APPLICATION LEVEL INTEGRATION




*Timelines* **F.34**

# 6.7. SYNERGIES WITH OTHER THEMES

For the Architecture, Design and Integration Technologies described in this chapter we expect huge potential for synergies with R&D&I Topics outlined in all other chapters. New and advanced applications described in Chapter 1 to 5 will give rise to further advances in design and integration technologies. We expect most R&D projects based on this SRA to result in innovations in applications as well as in accompanying design and integration technologies.

There is a strong link between the V&V and Test methods and tools described here and the techniques described in Chapter 8 on Safe and Secure Systems. Computing and storage nodes (Chapter 9) are essential components in most ECS systems; R&D&I topics to advance these nodes therefore strongly interact with the platform and Systems Design topics here. Connectivity and interoperability research (Chapter 7). Last, but not least, the Process, Technology and Materials Chapter 10 is of huge importance here.

The field of Physical and Functional Systems Integration draws upon key enabling technologies (KET) and integrates knowledge from a variety of disciplines. Furthermore, it bridges the gap between components and functional, complex systems. Within the framework of the ECS SRA, the field benefits from links to all other technology chapters. The development of Smart Systems will benefit from progress in nano-electronics, design methods and tool development. Smart Systems are key elements in a wide variety of activities, among others also in the Internet of Things and Services as well as for sensor-based electronic systems for Industry 4.0, Energy in buildings and micro-grids, Environment and Climate Action, Security, eHealth and wearables, transportation and food and water supplies.

# 7

# Connectivity and Interoperability

# 7.1. EXECUTIVE SUMMARY

Mobility being everywhere, connectivity and interoperability are today key enablers to support the development of innovative applications in various markets (consumer, automotive, digital manufacturing, network infrastructure …). The ubiquitous availability of smart phones and 4G wireless networks is of course a good example (one can have in mind the associated booming development of apps), but the availability of new innovative connectivity technologies (IoT, 5G, car to car, …) enables a wide range of enhanced and new business opportunities for the European industry to be envisioned (smart cities, autonomous driving, …).

To support this vision, smart, secure and user-friendly connectivity solutions are necessary in order to ensure citizen privacy and gain broad acceptance from consumer. Clearly, the main objective of this chapter is to enable the seamless integration of various technologies (hardware and software) in order to develop complex connected systems in an effective manner. To do so, semantic interoperability and heterogeneous integration are key game changers.

# 7.2. RELEVANCE

### 7.2.1. Competitive value

While connectivity is needed today in almost all application fields (consumer market, automotive, health, wellbeing, smart cities …), we can note that European players are stronger in terms of Internet of Things (IoT) and secured solutions (with hardware leaders such as NXP or STMicroelectronics, solution providers such as GEMALTO and service provider such as SIGFOX). On the other hand, mass-market oriented businesses such as the smart phone is today dominated by US (Qualcomm, Avago, etc…) or Asian players (Huawei, Murata, etc…) with European ones being focused on system integration, digitalisation, analytics, sensors/ actuators (Siemens, ABB, Ericsson, Danfoss, Thales, Philips, BMW, Daimler, Bosch, STMicroelectronics, etc…).

Consequently, in order to strengthen Europe's position and enable European industry to capture new business opportunities associated with the connected world we live in, it is vital to support Europe technological leadership in connectivity supporting digitalisation based on IoT and System of Systems (SoS) technologies (for example by being at the forefront of new standard development as for the current 5G initiative). Moreover, in order to bring added value and differentiation in comparison with US and Asian competitors, European industry has to secure the access to any innovative hardware or software technology enabling the development of complex connected systems (which will help to capture more value by targeting higher end or more innovative applications).

To illustrate the competitive value for Europe of connectivity and interoperability topics, we can quickly review a few challenges associated with the connectivity requirement in a market where European industry has been historically strong or has to secure its position for strategic reasons:

- **Automotive:** The main driver is here the deployment of Advanced Driver Assistance Systems (ADAS), which is a key opportunity for European semiconductor companies. While the ADAS market today generates moderate revenue (less than USD 2 billion in 2015), compared with USD 29 billion for automotive electronic systems, this market is expected to grow rapidly. Industry experts expect to see an annual increase of more than 10 per cent from 2015 to 2020. This could make ADAS one of the highest growth rates in the automotive sector and related industries. Moreover, it is likely that regulators will require vehicles to be equipped with certain ADAS applications over the next five years. For example, key automotive markets like Europe, Japan and North America are in the process of introducing legislation to aid the prevention of fatalities of vulnerable road users, with an emphasis on the use of vision systems, a trend that is driving the quick adoption of camera-based ADAS by car makers around the world. This trend will be reinforced by the development of autonomous driving technology (such as Tesla Autopilot technology). Connectivity technology is consequently a major challenge since inter-sensor communication requires high bandwidth, so innovative solutions will be necessary to prevent network overloads. A broadband network with hierarchical architectures will be needed to communicate in a reliable way with all the function domains of the car.

- **Digital Production:** Production of goods and services already involves a multitude of data obtained from various sources. Digitalisation demands a drastic increase of data sources ranging from sensors and simulators to models. Such data will be used for control, analytics, prediction, business logics etc. having receivers like actuators, decision makers, sales and customers. Obviously this will involve a huge number of devices with software systems that are required to interoperable and possible to integrate for desired combined functionality. This demands seamless and autonomous interoperability between the devices and systems involved, regardless of the chosen technology.

- Europe is the leading world region for production and manufacturing automation thanks to companies like Siemens, ABB, Schneider, Metso/Valmet, etc. Industrial control and manufacturing automation is projected to reach USD 153.30 billion by 2022, at a CAGR of 4.88% [Markets and Markets, 2016]. To this the MES and ERP markets should be added. The cloud ERP market size is estimated to grow from USD 18.52 billion in 2016 to USD 29.84 billion by 2021, at an estimated Compound Annual Growth Rate (CAGR) of 10.0% [Markets and Markets, 2016]. The Manufacturing Execution System (MES) market was valued at USD 7.63 billion in 2015 and is expected to reach USD 18.22 billion by 2022, at a CAGR of 13.6% [Market and Market 2016]. The factors that are driving the growth of these markets include low cost of deployment, increasing use of industrial automation, adoption of MES and ERP owing to growing benefits, and the importance of regulatory compliance. To this should be added the expected impact of Industry4.0 and its use of IoT and SoS technologies, most likely to occur after 2022. Companies like Cisco and Ericsson forecast that a very high number of IoT devices will be used in the development of digital production. It's clear that software and electronics hardware contributes to this market to a very large extent.

- **Data Centre:** In order to make 5G a reality, telecommunication operators and big internet companies such as Google, Apple, Facebook or Amazon will have to increase the size of their data centres in order to cope with user demand for more data. Due to the complexity of the mega data centres deployed today this create a huge interconnect challenge. For a data centre such as the Google ones currently deployed, people generally have in mind an optical fibre interconnect solution. Optical fibre is a key technology for high speed links (> 25 Gb/s) but in fact there is a lot of copper cable deployed in data centres these days. "We see copper as maybe not the principal but one of the main interconnects used inside the rack at 100GbE," says Mellanox senior director for marketing, Arlon Martin, who believes an 8m length could be enough to satisfy 98 percent of in-rack cabling requirements. The drawback of this approach is that each copper cable consumes more than 1 W. Having in mind that the biggest data centre currently deployed can has more than 400,000 servers, this means that big data centre may consume 400 kW/h just to connect the servers to each other. To put this number in perspective, the average power consumption of a house in Europe is 6 kW/h. Consequently, if we can develop an innovative cost-effective, power-efficient (~100 mW) and high-speed (at least 10 Gb/s) cable technology able to work up to 10 m, we will also open new business opportunities from the telecommunication infrastructure side by enabling greener services.

### 7.2.2. Societal benefits

Beyond their economic impact, connectivity and interoperability are also expected to play a key role in many societal challenges to be faced in next decades. As it will be illustrated below, the societal benefits associated with connectivity are then key assets in improving the living standard of European citizens and maintaining Europe leadership.

- **Education improvement:** The internet plays a pivotal role in extending access to educational resources and in accelerating knowledge sharing. The internet makes learning resources available to students and teachers; it allows learning and consultation online and can be a valuable complement to the classroom experience. The potential exists for students anywhere to have access to online educational eBooks, tests and courses. These resources can substitute traditional textbooks which may not be readily available or are prohibitively expensive in developing countries. Connectivity has then the potential to significantly extend the impact of the internet in increasing the quality of education (reliable access, improved student experience …) and ultimately academic proficiency, attainment levels and employment outcomes. Improved educational outcomes can have a strong positive impact on individuals' income and health as well as on the economy. Importantly, in addition to these effects, technology can expand opportunities for students to engage in collaborative learning, with great potential for learning and circulating ideas.

- **Healthcare improvement:** Connectivity has the potential to improve medical behaviour for patients and healthcare professionals as well as the delivery of improved medical service. Connected devices can transform the way healthcare professionals operate by allowing remote diagnosis and more efficient ways of treatment. For example, patient information could be sent to hospitals via mobile and internet applications, thus saving travel time and service costs and substantially improving access to healthcare, especially for rural populations. Connectivity and associated devices and services could complement and improve existing medical facilities. From the citizen side, monitoring of illnesses can also be enhanced by mobile and internet applications designed to remind patients of their treatments and control the distribution of medicinal stocks.

- **Energy and environment:** One of the projected impacts of digitalisation is better abilities to optimise energy utilisation and minimise environmental footprints. Connectivity and Interoperability are here critical parts of ICT infrastructure that is essential to allow such optimisation and minimisation.

Energy efficiency market is estimated to be USD 221 bn in 2015, which is 14% of the global energy supply investments [IEA 2016B]divided between buildings (53%) transport (29%) and industry (18%) [IEA, 2016A].

- **Improve public services, social cohesion and digital inclusion:** ICT technologies have long been recognised for promoting and facilitating social inclusion, i.e. the participation of individuals and groups in society's political, economic and societal processes. One way in which ICT technologies expand inclusion is through effective public services that rely on ICT infrastructure and through digital inclusion, i.e. the ability of people to use technology. These three aspects are deeply intertwined, and they span dimensions as diverse as disaster relief, food security and the environment as well as citizenship, community cohesion, self-expression and equality. Public authorities can enhance disaster relief efforts by promoting the spread of information online and by implementing early-warning systems. The internet also enables relief efforts through crowd-sourcing: during Typhoon Haiyan in the Philippines, victims, witnesses and aid workers used the web to generate interactive catastrophe maps through free and downloadable software, helping disseminate information and reduce the vulnerability of people affected by the disaster. Communities can also be strengthened by connectivity, thereby promoting the inclusion of marginalised groups.

Europe should recognise the importance of connectivity in complementing the delivery of healthcare, education and other social services and should promote investment in the development of innovative connectivity solution targeting this topics in order to improve the daily lives of European citizens.

# 7.3. MAJOR CHALLENGES

The connectivity and interoperability technology focus enabling the projected commercial and societal benefits are related to the OSI model layer 1,4,5 and 6.

| OSI MODEL | | | |
|---|---|---|---|
| Layer | | Protocol data unit (PDU) | Funtion |
| Host layers | 7. Application | Data | High-level APIs, including resource sharing, remote file acces |
| | 6. Presentation | | Translation of data between a networking service and an application; including character encoding, data compression and encryption/ decryption |
| | 5. Session | | Managing communication sessions, i.e. continious exchange of information in the form of multiple back-and-forth transmissions between two nodes. |
| | 4. Transport | Segment (TCP) / Datagram (UDP) | Reliable transmission of data segments between points on a network, including segmentation, acknowledgement and multiplexing. |
| Media layers | 3. Network | Packet | Structuring and managing a multi-node network, including adressing, routing and traffic control |
| | 2. Data link | Frame | Reliable transmission of data frames between two nodes connected by a physical layer |
| | 1. Physical | Bit | Transmission and reception of raw bit streams over a physical medium |

*The focus for connectivity and interoperability R&D&I are related to the OSI model layers 1,4,5 and 6*

**F.35**

## 7.3.1. Major Challenge 1: Meeting future connectivity requirements leveraging heterogeneous technologies

### 7.3.1.1. Vision

Targeting system and application, we have to consider the interconnection between sub-systems and should focus on individual component technology development according to needs identified at 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 sub-system that are integrated into a single system. The operating characteristics should also be taken in its broadest meaning including characteristics such as system level cost-of-ownership.

This is especially true from hardware side in the context of the end of Moore's law. It is the interconnection of the transistors and other components in the IC, in the package, on the printed circuit board and at the system and global network level, where the future limitations in performance, power, latency and cost reside. Overcoming these limitations will require heterogeneous integration of different materials, different devices (logic, memory, sensors, RF, analogue, etc...) and different technologies (electronics, photonics, MEMS and sensors).

#### 7.3.1.2. Scope and ambition

This major challenge involves the full leveraging of Europe's existing semiconductor manufacturing strength and especially the availability of derivative semiconductor processes (BiCMOS, Si Photonics, RF SOI, FDSOI, GaAn ...). The ambition is to develop an innovative connectivity solution (for example, investigating a new frequency band or medium to propagate the signal) and strengthen Europe leadership on 5G and IoT markets.

An innovative connectivity solution is envisioned that should drive the development in Europe of innovative packaging, MID and printed circuit technologies (by providing system requirements and then facilitating the specification of required technologies) in order to enable the development of differentiated and higher-value connectivity systems leveraging heterogeneous integration schemes.

#### 7.3.1.3. Competitive situation and market changers

While Europe has a very clear technology lead in derivative semiconductor technology, we can note that most of the end users developing the final connectivity system are based either in Asia or in the US. Europe may be strong in RF SOI (STMicroelectronics, SOITEC, etc...) and BiCMOS (Infineon NXP, STMicroelectronics, etc...) but the module makers capturing the main part of the value associated with the 4G Front End Module are based in the US (Avago, Qorvo, Skyworks, etc...) or in Asia (Murata, Huawei, etc...).

In order to enable the emergence of a European champion delivering a connectivity module/solution, the key game changer will comprise enabling the necessary ecosystem required to develop an innovative connectivity system leveraging both heterogeneous integration schemes and derivative semiconductor processes already available in Europe.

**High priority R&D&I areas**

The high priority technical and scientific challenges are:

- 5G technologies from IoT to backend (HW, control, envelope tracking, system integration ...)
- Evaluation of a new frequency band (5G, > 100 GHz ...)
- Evaluation of new medium (RF/mmW signal propagation over plastic, single mode optical waveguide using laminated polymer platform ...)
- Enabling a European ecosystem able to support heterogeneous integration (multi die System in Package, advanced assembly capability, advanced substrate manufacturing ...)

#### 7.3.1.4. Expected achievements

- Innovative connectivity technology working in new frequency band and achieved using Europe derivative technologies (RF SOI, BiCMOS, GaN ...)
- Innovative connectivity solution using new medium
- Highly integrated connectivity module/system heterogeneously integrating Europe derivative technologies

## 7.3.2. Major Challenge 2: Enabling nearly lossless interoperability across protocols, encodings and semantics

### 7.3.2.1. Vision

To fully leverage this heterogeneous integration at hardware level, software interoperability is the parallel challenge in order to provide connectivity that will allow for System of Systems (SoS) integration connectivity from IoT to backend systems, enabling usage of the available data for application in digital production, automotive, data centres, healthcare, energy usage optimisation and minimisation of environmental impact. Thus an alternative expression of the major challenge is: Enabling SoS integration through nearly lossless interoperability across protocols, encodings and semantics. To do so, dedicated software tools, reference architecture and standardisation are key to supporting SoS integration, thus enabling the provision of a scalable and evolvable System of Systems.

### 7.3.2.3. Scope and ambition

This grand challenge scope involves interoperability of service or agent protocols including encoding and semantics wherebysemantics interoperability is a specific focus, leading to architectures, technologies and engineering tools supporting integration of SoS for highlighted application areas at design time and runtime.

The ambition is a technology that enables nearly lossless interoperability across protocols, encodings and semantics while providing technology and engineering support foundations for low-cost integration of very complex and evolvable SoS.

### 7.3.2.4. Competitive situation and market changers

Europe has a very clear technology lead in automation technology in general. The next generation of automation technology is now being pushed by Industri4.0 initiatives backed by EC and individual countries. In the automotive sector the autonomous car vision is the driver. Here Europe has a strong competitive position. Robust and dependable connectivity and interoperability are fundamental to market success here. In healthcare the ageing population is the driver. Europe's position is good but fragmented. To maintain and strengthen the European lead, advancements in interoperability, integrability and associated engineering tools is necessary. The game changers are:

- IoT interoperability, SoS integration technology and engineering tools reducing connectivity developments cost by 80%
- Open interoperability and integration frameworks and platforms.
- Ease of integration of new and secure IoT hardware and radio solutions like 5G.

### 7.3.2.5. High priority R&D&I areas

The high priority technical and scientific challenges in both design time and runtime are:

- Semantics interoperability
- Autonomous translation of protocols, encodings and semantics.
- Enabling of IoT and SoS evolvability over time and technology generations
- Integration with security aspects of Major Challenge 3, see below.

### 7.3.2.6. Expected achievements

- Reference architectures with implementations enabling evolvability and autonomous behaviour
- Autonomous translation across protocol, encodings and semantics
- Architecture implementations with performance that meets critical performance requirements in focused application areas

## 7.3.3. Major Challenge 3: Ensuring secure connectivity and interoperability

### 7.3.3.1. Vision

Data protection has to be ensured at an appropriate level for each user and functionality regardless of technology. Thus an alternative formulation of the major challenge is: Ensuring security interoperability across any connectivity. This foresees the usage of different technologies in connectivity networks. Technology differences impose security incompatibilities leading to increased engineering costs. Therefore, the development of an innovative hardware and software security solution is of fundamental importance. Such a solution will have to be linked with the challenges 1 and 2 in order to ease SoS engineering, deployment and operation in a seamless manner.

### 7.3.3.2. Scope and ambition

The scope is to enable connectivity chains and networks that go from hardware over software to system of systems where appropriate security can be engineered and enabled in both design time and runtime. The ambition is that such connectivity chains and networks can be engineered at 20% of current costs.

### 7.3.3.3. Competitive situation and market changers

It's clear that the US is the security leader when it comes to computer connectivity. The big potential game changer is here 5G where Europe has a leading role.

To advance the European position, flexible security integration with 5G connectivity to European strongholds like automation and automotive seems of vital importance.

The game changers are:

- Flexible and adaptable IoT and SoS connectivity security technology and engineering tools reducing security deployment, operations and maintenance cost by 40%
- Open security and integration frameworks and platforms.

### 7.3.3.4. High priority R&D&I areas

The high priority technical and scientific challenges are:

- Security semantics
- Autonomous security translation in connectivity chains and networks
- Enabling of IoT and SoS security evolvability over time and technology generations

### 7.3.3.5. Expected achievements

- Open implementation of reference architectures supporting security evolvability and autonomous behaviour
- Tools and technology supporting autonomous security translation in connectivity chains and networks
- Architecture reference implementations with performance that meets critical performance requirements in focused application areas

7.4.
# MAKE IT HAPPEN

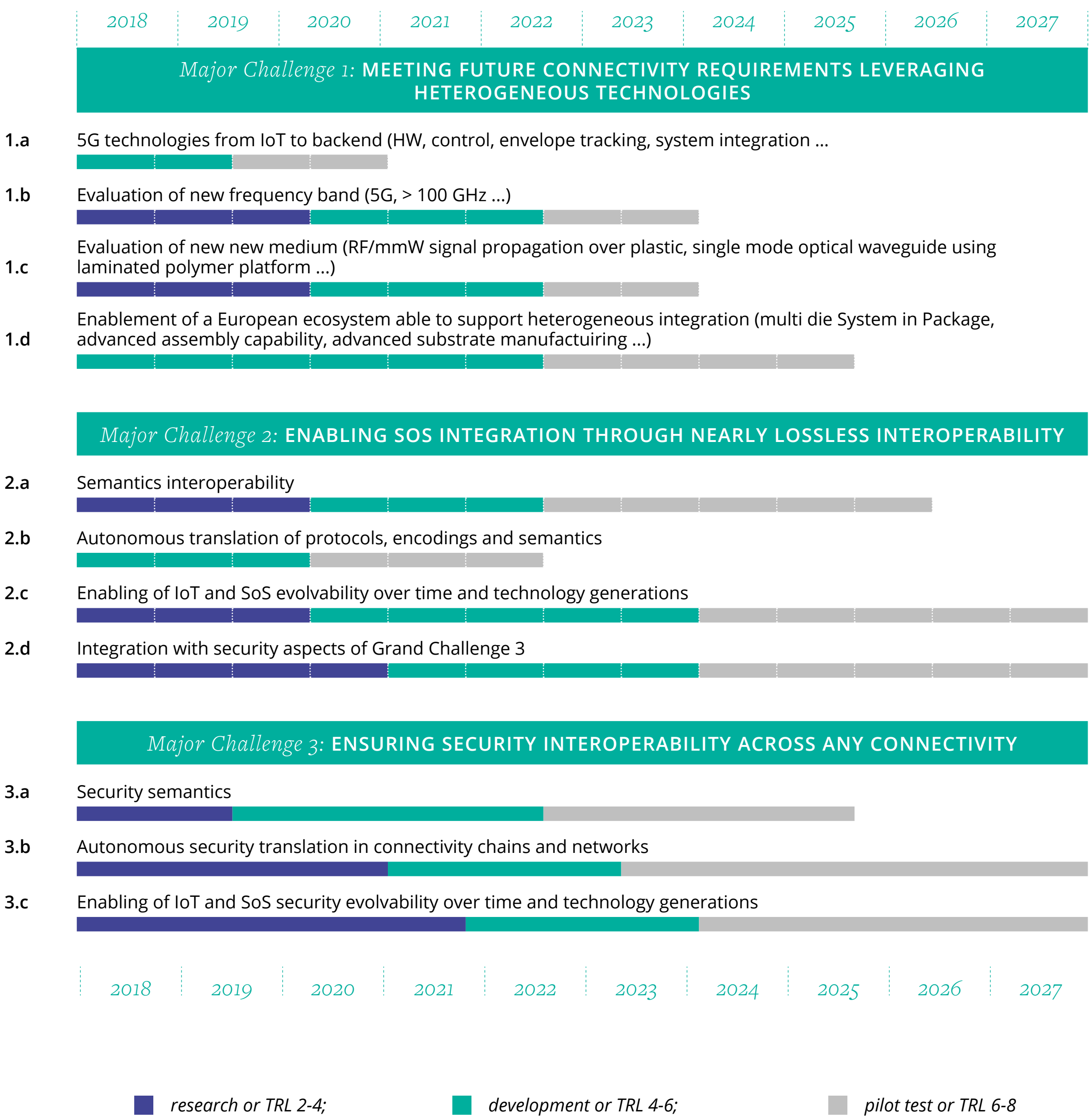
To provide the connectivity and interoperability requested by applications a transition from always best connected to always best integrated is necessary. For the purpose interoperability at all layers in the ISO a communication stack is necessary. For example at the application level machine understanding of data semantics is vital to reduce engineering costs. At the physical level, hardware supported payload transfer from 5G to Ethernet and vice versa, for example, will enhance security better than software supported transfer.

This requires substantial standardisation efforts both from an international and technology HW/SW perspective.

The availability of engineers having interoperability and dynamic integration competencies is currently limited mainly due to limited academic research and education on SoS problems, so a joint industrial and academic effort is vital to rapidly increase the availability of such competencies.

# 7.5. TIMEFRAMES

The anticipated time line for finding solutions and mature implementations to the stated major challenges is depicted in the table below.




**F.36** *Connectivity and Interoperability timeline*

# 7.6. SYNERGIES WITH OTHER THEMES

Interoperability and connectivity provides foundation properties for all targeted application areas, Ch1-Ch5. There is also a close relationship with Ch 4 where interoperability and connectivity also provide a foundation for the CPS systems and engineering aspects of Ch6. The specific problem of security interoperability and coexistence and translation between different security technologies is an area for strong synergies with Ch8.

# 8

# Safety, Security and Reliability

# 8.1.
# EXECUTIVE SUMMARY

Safety, security and reliability are fundamental components of any innovation in the digital economy. Novel products and services such as personal healthcare monitoring, connected cars or smart homes will bring strong benefits to our society only if users are assured that they can depend on and trust them, especially for artificial intelligence (AI) based systems.

Safety and security, as well as dependability engineering, require the consistent merging of different engineering disciplines, leading to heterogeneous and possibly contradictory requirements. Dependability in its full sense includes system properties like availability, resilience, survivability, adaptability, maintainability and so forth. This chapter introduces and describes four Major Challenges that have been identified for the European Research and Development community over the next five years in the area of "Dependability and Trustability". It covers all aspects to build trustable technology, either by measures against technical faults (safety, reliability) or with protection against malicious or unintended human intervention (security) and the related use of personal data (privacy).

The Major Challenges in Safety, Security and Reliability are:

1. Safety, security and privacy by design
2. Reliability and Functional Safety
3. Secure, safe and trustable connectivity and infrastructure
4. Privacy, data protection and human interaction.

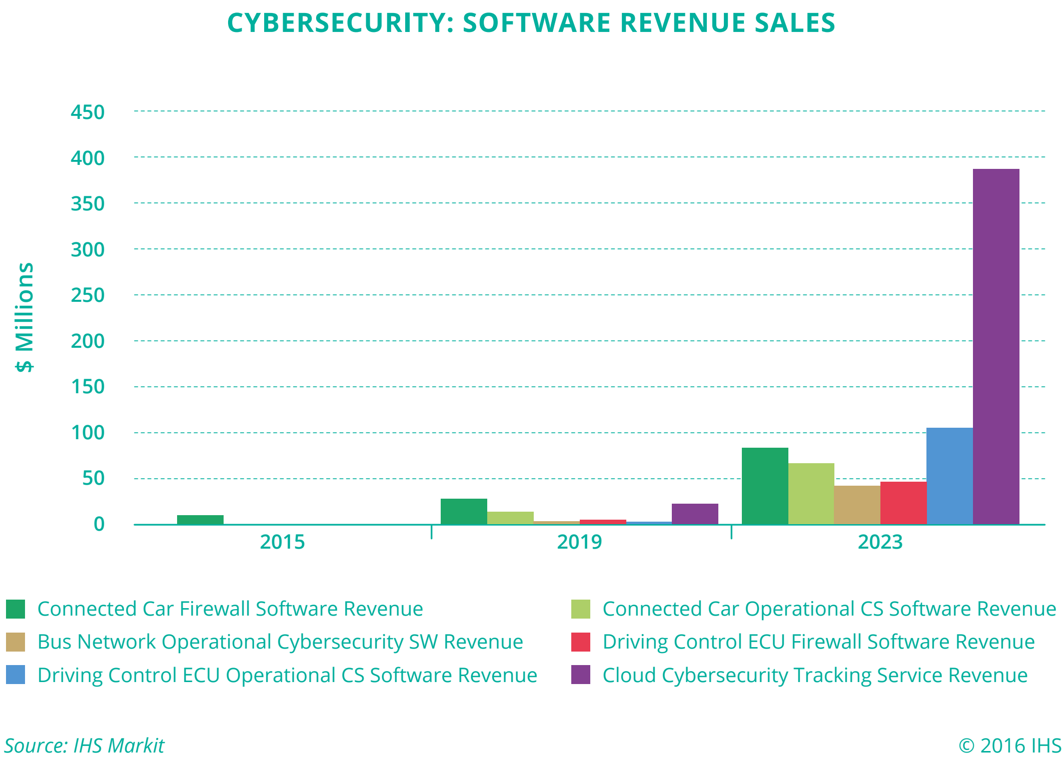
# 8.2.
# RELEVANCE

## 8.2.1. Competitive value

Since safety, reliability, privacy and security are mandatory items to be considered in many sectors where Europe has leadership or a significant position, European industrial competitiveness will be driven by a growth of safety & security revenues in the European market (500 million of habitants) but also a re-enforcement of European companies' position and market share in this domain.

On the other hand, European actors involved in the domain will have to transform innovations to market products and services through standardisation, assurance and certification. Depending on the level of maturity of the different sectors, this will enable an increase in the penetration of safety and security solutions within the applications and supporting infrastructures.

According to Gartner [1] worldwide spending on information security products and services will reach USD 86.4 billion in 2017, an increase of 7 per cent over 2016, with spending expected to grow to USD 93 billion in 2018. A good example is automotive cybersecurity. According to IHS [2] this market will reach USD 753 million in 2023 with variable growth according to the segment (see Automotive Cybersecurity and Connected cars , IHS Automotive , September 2016).




**F.37** *Cyber Security Software Revenue Sales*

## 8.2.2. Societal benefits

Dependability and Trustability are fundamental components of any innovation in the digital economy. It is undeniable that novel products and services like personal healthcare monitoring, connected cars or smart homes bring strong benefits for the society, provided that dependability and trustability are taken care of. If not, there is a significant risk that these innovations will not be accepted by society due to a lack of consumer confidence.

### A. Benefits for individuals

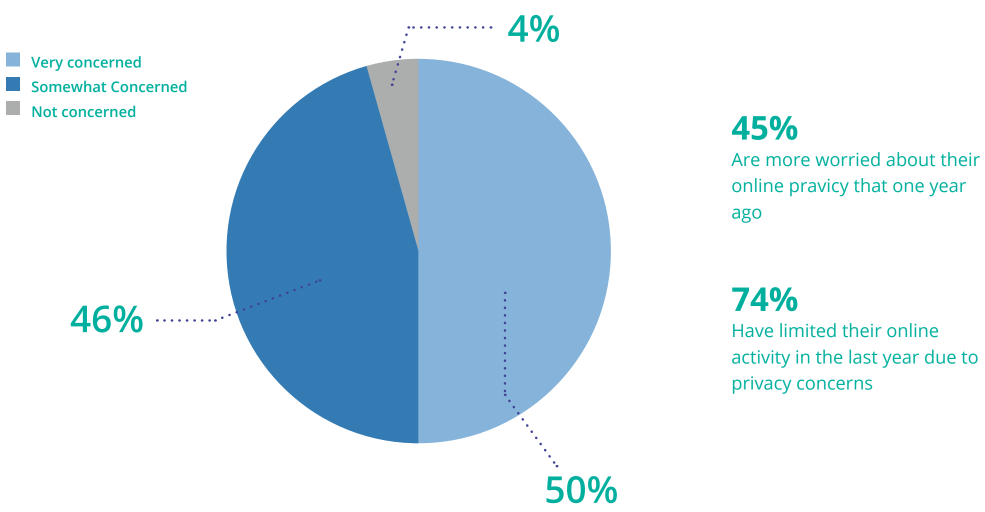
Individuals tend to become more and more sceptical towards novel digital innovations due to unprecedented worldwide cyber security attacks like that by the Wannacry ransomware cryptoworm in May 2017 that encrypted 400,000 computers globally and demanded ransom payments in the Bitcoin cryptocurrency, or Safety issues such as the Toyota throttle bug causing the death of one occupant, and having cost more than

USD 1 billion. In addition, individual trust is also massively impacted by privacy concerns when people no longer know who accesses their private data. According to a KPMG survey in 2016 [3], 55% of consumers surveyed globally said they had decided against buying something online due to privacy concerns. Figure 38 also shows these increasing concerns for online activities. Safety aspects have a major impact in the case of public knowledge of accidents caused by technical failure. Moreover, safety challenges are getting quite tough because of complex functionalities (autonomous car, avionics for dense traffic) and because of the security vulnerabilities of interconnected systems.

Hence, if European industry manages to create dependable, trustworthy and transparent products and services, strong benefits will become apparent in seeing individuals in regaining this lost trust.

**CONSUMER DATA PRIVACY CONCERNS RISING RAPIDLY**

How concerned are you about data privacy & how companies use customer data?




*Consumer data privacy concerns for online activities [4]*

**F.38**

### B. Benefits for organisations and businesses

Businesses will benefit from proactively tackling security and privacy issues in one of several ways: protecting the brand name, offering a competitive advantage from integrating privacy and security features into products and services, and creating new products and services designed to protect personal data. The most important characteristics for businesses in the future will be the aspect that they are perceived as trusted companies. Only as trusted organisations can they maintain a long-term relationship with their customers. New “trusted products” represent a great opportunity for European companies, for example with the development of a “Trusted IoT” label 0. Companies also benefit from safety assessment and certification.

# 8.3. INTRODUCTION TO MAJOR CHALLENGES

## 8.3.1. Major Challenge 1: Ensuring safety, security and privacy by design

Breaches of sensitive data, mass disinformation campaigns, cyber espionage and attacks on critical infrastructures – these are no longer futuristic threats, but real events that affect individuals, businesses and governments on a daily basis. Yet they remain largely unprosecuted. Increasingly non-conventional threats, using the digital space with complex cyber attacks, seek to undermine core European values and cohesion. Recent coordinated cyber attacks across the globe, for which attribution has proved challenging, have demonstrated the vulnerabilities of our societies and institutions.

In this rapidly evolving context, the European Union and its Member States need to anticipate and plan for hitherto unimaginable scenarios in which they would be put under severe attack. Given the non-territorial nature of cyber threats and their increasingly disruptive effect, it is urgent to build up cyber capabilities at all levels – from basic cyber hygiene to advanced cyber intelligence, cyber defence and cyber resilience – in each Member State, and scale up European cooperation.

### 8.3.1.1. Vision

Although the shift towards a digital world offers huge opportunities, it also comes with new types of risks and threats. As all sectors of our lives increasingly depend on cyber activity, any one of them could be targeted by a cyber attack.

These attacks can be carried out at the micro level, targeting individual citizens and businesses, or – as is increasingly the case – at the macro level, with a view to destabilising governmental institutions and state security, public policies and entire economies.

Apart from the indirect transversal destabilising impact, the sheer economic value of these breaches is huge. Restricting the outlook just in the European Union, the average cost of a breach in 2017 fluctuates from USD 2.8 m to USD 4.6 m, being then a large loss factor for the targeted organisation [7].

The landscape described till now – in which we move, live, create trust and produce sensitive data, and in which our systems, hardware and software have to reside for way longer than 1.5 years, whereas for some sectors, like railway or automotive, it is ten times that – is much more wild and balkanised than we would like to think. This is the very reason why security, safety and privacy cannot be plugged into any system or software "at a later stage". Instead, they have to be rooted in the foundations, supporting and being integrated in hardware and software definition, design, development and deployment, and during operation and optimisation.

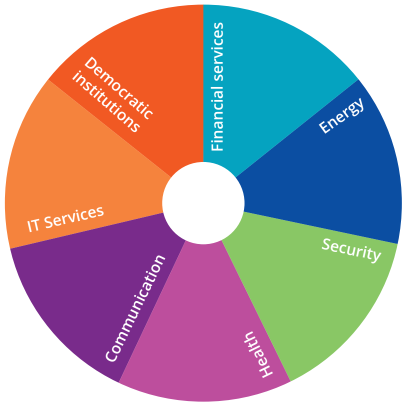
**November 2016**
*NHS hospitals*
Hospital machines were frozen to demand ransom cash; at least four NHS (National Health Service) funds were attacked

**November 2016**
*Yahoo*
Data breach of 1 billion accounts

**December 2015 & December 2016**
*Power grid in Ukraine*
230,000 people were left without power for up to 6 hours: first time that a cyber-weapon was succesfully used against a nation's power grid

**November 2016**
*Tesco Bank*
Around £2.5 million was stolen from around 9,000 customers in this hack, the largest on a UK bank

**February 2016**
*Central back of Bangladesh*
USD 81 million were lost and a further USD 850 million in transactions were prevented from being precessed




**November 2016**
*Deutsche Telekom*
900,000 (or about 4.5 percent of its 20 million fixed-line customers) suffered Internet outages over two days

**February 2016**
*FBI and Home Security*
Personal details of over 20,000 employees of the Federal Bureau of Investigation and 9,000 of the Department of Homelanf Security were accessed

**Ocotober 2016**
*Australian Red Cross*
Personal data of 550,000 blood donators stolen

**April 2016**
*Philippines' Commission on Elections (COMELEC)*
Personal information of every single voter in the Philippines - approx 55 million people - was compromised by Anonymous

**Ocotober 2016**
*Domain name provider Dyn*
A distributed denial of service attack resulted in the break-down of some of the biggest websites in the world including Twitter, The Guardian, Netflix, Reddit, Airbnb and CNN

**April 2016**
*Democratic National Committee*
Publication of 20,000 e-mails stolen from the Democratic National Committe

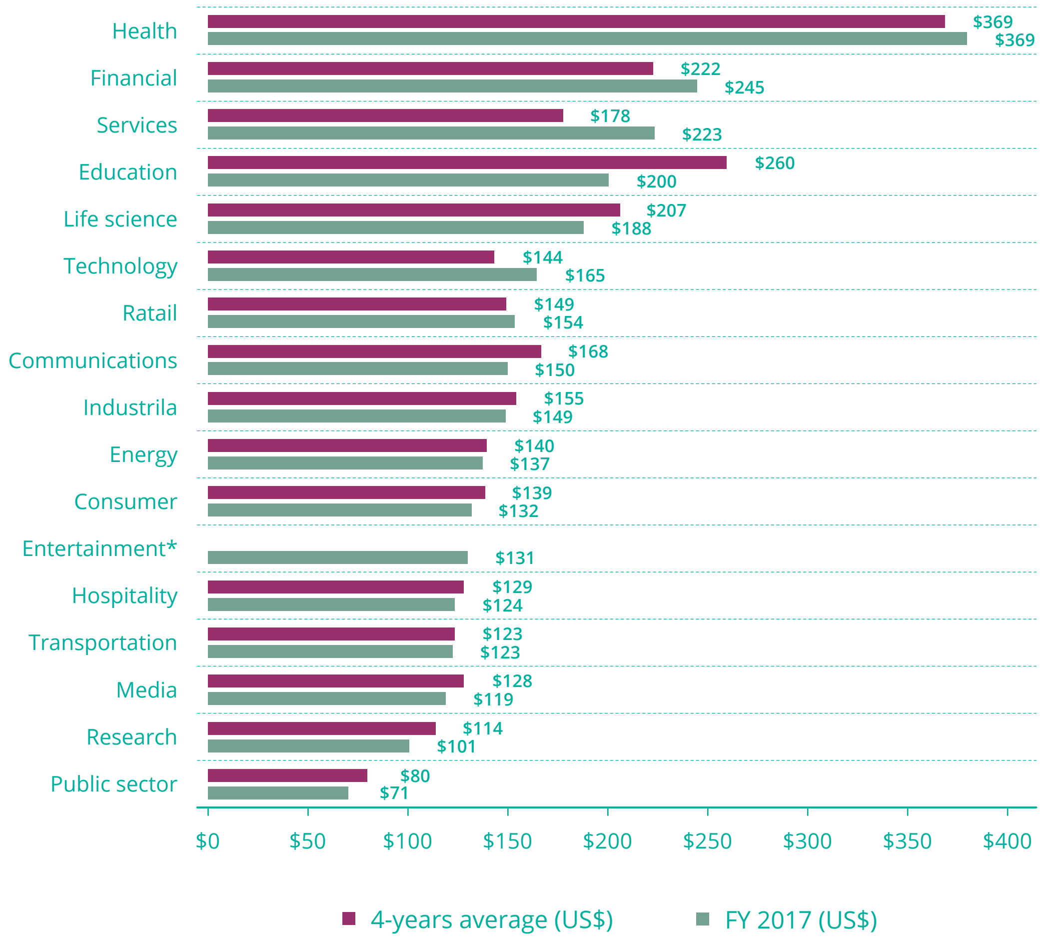
*No critical sector escapes the cyber threat. This figure features only a small selection of incidents that took place in 2016. Many more attacks occur every day all over the world.*

**F.39**

### 8.3.1.2. Scope and ambition

The scope of this Major Challenge covers dependability and trustability from design to deployment, with a further glance to the hardware and software lifecycle. It covers the enablers to be as future-proof as industrially imaginable today, so to be reliable and resistant to attack techniques that can be envisioned 5-7 years from now. It covers centralised, cloud-based and edge paradigm as well as both industrial and consumer worlds, striving to cover the short-life and extremely manifold consumer scenario and the long-life, reliability-centric industrial one.

The ambition is to facilitate the uptake worldwide of "European Technology" and infrastructure with the goal of earning an international reputation for secure, safe, dependable and trustable hardware, software and hybrid definition, design, development and deployment.




**F.40** *No critical sector escapes the cyber threat. This figure features only a small selection of incidents that took place in 2016. Many more attacks occur every day all over the world.*

### 8.3.1.3. High priority R&D&I areas

**Activity field 1: Reinforce the Design**

- Strengthened methods for risk management, specifications, architecture and development, development, integration, verification and validation
- New methods and tools for formal verification of specifications, designs and implementations (model level proofs, source code analysis, binary analysis, hardware analysis, etc…)
- New design tools for safety/security engineering
- Delivering high-assurance proofs over the whole lifecycle
- Designed to fail in a secure way – cyber threat analysis, susceptibility, assessment, drive pattern of failure
- Multi-level security assessment tools (may they be for security certifications or the security characterisations)
- Certification and standardisation of the complete lifecycle of hardware and software (by components and by relations with other components)

- Combined safety and security certification
- Support the evaluation of the systems examined within the safety/security assessment process
- Hardware/Software and hybrid track record
- Security and safety for hardware and software throughout the whole lifecycle
- Real-time safe high-performance computing
- Modelling of safety and security requirements in early design steps to get certification approval and enable incremental certification
- Design methods and tools for Safety and Security Co-Engineering (Modelling, Dependencies, Analysis)
- Architectural principles to support dynamic safety evaluation and assurance (runtime certification/validation)
- Architecture principles supporting compositional safety and security proofs

### Activity field 2: **Harden the Edge**

- On-Chip Encryption
- Integrated security, privacy, trust and data protection solutions or smart systems
- Addition of security capabilities to non-secure legacy technologies,
- Integration of hardware and software
- Safe & Secure execution platform
- Safe and Secure certifiable software infrastructures
- Power efficient security features
- Secured devices – Trusted boot, trusted execution, authentication, anti-counterfeiting mechanisms
- Resistance to eavesdropping & injection attacks
- Cyber-security to make products tamper-proof in attacks from hackers
- Tamper Proof technologies
- Segregation and isolation of functional layers of components communication architecture
- Secure real-time systems, protocols, packaging, chip architecture
- Mitigate processor performance variability
- Secure sensor data storage in a standardised way
- (Secure) HW Upgrades and SW Updates
- Multi-tenancy in embedded hardware infrastructures
- Virtualisation and hypervisoring

### Activity field 3: **Protect the Reach**

- Standards, information models and interoperability for smart systems integration
- Secured device management
- Certification of safe and secure products (certification standards, design rules, testing and inspection methods, certification scheme for third party evaluation)
- Modular certification
- Certificate management and distribution including certificate revocation lists
- Secured availability and maintainability within product lifecycle
- Quantum Computing exploitation and/or attack hardness
- Risk Management

#### 8.3.1.4. Competitive situation

Speaking of information technology, there is little excellence that is entirely born and raised in the EU, as base industrial technologies are dominated by giants like Intel, CISCO, Microsoft and the US in general. At the same time, European framework programmes are fostering basic STEM research and capabilities we need to look upon for our challenge, like the Quantum Flagship.

In the domain of engineering theory, methods, languages and tools, the European ecosystem has been a significant contributor over the past decades, both in the formal and the semi-formal design areas. Further developing these methods for effective applicability to complex systems in industry remains a challenge, **where supporting a good combination of European academics, tool vendors and industry will be instrumental**.

From an industrial point of view, the European ecosystem possesses huge potential in the research and design through the leadership in embedded systems and semiconductors. When utilising this advantage, European industry has a strong chance to increase market shares for safe, secure and privacy-preserving systems.

#### 8.3.1.5. Expected achievements

Expected achievements are secure, safe, dependable and trustable design methodologies, practices, and standards for products and infrastructure that customers can rely on.

### 8.3.2. Major Challenge 2: Ensuring reliability and functional safety

#### 8.3.2.1. Vision

The vision of the Major Challenge 2 is to provide all the means and methods needed for the new ECS solutions to meet the reliability and functional safety targets and achieve resilience of ECS systems. This wiall even be achieved under the following conditions, which actually rather increase the risks of early and wear-out failures or software defects and worsen the severity of their consequences:

- Continuous growth in number, complexity and diversity of the functional features, of the devices and components integrated as well as of the technologies and the materials involved in each product
- Increase in reliability and safety level to be achieved by the products, which will simultaneously and more frequently be deployed to ever harsher environments
- Reduced time-to-market and cost per product due to the stronger global competition
- Higher complexity and depth of the supply chain raises the risk of hidden quality issues

### 8.3.2.2.. Scope and ambition

When creating new functionalities and/or increasing the performance of ECS, the concerns of reliability and functional safety must be accounted for right from the start of the development. This avoids wrong choices, which otherwise may lead to costly and time-consuming repetitions of several development steps or even major parts of the development. In the worst case, unreliable products could enter the market with dramatic consequences for customers and suppliers. The improvements in reliability and safety methodologies as well as their prompt implementation in transfer into industrial practice by R&D&I actions strictly aim at enabling the new European ECS products to enter the world market fast, and to gain market shares rapidly, and to keep leadership positions sustainably in order to secure jobs and wealth in Europe:

- Determination of the 'Physics of Failure' **(PoF)** for all key failure modes and interactions
- Development of fast and comprehensive technology / product **qualification** schemes
- Creation of commonly accepted PoF based design for reliability, testing, manufacturing, … **(DfX)** methods based on calibrated models and validated numerical simulations and/or formal approaches
- Strategies for field data collection, prognostic health management **(PHM)** and autonomic development of ECS

### 8.3.2.3. High priority R&D&I areas

#### Activity field 1: **Experimental techniques for PoF assessment, analytics, and testing**

- Physical failure analysis techniques
- Realistic material and interface characterisation depending on actual dimensions, fabrication process conditions, ageing effects etc. covering all critical structures
- Tamper-resistant design, manufacturing & packaging of integrated circuits
- Comprehensive understanding of failure mechanisms, lifetime prediction models
- Integrated mission profile sensors in field products avoiding security or privacy threats
- Wafer fab in-line and off-line tests for electronics, sensors, and actuators, and complex hardware (e.g., multicore, GPU) also covering interaction effects such as, heterogeneous 3D integration, packaging approaches for advanced nodes technologies
- Accelerated testing methods (e.g., high temperature, high power application) based on mission profiles and failure data (from field use and from tests)
- Multi-mode loading based on mission profile

#### Activity field 2: **Pro-active DfX strategies based on virtual techniques**

- Virtual testing – design of very harsh tests for component (and system) characterisation
- Mathematical reliability models also accounting for the interdependencies between the hierarchy levels: device – component – system
- Mathematical modelling of competing and/or super-imposed failure modes
- Failure prevention and avoidance strategies based on a hierarchical reliability approaches
- Virtual prototyping – DfX – building blocks
- Standardisation of the simulation driven DfX
- Automation of reliability assessment based on electronic design input
- Coordination action: Providing room for companies and research institutes to exchange expertise on reliability issues for advanced technologies
- European portal for DfR service provided by institutes and SMEs (provides access to DfR service at reduced cost - similar to 'Europractice' for wafer processing service)

### Activity field 3: **Functional safety – Prognostic Health Management (PHM)**

- Self-diagnostic tools and robust control algorithms, validated by physical fault-injection techniques (e.g., by using end-of-life components)
- Hierarchical and scalable health management architectures, integrating diagnostic and prognostic capabilities from components to complete systems
- Monitoring test structures and/or monitor procedures on component and module level for monitoring temperatures, operating modes, parameter drifts, interconnect degradation etc.
- Identification of early warning failure indicators and development of methods for predicting the remaining useful life of the concrete system in its use conditions
- Functional safety aspects for autonomous systems including self-diagnostic and self-repair capabilities
- Development of schemes and tools using machine learning technique and AI for PHM
- Big sensor data management (data fusion, find correlations, secure communication)
- Safety certification on key domains like automotive, railway, industrial machinery, and avionics

### Activity field 4: **Dynamic adaptation and configuration, self-repair capabilities, resilience of complex systems**

- Self-diagnostic architecture principles and robust control algorithms that ensure adaptability and survivability in the presence of security attacks, random faults, unpredictable events, uncertain information, and so-called sensor false positives.
- Architectures, which support distribution, modularity, and fault containment units in order to isolate faults.
- Support for dependable dynamic configuration and adaptation/maintenance: as to cope with components to appear and to disappear, as ECS devices to connect/disconnect, and communication links are to be established / released depending on the actual availability of network connectivity; this includes e.g. patching, to adapt to security countermeasures.
- Concepts for runtime or dynamic certification/qualification, like runtime or dynamic safety contracts, to ensure continuing trust in dynamic adaptive systems in changing environments.
- Concepts for SoS integration including the issue of legacy system integration.
- Concepts and architecture principles for trustable integration and verification & validation of intelligent functions in systems / products: dedicated uncertainty management models and mechanisms (monitoring and issue detection) for automated or human-in-the loop online risk management. This includes machine-interpretation of situations (situational awareness) and machine-learning, for handling SotiF (Safety of the intended Functionality) and fail-operational issues, decision taking, prediction and planning.

#### 8.3.2.4. Competitive situation

The current reliability and safety assessment practice shows the following shortcomings:

- **PoF & Qualification**: Predefined qualification plans are applied based on inherited standards often without adaption to the specific new PoF situation.
- **DfX**: While virtual schemes based on numerical simulation are widely used for functional design, they lack a systematic approach when used for reliability assessments.
- **Lifetime prediction**: System-level lifetime predictions are still based on MIL standards (FIDES, Telcordia etc.) with a constant failure rate statistics.
- **PHM**: Rarely any solutions on component or system level are available except for high-end products (e.g., in avionics and energy infrastructure). Search for early warning failure indicators is still at basic research stage.

- **Dynamic adaptation**: Highly dynamic architectures are pushed by data centre providers to provide resilience and adaptability such as RackScale architecture, but these are not designed with safety in mind.

Intense research in the U.S and Asia tackles these shortcomings. Local conferences disseminate the results. Europe contributes details but does not set the standards.

#### 8.3.2.5. Expected achievements

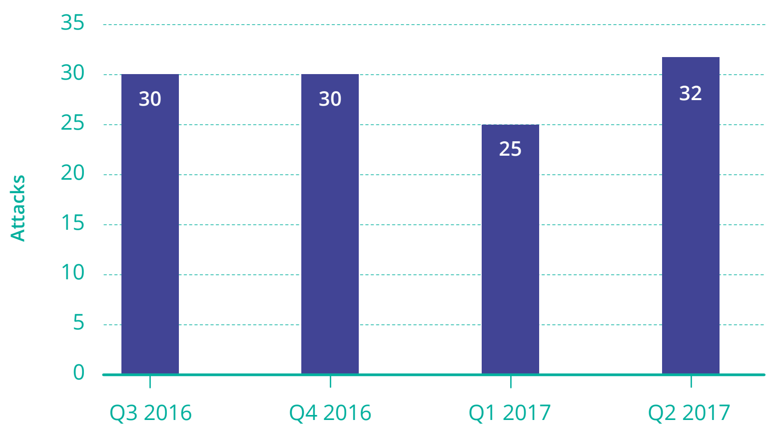
Public authorities and customers will accept innovative products only with all reliability and safety requirements fully met besides all the new functional features offered. Hence, this transversal topic is most essential for paving the way to the market for the new ECS products. Moreover, reliability and safety are concerns with great influence on customer satisfaction and trust. They enable a positive attitude of easy acceptance to be generated helping to unleash the great potential of ECS technologies for creating products that benefit public health and ecology, and create economic growth at the same time.

### 8.3.3. Major Challenge 3: Ensuring secure, safe and trustable connectivity and infrastructure

#### 8.3.3.1. Vision

More and more Internet-connected devices find their way into homes and businesses. According to Gartner, there will be 20 billion Internet-connected devices by 2020. However, insecure IoT devices pose an increasing risk to both consumers and the basic functionality of the Internet. Insecure devices serve as building blocks for botnets, which in turn provide attackers access to compromised devices, perform DDoS attacks, send spam as well as steal personal and sensitive data.

AVERAGE NUMBER OF DDOS ATTACKS PER TARGET, Q3 2016-Q2 2017




Top target organization DDoS attack count Q2 2017: **558**

*Sustained attack campaigns are constantly hitting companies* **F.41**

The sheer number and volume of attacks rendered possible by the IoT explosion makes very clear the paramount importance of having a sound, secure and trustable infrastructure. Globally, we assisted in assessing the capabilities of the three largest attacks in history to literally bring down the internet. Security personnel are concerned the use of DDoS attacks could cause widescale interruptions to our critical infrastructure, including public health and safety services. These high number of sources are most probably driven by attacks from Mirai botnets. Mirai is a malware that turns networked devices into remotely controlled "bots" that can be used as part of a botnet in large-scale network attacks. It primarily targets online consumer devices such as IP cameras and home routers [1].

Without a significant change in how the IoT industry approaches security, the explosion of IoT devices increases the risk to consumers and the whole industry. Therefore, industry must work to develop and adopt the necessary standards to ensure connected devices with sufficient incorporated security. This required change is addressed by the vision of secure and trustable connected devices that are robust, use broadly adopted security standards and have strong certification testing and enforcement mechanisms. Involved infrastructure like networks and cloud computing systems must be capable of detecting and containing potential security incidents.

### 8.3.3.2. Scope and ambition

The scope of this Major Challenge covers security and trustability for devices with communication capabilities, either via Internet connectivity or locally towards other nodes. Safety is also covered in the case of safety functions realised via connected devices. This includes IoT nodes like networked sensors and actuators, fixed and wireless networks as well as centralised (cloud computing systems) and non-centralised (fog and edge computing) processing elements. It also covers security for communication protocols on different layers.
The ambition is to facilitate the uptake of "European Technology" and infrastructure worldwide with the goal of earning an international reputation for secure, safe and trustable networking elements, in particular for industrial applications.

### 8.3.3.3. High priority R&D&I areas

#### Activity field 1: **Secure IoT devices**

- Processes for adding new devices/capabilities to the network ("onboarding")
- Strong security with immutable, attestable and unique device identifiers
- Onboarding "weak" AI at the edge
- Authentication, Authorisation, Revocability and Accountability
- Hardened devices with high integrity, confidentiality and availability
- Inherently trusted processor that would, by design, ensure security properties
- Lifecycle management
- Standardised, safe and secure "over the air" SW updates
- End-of-life (EOL) / End-of-Support (EOS) functionality
- Upgradable security for devices with long service life
- Secure components and secured ownership within an insecure environment
- Certification processes, testing and enforcement

#### Activity field 2: **Secure communication protocols**

- Ensuring high standards for secured communication
- Secure interoperability of protocols, components and communications
- Monitoring, detection and mitigation of security issues on communication protocols

- Quantum key distribution (aka “Quantum Cryptography”)
- Formal verification of protocols and mechanisms
- Production of verified reference implementations of standard protocols and the guidelines to securely deploy them

Activity field 3: **Secure IT infrastructure**

- Infrastructure resilience and adaptability to new threats
- Continuous secure end-to-end systems
- Secure cloud solutions
- Secure edge/fog computing
- Secure wireless and wired networks
- Low-power wide area networks
- 5G-related aspects of softwarisation, SDN and security of professional communications
- Artificial Intelligence for networks and components autonomy, network behaviour and self-adaptivity

#### 8.3.3.4. Competitive situation

When looking at IoT technology, the global market is dominated by US companies like Apple, Amazon, Microsoft or Google. These companies operate worldwide and provide cloud computing platforms and data centres in many countries close to their customers. Wireless technology on the other hand is traditionally strong in Europe, originating from the success of the GSM technology up to ongoing development for 5G systems. Europe has several renowned, internationally operating mobile network equipment suppliers. However, recently competition from Chinese companies in this field has significantly increased.
From an industrial point of view, European companies possess huge potential in the IoT market through the leadership in embedded systems and semiconductors, particularly in the automotive industry. When utilising this advantage, European industry has a strong chance to increase market shares for secure connectivity and infrastructure.

#### 8.3.3.5. Expected achievements

Expected achievements are secure, safe and trustable connected products and infrastructure that customers can rely on. This will be achieved with certified products according to a comprehensive security standard consisting of elements from the high priority R&D&I areas described above.

### 8.3.4. Major Challenge 4: Managing privacy, data protection and human interaction

#### 8.3.4.1. Vision

More and more Internet-connected devices find their way into homes and businesses. According to Gartner there will be 20 billion Internet-connected devices by 2020. As of today, the IoT already generates a vast amount of information about our activities. This data can be used to create unexpected and undesirable influence to people. For example, some rental car companies include sensors in vehicles to warn drivers if they drive too recklessly. If such kind of data is given to car insurance companies, they may deny insurance to users without transparently providing reasons to users. There are many similar examples that make people nervous about the use of big data technology.

Several measures have already been taken by the European Parliament and its national counterparts which aim to strengthen Europe’s resilience. Two of these are the EU General Data Protection Regulation (GDPR)

(Regulation (EU) 2016/679) 0) and the EU Directive on security of network and information systems (EU Directive 2016/1148) 0) as well as corresponding national laws in many EU Member States. The EU Directive 2016/1148 (better known as NIS directive) states that every operator of critical infrastructure and digital service providers must cooperate by exchanging security relevant information and are liable to maintain a certain level of security.

The acceptability of novel innovations with regard to privacy also involves strong human interaction including non-technical factors like psychological, social and occupational contexts. Therefore, people must be able to transparently see how much and to what extent data about themselves is being shared in products and services, e.g. with the vision of using a "Trusted IoT label" as identified by the European Commission.

#### 8.3.4.2. Scope and ambition

The scope of this Major Challenge is to develop methods and a framework enabling the deployment of privacy, data protection and human interaction for different markets without impacting customer acceptance. Hence, different contradictory requirements will be satisfied:

- Limited computing resources vs. appropriate security level and real-time requirements
- Consistent (interoperable) Integration in different application domains having heterogeneous technical and market constraints
- Agility for new product development and optimised time to market while integrating and validating appropriate privacy framework
- High degree of product customisation and validation of privacy attributes
- Compliance with European directives and national regulations
- Data management and ownership in multi-stakeholder (multi-sided) market

#### 8.3.4.3. High priority R&D&I areas

Activity field 1: **(Local) Technical solutions for privacy and data management**

- Security for privacy and personal data protection
- Identity, access management and authentication mechanisms
- Trusted devices based on blockchain
- Secure aware data processing and storage
- Biometric technologies

Activity field 2: **(Global) Data management for privacy and protection**

- Data privacy & data ownership (use of enormous amount of data respecting privacy concerns)
- Data Protection, data standards
- Data pedigree
- Definition of models for data governance
- Supply chain security and zero-trust supply chain
- IoT Forensic capability for insurance & investigation purposes

Activity field 3: **Human interaction**

- Evaluation and experimentation for ECS platforms directly interfacing human decisions
- Establish a consensus for societal expectations for safety margin, ethic and mobility issues
- User acceptability and usability of secure solutions
- Design of trusted systems considering non-technical factors including psychological, social and occupational contexts
- Evaluation and experimentation using extended simulation and test-bed infrastructures for an integration of Cyber-Physical Systems Platforms that directly interface with human decisions.

#### 8.3.4.4. Competitive situation

The European General Data Protection Regulation (GDPR) will have a global impact after it goes into effect on 25May 2018 because it not only affects EU companies but also any companies that do business with the EU. Hence, this stringent data privacy regulation already creates a leading role for Europe since other countries implement and follow it even for their own markets.

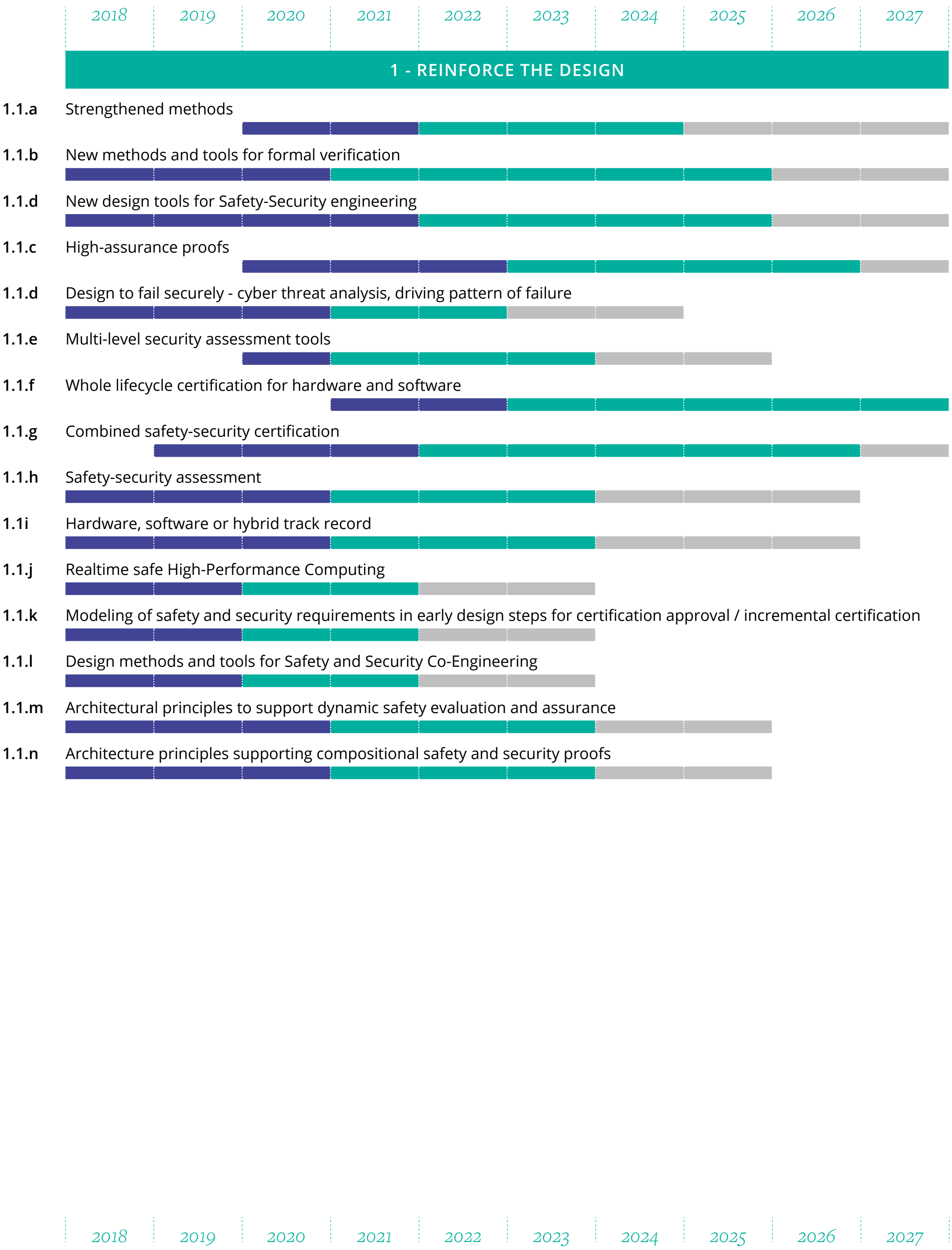
From an application point of view, European companies have a leading edge in different markets such as automotive and semiconductors or advanced production. Exactly the mix between domain-specific knowledge (subject matters) and connectivity technology will be required to create the added value in the end customer market.

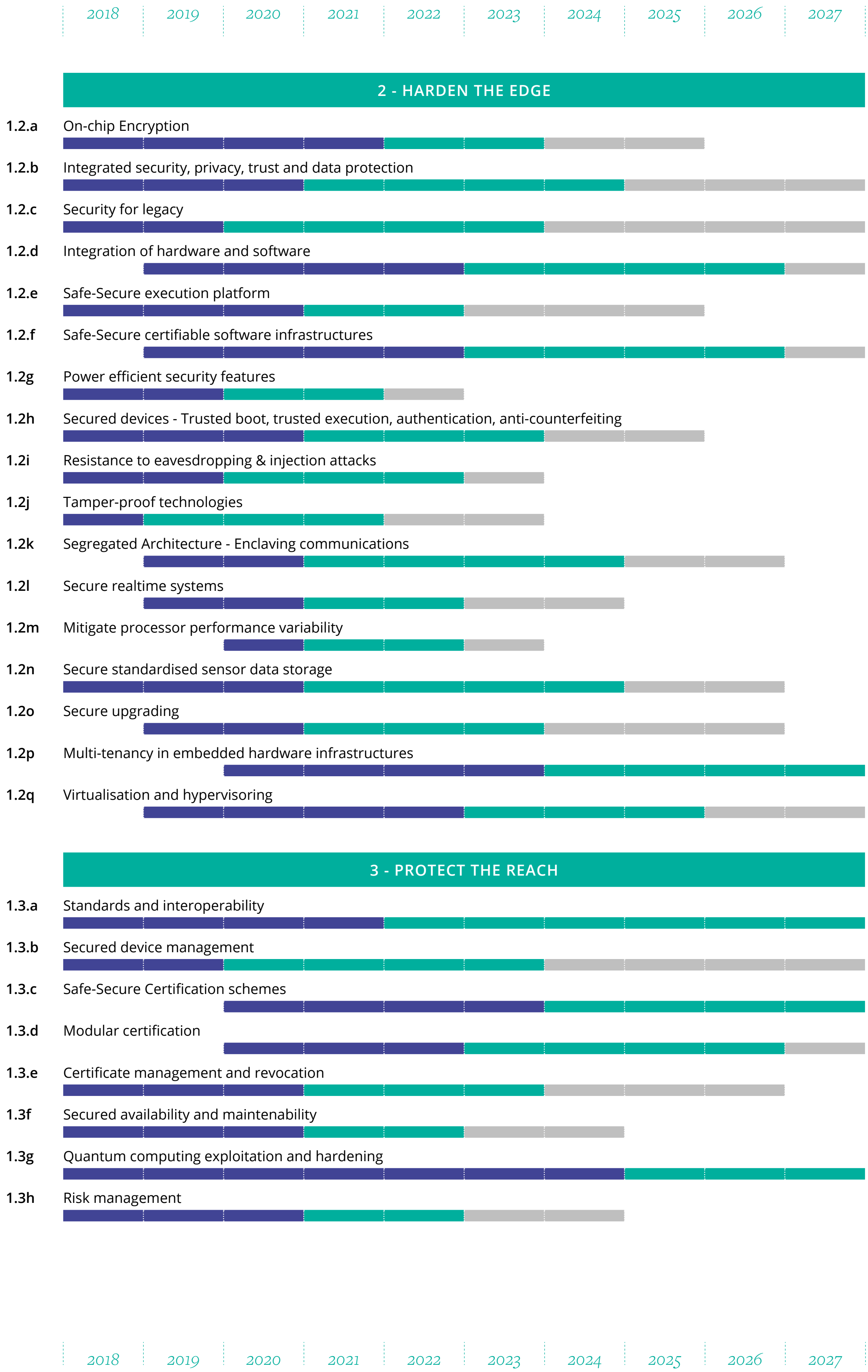
#### 8.3.4.5. Expected achievements

The expected achievements are a set of frameworks to facilitate the uptake of connected services and products for all industry sectors, while ensuring compliance with European directives and national regulation. The development of these methods is central to the success and security of our future smart environments, for customer trust and acceptance and, therefore, to maintaining European society and its position in globally competitive economic markets.

## 8.4.
# TIMEFRAMES

### *Major Challenge 1:* SAFETY, SECURITY AND PRIVACY BY DESIGN




2018 2019 2020 2021 2022 2023 2024 2025 2026 2027
2 - HARDEN THE EDGE
1.2.a On-chip Encryption
1.2.b Integrated security, privacy, trust and data protection
1.2.c Security for legacy
1.2.d Integration of hardware and software
1.2.e Safe-Secure execution platform
1.2.f Safe-Secure certifiable software infrastructures
1.2g Power efficient security features
1.2h Secured devices - Trusted boot, trusted execution, authentication, anti-counterfeiting
1.2i Resistance to eavesdropping & injection attacks
1.2j Tamper-proof technologies
1.2k Segregated Architecture - Enclaving communications
1.2l Secure realtime systems
1.2m Mitigate processor performance variability
1.2n Secure standardised sensor data storage
1.2o Secure upgrading
1.2p Multi-tenancy in embedded hardware infrastructures
1.2q Virtualisation and hypervisoring
3 - PROTECT THE REACH
1.3.a Standards and interoperability
1.3.b Secured device management
1.3.c Safe-Secure Certification schemes
1.3.d Modular certification
1.3.e Certificate management and revocation
1.3f Secured availability and maintenability
1.3g Quantum computing exploitation and hardening
1.3h Risk management
2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

## *Major Challenge 2:* RELIABILITY AND FUNCTIONAL SAFETY

### 1 - EXPERIMENTAL TECHNIQUES FOR POF ASSESSMENT, ANALYTICS, AND TESTING

**2.1.a** Physical failure analysis techniques

**2.1.b** Material and interface characterization

**2.1.c** Tamper-resistant design, manufacturing & packaging of integrated circuits

**2.1.d** Understanding of failure mechanisms, lifetime prediction models

**2.1.e** Integrated mission profile sensors in field products avoiding security or privacy threats

**2.1.f** Wafer fab in-line and off-line tests for electronics, sensors, and actuators, and complex hardware

**2.1.g** Accelerated testing methods

**2.1.h** Multi-mode loading based on mission profile

### 2 - PRO-ACTIVE DFX STRATEGIES BASED ON VIRTUAL TECHNIQUES

**2.2.a** Validated virtual testing methods

**2.2.b** Mathematical reliability models accounting for interdependencies betw. hierarchy levels: device – component – system

**2.2.c** Mathematical modelling of competing and/or super-imposed failure modes

**2.2.d** Failure prevention and avoidance strategies based on a hierarchical reliability approaches

**2.2.e** Virtual prototyping – DfX – building blocks

**2.2.f** Standardisation of the simulation driven DfX

**2.2.g** Automation of reliability assessment

**2.2.h** Providing room for companies and research institutes to exchange expertise on reliability issues for advanced technologies

**2.2.i** European portal for DfR service provided by institutes and SMEs

### 3 - FUNCTIONAL SAFETY – PROGNOSTIC HEALTH MANAGEMENT (PHM)

**2.3.a** Self-diagnostic tools and robust control algorithms

**2.3.b** Hierarchical and scalable health management architectures, integrating diagnostic and prognostic capabilities

**2.3.c** Monitoring test structures and/or monitor procedures

**2.3.d** Identification of early warning failure indicators and development of methods for predicting the remaining useful life

**2.3.e** Functional safety aspects for autonomous systems including self-diagnostic and self-repair capabilities

**2.3.f** Development of schemes and tools using machine learning technique and AI for PHM

**2.3.g** Big sensor data management

**2.3.h** Safety certification on key domains such as automotive, railway, industrial machinery, and avionics

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

### 4 - DYNAMIC ADAPTATION AND CONFIGURATION, SELF-REPAIR CAPABILITIES, RESILIENCE OF COMPLEX SYSTEMS

**2.4.a** Self-diagnostic architecture principles and robust control algorithms

**2.4.b** Architectures supporting distribution, modularity, and fault containment units

**2.4.c** Support for dependable dynamic configuration and adaptation/maintenance

**2.4.d** Concepts for run-time or dynamic certification/qualification

**2.4.e** Concepts for SoS (Systems-of-systems) integration including the issue of legacy systems integration

**2.4.f** Concepts and architecture principles for trustable integration of intelligent functions in systems / products

## *Major Challenge 3:* SECURE, SAFE AND TRUSTABLE CONNECTIVITY AND INFRASTRUCTURE

### 1 - SECURE IOT DEVICES

**3.1.a** Processes for adding new devices/capabilities to the network (“onboarding”)

**3.1.b** Strong security with immutable, attestable and unique device identifiers

**3.1.c** Onboarding “weak” AI at the edge

**3.1.d** Authentication, Authorization, Revokability and Accountability

**3.1.e** Hardened devices with high integrity, confidentiality and availability

**3.1.f** Inherently trusted processor

**3.1.g** Lifecycle management

**3.1.h** Standardized, safe and secure “over the air” SW updates

**3.1.i** End-of-life (EOL) / End-of-Support (EOS) functionality

**3.1.j** Upgradable security for devices with long service life

**3.1.k** Secure components and secured ownership within an insecure environment

**3.1.l** Certification processes, testing and enforcement

### 2 - SECURE COMMUNICATION PROTOCOLS

**3.2.a** Ensuring high standards for secured communication

**3.2.b** Secure interoperability of protocols, components and communications

**3.2.c** Monitoring, detection and mitigation of security issues on comm. protocols that occur due to external, malicious activities

**3.2.d** Quantum key distribution (aka “Quantum Cryptography”)

**3.2.e** Formal verification of protocols and mechanisms

**3.2.f** Production of verified reference implementations of standard protocols and the guidelines to securely deploy them

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

### 3 - SECURE IT INFRASTRUCTURE

- **3.3.a** Infrastructure resilience and adaptability to new threats
- **3.3.b** Continuous' secure end-to-end systems
- **3.3.c** Secure cloud solutions
- **3.3.d** Secure edge/fog computing
- **3.3.e** Secure wireless and wired networks
- **3.3.f** Low-power wide area networks
- **3.3.g** 5G-related aspects of softwarisation, SDN and security of professional communications
- **3.3.h** Artificial Intelligence for networks and components autonomy, network behaviour and self-adaptivity

## *Major Challenge 4:* PRIVACY, DATA PROTECTION AND HUMAN INTERACTION

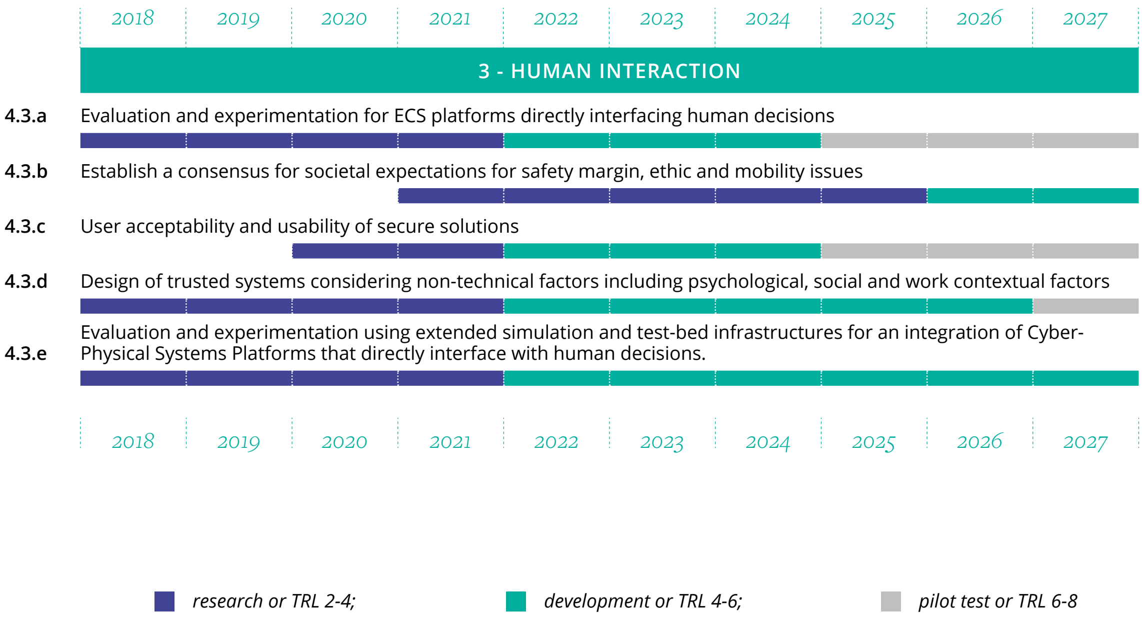
### 1 - (LOCAL) TECHNICAL SOLUTIONS FOR PRIVACY AND DATA MANAGEMENT

- **4.1.a** Security for privacy and personal data protection
- **4.1.b** Identity, access management and authentication mechanisms
- **4.1.c** Trusted devices based on block chain
- **4.1.d** Secure aware data processing and storage
- **4.1.e** Biometric technologies

### 2 - (GLOBAL) DATA MANAGEMENT FOR PRIVACY AND PROTECTION

- **4.2.a** Data privacy and data ownership (use of enormous amount of data respecting privacy concerns)
- **4.2.b** Data Protection, data standards
- **4.2.c** Data pedigree
- **4.2.d** Definition of models for data governance
- **4.2.e** Supply chain security and zero-trust supply chain
- **4.2.f** IoT Forensic capability for insurance & investigation purposes

2018 2019 2020 2021 2022 2023 2024 2025 2026 2027




*Safety, Security and Reliability timelines* **F.42**

# 8.5. SYNERGIES WITH OTHER THEMES

| | MC1: SAFETY, SECURITY AND PRIVACY BY DESIGN | | | MC2: RELIABILITY AND FUNCTIONAL SAFETY | | | |
|---|---|---|---|---|---|---|---|
| | *Secure the Design* | *Harden the Edge* | *Protect the Reach* | *PoF assessment & analytics, PoF-based testing* | *Pro-active DfX based on virtual techniques* | *Functional safety by PHM* | *Dynamic adaptation and configuration, self-repair capabilities, resilience of complex systems* |
| **Transport** | x | x | x | x | x | x | x |
| **Health** | x | x | x | x | x | x | x |
| **Energy** | x | x | x | x | x | X | x |
| **Industry** | x | x | x | x | x | x | x |
| **Life** | x | x | x | x | x | | x |
| **Architecture, Design, and Systems Integration Technology.** | x | x | x | x | x | x | x |
| **Connectivity** | x | x | x | x | | | x |
| **Computing & Storage** | x | x | x | x | x | x | x |
| **Process Technology, Equip, Mat & ECS Manuf** | x | x | x | x | x | x | |

**F.43** *Synergies with other chapters*

| **MC3:** SECURE, SAFE AND TRUSTABLE CONNECTIVITY AND INFRASTRUCTURE | | | **MC4:** PRIVACY, DATA PROTECTION AND HUMAN INTERACTION | | |
|---|---|---|---|---|---|
| *Secure IoT devices* | *Secure communication protocols* | *Secure IT infrastructure* | *Technical solutions for privacy and data management* | *Data management for privacy and protection* | *Human interaction* |
| x | x | x | x | x | x |
| x | x | x | x | x | x |
| x | x | x | x | x | |
| x | x | x | x | x | x |
| x | x | x | x | x | x |
| x | x | | x | | |
| x | x | x | x | x | x |
| x | x | x | x | x | |
| x | x | | x | x | |

# 9

# Computing and Storage

# 9.1. EXECUTIVE SUMMARY

Computing and storage are the fuel of the digital revolution in providing ever increasing performance for existing and new applications at a constant or decreasing cost.

As the Moore's Law started to break down with the size of transistor shrinking to near atomic scale, chipmakers increasingly face issues trying to pack more and more transistors onto a chip and hence computing turns towards alternative ways to get more computing power including massively parallel, heterogeneous, distributed designs of processors and accelerators. But it has a drastic impact on programming and on the efficient management of the ever-increasing complexity of computing and storage systems. Performance is also shifting from an absolute number of operations per second to operations per second and per watt for all domains of computing.

Investigations of new technologies from neuromorphic computing, spintronic, optical to quantum for the long term open the way to new computing paradigms with new Cyber-Physical Systems and Artificial Intelligence driven applications.

This trend leads to the following major challenges for computing technologies:

- Increasing performance at acceptable costs
  - For High Performance Computing (HPC)
  - For low power and ultra-low power computing
- Making computing systems more integrated with the real world
- Making "intelligent" machines
- Developing new disruptive technologies: Quantum technologies, neuromorphic computing, spintronic and optical Computing

# 9.2. RELEVANCE

### 9.1.1. Competitive value

The key ingredient to the digital world is the availability of affordable computing and storage resources. From deeply embedded microcontrollers to supercomputers, our modern civilization demands even more on computing and storage to enable new applications and change our way of life. In less than 10 years, mobile computing, a.k.a smartphone, have changed the way we see, interact and understand the world. Even in less developed countries, having a smartphone is nearly as vital as food. Computing and storage systems are morphing from classical computers with a screen and a keyboard to smart phones and to deeply embedded systems in the fabric of things.

Computing and storage should also enable more products (diversification) at affordable prices.

This should cover the complete spectrum, from ultra-low power wearable devices to Exascale systems.

While Europe is recognised for its knowhow in software and especially in embedded systems architecture and software, it should continue to invest in this domain to continue to be at the top, despite fierce competition from countries like China, India, etc.

European companies are also in the leading pack for embedded microcontrollers. Automotive, IoT and all embedded systems consume a large number of low-cost microcontrollers, integrating a complete system, computing, memory and various peripherals in a single die. Again, a pro-active innovation is necessary to cope with the new applications and constraints, like for Cyber-Physical Systems and Edge computing, especially when local AI is required.

Europe no longer has a presence in "classical" computing such as processors for laptops and desktop, servers and HPC, but the new initiative of the European Commission, *"for the design and development of European low-power processors and related technologies for extreme-scale, high-performance big-data and emerging applications, in the automotive sector for example"* could reactivate an active presence of Europe in that field. The ECS SRA recognises that this initiative is important for Europe.

Coprocessors, GPU and Deep Learning accelerators (and other accelerators) are also becoming more and more important. European solutions exist, but the companies are often bought by foreign companies.

In a world in which some countries are more and more protectionist, not having high-end processing capabilities (i.e. relying on buying them from countries out of Europe) might become a weakness. China, Japan, India, Russia are starting to develop their own processing capabilities in order to prevent potential shortage.

### 9.1.2. Societal benefits

Computing is at the heart of a wide range of fields by powering the most of the systems with which humans interact. It enables Transformational Science (Climate, Combustion, Biology, Astrophysics, etc...), Scientific Discovery and Data Analytics. The advent of complete or partial autonomous system, in addition to CPS, requires tremendous improvement in the computing fabric. Even if deeply hidden, these computing fabrics directly or indirectly impact our ways of life: Autonomous systems (car, aircraft, train, etc.), Quality of life (healthcare, transportation, energy, etc.), Communication (Satellite, 5G, etc.).

For example, computing and storage are key to solving societal challenges listed in the previous chapters, like monitoring and using the right amount of material and energy to save goods and energy. They will allow industrial processes to be optimised and thus save money. They enable cheaper products because they allow more efficient solutions to be built. In the medical domain, for example, they will allow healthcare to be delocalised (for example in the countryside, where no specialists are available). There will be synergies between domains: the developments on computing and storage for self-driving vehicle with higher reliability and predictability will directly benefit medical systems, for example. New applications, relying on complex computing and storage systems, allows you to monitor your heath thanks to smart bracelets or smart watches, and could reduce the impact of a heart attack or other health problems. Cars will send their location and call for help after an accident. Intelligent applications helping the driver will reduce the number of accidents by monitoring the environment and warning the driver. Surveillance systems will allow security to be improved in various locations.

# 9.3. MAJOR CHALLENGES

## 9.3.1. Increasing performance at acceptable costs

### Efficient systems and management of complexity

#### 9.3.1.1. Vision

This major challenge addresses the course of computing technology and determines whether or not it would allow a 50× increase in peak performance in viable operating costs (i.e. energy, financial cost, reliability, size, etc.) by 2020 and to continue such progression beyond. The focus will be put on the main technological challenges that might prevent such an objective from being reached: energy consumption increase, memory and storage limitation, increasing complexity of applications *versus* achievable parallelism and resilience.

#### 9.3.1.2. Scope and ambition

Computing solutions need to cover the whole range of applications, going from low-end IoT devices up to *Exascale Computing*. The expectation is not just to get more processing power, but at affordable cost in terms of power, size, price, cyber security. It is a shift from absolute number of operations per second to systems with a high efficiency.

An ambitious goal the High-Performance Computing community has set for itself is Exascale Computing as the next major step in computer engineering. The unprecedented level of computing power offered by Exascale is expected to significantly enhance our knowledge for the benefit of a large spectrum of industries including Energy (e.g. modelling and simulation of nuclear engineering analysis, etc.), Bioinformatics and Medical Systems (e.g. multi-scale approach to biological modelling, Medical Image Analysis (at microscopic/spectral level, pharmaco-genetics, computer-aided surgery, discovery of new therapeutic molecules, etc.), Materials Science (e.g. investigation of 3D molecular structure design of engineering properties), Transportation (as exemplified by aerospace, airframes or autonomous vehicle applications, Entertainment (e.g. virtual reality), and many others.

The autonomous systems (such as automotive, train, aircraft) require embedded vision, complex decision-making and sensor processing (Radar, Lidar, Positioning, etc.) that were only possible with HPC systems of few years ago, but need now to be realised with cost and energy effective systems that don't have to be installed in dedicated rooms.

#### 9.3.1.3. Competitive situation and game changers.

The major consolidation of the of the semi-conductor market observed in 2015 is continued with new mergers still on-going. The top ten players have gained an aggregated market share of almost 60%.

This creates a situation where few major companies are providing computing solutions, notably for the high-end, for the world. According to the 2017 McLean report, in the top 10 Worlwide Semiconductor Sales leaders, only 2 companies are still European, putting at risk the capability of Europeans to make their own decisions. For sovereign domains, but with small volumes, such as HPC, space, aeronautic, military, it may be difficult in 10-15 years to get access to some technologies.

Maintaining European knowhow on these technologies is required to meet the challenges at all stages of the data-processing chain. Indeed, the intelligence of today's systems is not coming from a single element but from a tight collaboration between distributed elements like Smart Sensors, CPS, Iot, Edge, Cloud and HPC. At each level, the large amount of data (*"data deluge"*), resilience, confidentiality and autonomy require new innovative computing solutions to satisfy emerging needs that are not satisfied anymore with the "ever-shrinking technology nodes" as highlighted in the HiPEAC vision document (http://www.hipeac.net/roadmap). The industrial and research computing community must support these evolutions by aiming at providing from 1 ExaFlops/s for HPC down to 1 TeraFlops/s/Watt for embedded CPS in 2020.

European innovation is required, and processing cores that are accessible, either under licensing (such as ARM cores) or open source (such as RISC V) are possibilities for European research and industry to develop innovative solutions while benefiting from established ecosystems.

On the other hand, the Industrial and Automotive sectors are seen as growth potential sectors in which European actors are well positioned (see figure 4 in chapter 0).

In addition to this good positioning, the forecast of the annual growth rates in Europe will be higher than other regions (see figure 5 in chapter 0).

The Europe positioning in these innovative fields must be maintained and leveraged to gain in others sectors. The industrial applications (such as Industry 4.0) and automotive (such as autonomous car) are launch pads for new technologies trying to cope with the challenges that are shared by embedded, mobile, server and HPC domains: **energy and power dissipation, and complexity management**. The safety requirements, applicable even in loss of connectivity, prevents Cloud-only based solutions for Artificial Intelligence, Image processing, Complex decision-making (including preserving human life) with strong real-time constraints

CPS used in harsh environments (high temperature, radiation, vibration, etc.) requires either dedicated or finely tuned architecture to run critical and highly intensive application: on-board satellite data processing, aircraft or cars self-monitoring.

#### 9.3.1.4. High priority R&D&I areas

**The hardware and architecture challenges**

Next generation hardware[34] faces a huge challenge: an increase by a factor of at least 50 in performance to be combined with technology breakthroughs to reduce the power consumption by a factor of 100 (e.g. an extrapolation of the power load using current technology will require over a gigawatt for future exascale systems). The technical axes of exploration for power reduction in hardware design include: energy efficient building blocks (CPU, memory, reducing length of interconnects) possibly based on 3D silicon technologies, extensive usage of accelerated computing technologies (e.g. GPU, FPGA) to complement general-purpose processor, domain specific integration (System in Package, System on Chip), domain specific customized accelerators (e.g. for deep-learning, cryptography, …), integrated photonic backplane, cooling and packaging technologies, etc. This challenge is recognised by Europe that launched a "Framework Partnership Agreement in European low-power microprocessor technologies" (call ICT-42-2017 closed on September 26, 2017), but the effort needs to continue.

Progress on ultra-low power hardware, generally powered by energy harvesting or capacitor, is needed to support the integration of intelligence into very small devices: biological implants, smart tattoos, RFC/RFID type solutions, home automation, food and goods tracking, in-material health monitoring.

In addition to the critical power issue, comes the memory wall. Today limitation is not coming from the pure processing power of systems but more from the capacity to bring data to the computing nodes within a reasonable power budget. As the memory dictates the size of the problem that can be solved, the need to scale the application to the computing power requires a huge improvement in memory access time and this issue gets worse due to the fact that memory access time (typically a doubling of the bandwidth every 3 years) is lagging behind the progress made in CPU cycle time. Furthermore, the system memory challenge is only part of a broader Data Movement challenge which requires significant progress in the data access/storage hierarchy from registers, main memory (e.g. progress of NVM technology, such as the Intel's 3D-xpoint, etc.), to external mass storage devices (e.g. progress in 3D-nand flash, SCM derived from NVM, etc.). In a modern system, the major part of the energy is dissipated in moving data from one place to another: computing in memory, or decreasing the communication cost between the storage and where the data are processed, is crucial. Another important point is the emerging of new memory technologies (PCM, MRAM, ReRAM, …) with access performances that are much better than standard flash memories but not yet at the level of DDR. This allows new application partitioning between volatile and non-volatile memory and more generally a complete review of the system memory hierarchy. This is very important especially regarding energy-saving policies. One of the main interests is the capacity to change from one operating point to another very rapidly, in any case much faster than saving an execution context from DDR to Flash as is the case today. This opens a path to very aggressive energy-saving policies as both the latency and the switch from one mode to another can be extremely short. As a consequence, it drives needs in the Application frameworks to integrate these new capabilities in order to give application developers the capacity to use these new features. The usage of 64-bit addressing scheme and large (non-volatile) memories could also have a drastic impact on what is one of the bases of most current computing system: the notion of file system. Objects can be directly addressed and mapped in the memory space.

Finally, the increasing size and complexity of such system architectures is challenging their design and development, implying in turn the revision of their design methodology (see chapter 6 for more details).

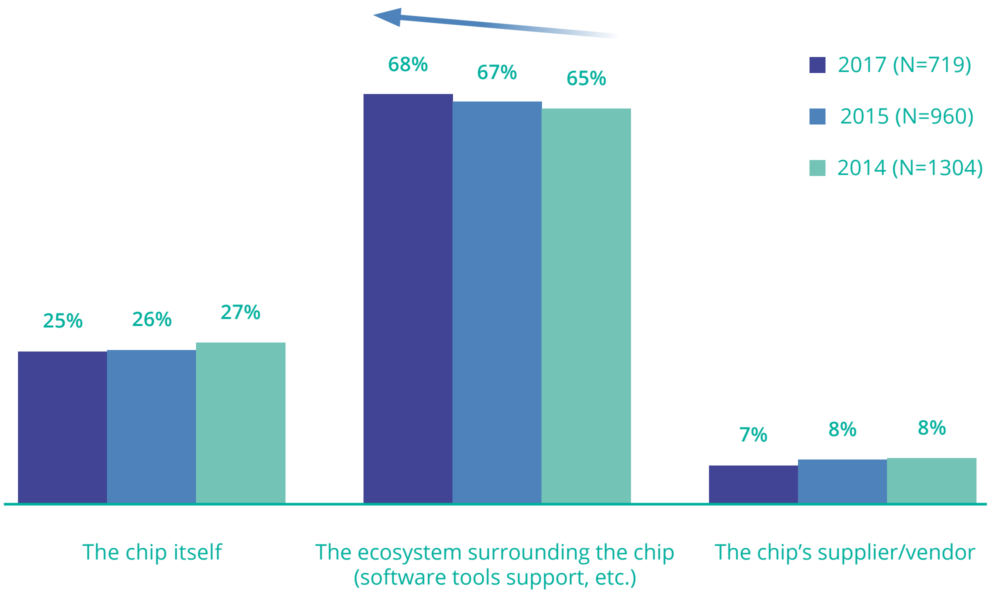
### The software challenges

The choice of a computing solutions is not driven mainly by its intrinsic performances but by the software ecosystem. With the ever-increasing complexity of processors, more advanced Software infrastructure has to be developed.

←

[34] *The state-of-the-art is illustrated in the following respective references: CPU:http://wccftech.com/intel-skylake-cpu-10-20-performance-boost-faster-igpu-ddr4-overclocked/ Memory:https://www.intel.com/content/www/us/en/architecture-and-technology/intel-optane-technology.html Interconnect: http://www.infinibandta.org/content/pages.php?pg=technology_overview Storage:http://www.zdnet.com/article/ibms-world-record-330tb-uncompressed-data-on-a-palm-sized-tape-cartridge/*

## WHAT'S MOST IMPORTANT WHEN CHOOSING A MICROPROCESSOR




**F.44** *Source: AspenCore 2017 Embedded Markets Study*

It is well known that the gap between hardware and software capabilities is widening in high-performance systems. While a single processor chip can provide several cores up to thousands of processing cores, many applications still (sometimes poorly) exploit only few cores in parallel. Safety Critical applications hardly start to use multi-core processors. Therefore, there is an urgent need to upgrade the software to the hardware capacity through the following potential actions:

- Middleware/Software: the data movement constraints (streamed, stored and even replayed from stream) must be used to dynamically or statically schedule massively parallel tasks in order to optimise the core's usage. This scheduling strategies must not only optimise processor usage but also prevent any data loss and decrease processing latencies. Guaranteeing both real-time and safety properties will come from a close collaboration between hardware and software, where time is frequently absent from the underlying programming language. For HPC, coordinated and hierarchical checkpoint/restart, new strategies become mandatory to unload this burden from application level to system level and to manage heterogeneity optimally.
- Programming Models and Methods: Massively and Hybrid Parallel Computing requires new programming models suitable to support scalability and a large range of heterogeneous computing, such as for vector accelerators. The main challenge is to have programming models integrating multi-dimensional constraints. Up to now the programming models have been mainly based on maximising the efficiency of the computing system regarding the type of data and their type of use case. Now things are different as this optimisation still needs to happen but other aspects such as power consumption, scalability security, and dependability have to be managed simultaneously.

This is even more important for the IoT system where resources are very scarce and for which efficient resource management is a highly differentiating factor. One of the challenges is to provide application designers with the right knobs in order to make the best trade-off. There is a strong need for new languages or programming framework where this security, dependability and power consumption are built-in features whereby adequate control is given to the programmer to ensure the most optimal solution in terms of design decisions. It is mandatory to offer the best expertise in every domain even for developers who are not the best experts in all facets of today's systems: the underlying complexity increase should be hidden to the programmers. This type of requirement ranges from very small IoT devices up to very large computing systems.

- This requirement necessitates, in turn, the definition of common communication protocols (e.g. CCIX, Gen-Z, OpenCAPI) and the improvement of existing standards (e.g. PThreads/OpenMP, OpenCL, OpenACC, CUDA, HLS, MPI, auto-vectorisation, etc.) to provide better support for both precision and coarse parallelism, interoperability, scalability, portability, latency awareness.

The application complexity is increasing dramatically and optimisation represents a challenge. Improvement of existing codes is just impossible, which implies the need to invent new parallelisation strategies. The development of such massively parallel applications also requires new tools to support the debugging, validation and certification tasks.

In addition, the software should also contribute to the solution of hardware-critical challenges *(Cf. §3.1.3.1)* by providing robust, energy-aware and fault-tolerant, self-healing applications.

### System challenges and applications/architecture co-design

Emerging computing systems (IoT, CPS, HPC, etc.) cannot be a mere assembly of disparate improvements issued from the previous steps but a smart combination of them to provide efficient solutions. That leads to the concept of software/hardware co-design challenge which can be defined as the simultaneous design/development of both hardware and software to be optimally implemented in a desired function. The high-level approaches are shown in chapter 6, but the complexity of co-design of computing and storage stems from the combination of the following themes of work:

- Reconsideration of basic mathematical models and reworking of algorithms (e.g. massively parallel algorithms, genetic programming, etc.); they have to remain platform-independent to suit any future candidate targets. Algorithms that a priori include sequential sections have to be restructured to open ways to extract as much inherent parallelism as possible through suited state-of the-art tools to cope with the capabilities of the computing fabric.
- Scalable implementation on large and heterogeneous platforms (different computing architectures, accelerators, etc) using new interoperable and composable programming paradigms (energy-aware static/dynamic placement, scheduling, communication, etc.) that can be transparent to the user. All these challenges should be addressed in an integrated manner, in connection within a 'Grand Mission' addressing the need for a European hardware platform for new generation of computing.
- Optimal composition of hardware and of the constraints of users according to many variable criteria including computing technologies, use of reconfigurable logic, memory access and interconnection and I/O (e.g. combination of communication protocols, support of data coherence/consistency models, memory and network contention etc.). It yields a design space exploration problem that we are able to face with appropriate tools, possibly using Artificial Intelligence related techniques. This huge complexity will be managed by selecting only some relevant solutions that match the user multi-criteria. This kind of tooled-up approach enables future products to be properly sized.

### 9.3.1.5. Expected achievements

**HPC and related application domains**

As stated in previous sections, HPC has become indispensable to all branches of government, education and all fields of industry and thus it impacts almost every aspect of daily life. To date, progress towards petascale computing has been achieved mainly through an evolutionary enhancement of microprocessor technology but the transformation towards the next step of exascale computing represents a challenging venture: an in-depth reworking of application codes in conjunction with radical changes in hardware to optimally exploit high levels of parallelism in solving ever-increasing complex problems.

HPC technology will in turn extend itself into a set of immediate application areas including Data Centre and Cloud Computing, and offers a convergence with Big Data to form the new HPDA ("high-performance data analytics") discipline.

And the technologies developed for HPC generally become mainstream a few years after: self-driving cars required a processing power of super-computers of few years ago, it is the "ripple down effect".

**CPS domain**

More and more heterogeneity is the way to reach the performance expected from CPS with always more energy efficiency. Considering that the use of multi-core processor is not yet fully managed for safety critical application, for which determinism is mandatory, adding heterogeneity is just moving to another order of complexity. Current programming solutions for dedicated accelerator, even if promising such as High Level Synthesis for FPGA, rely too heavily on the programmer being able to understand the underlying architectures. The advent of FPGA as part of Cloud building blocks, such as F1 Amazon EC2, and Microsoft Brainwave dedicated to Deep Learning, will accelerate the development of scalable, hardware-agnostic and energy-efficient programming solutions. Such solutions must encompass FPGA, DSP, GPU, CNN/DNN Accelerator, or even more innovative hardware.

Distributed intelligent platforms will be part of the landscape of everyday life activities (healthcare, transportation, education, business, etc.) to reduce the event-response latency by providing real-time decisions, capturing live data streams, building complex decision logic and enabling real-time monitoring, predictive alerts and guided interactions.

**Extreme low power and IoT**

Extreme low-power computing is necessary in many advanced systems based on pervasive computing, including sometimes devices where computing is necessary but no battery is available. Beyond the challenge of harvesting energy, there is a pressing need for architectures that fully optimise the energy consumption with dedicated processing cores, accelerators and energy management systems.

## 9.3.2. Making computing systems more integrated with the real world

**Dependability and real time**

### 9.3.2.1. Vision

Computing systems are more and more pervasive and they are present in almost all objects of current life (wearable objects, home appliances, retail and home automation, etc.). These systems bring intelligence everywhere (Smart Anything Everywhere) and are usually referred to as Cyber-Physical Systems, and they will evolve towards Autonomous Cyber-Physical Systems (ACPS). Their role in complex systems is becoming increasingly necessary (in cars, trains, airplanes, health equipment, etc.) because of the new functionalities they provide (including safety, security, autonomy). They are also required for the interconnection and interoperability of systems of systems (smart cities, air traffic management, etc.).

Because of their close integration with the real world, the systems have to take into account the dynamic and evolving aspect of their environment, to provide altogether deterministic, high-performance and low-power computing as well as efficient processing of deep-learning algorithms.

Finally, because of their usage in dependable systems they have to follow certification / qualification processes imposing guarantees regarding their functional and non-functional specifications.

### 9.3.2.2. Scope and ambition

The ambition for computing systems when they need to be integrated in the real world is the realisation of systems offering altogether a large computing local performance (since they need to be smart), a good level of performance predictability (implying deterministic architecture suited to certification/qualification processes) and efficient interconnection capabilities (distributed systems and systems of systems).

To interface with the physical world, these CPS require a fine, fast and dynamic understanding of their environment through real-time analysis based on AI technologies.

Their natural interconnectivity requires the establishing of connections to the external world with high levels of safety, privacy and security as described in chapter 8. Moreover, the realisation of trustable computing systems ensuring reliability, predictability, safety, security and privacy is generally necessary, even when connected to systems and networks that have low security, safety or reliability levels.

Engineering methods (including analysis, verification and validation to ensure properties such as security) scaled to the complexity and high-level non-functional requirements of CPS are necessary especially in the case of adaptive systems. They must satisfy the multidisciplinary challenge of designing CPS with numerous constraints, objectives and functional or non-functional requirements which are often contradictory (response time, safety, trust, security, performance, QoS, energy efficiency, size, reliability, cost).

### 9.3.2.3. Competitive situation and game changers

Europe has a good position in smart systems connected to the real world. This strong position is confirmed at product level (cars, planes, industry, robots, etc) as well as scientific level (formal methods, time analysis, design methodology) and general knowhow in embedded systems.

However, as this domain is undergoing tremendous changes (due to the increased need for more computational resources), it remains a great opportunity for future developments. The good technological level of Europe must be maintained and improved.

### 9.3.2.4. High priority R&D&I areas

**System challenges and applications/architecture co-design**
As explained in the previous challenge, computing in embedded systems faces fundamental challenges of power, bandwidth, and synchronisation.

But **dependability** is a key for these embedded systems, which are the heart of systems used by people (planes, self-driving cars, etc). Knowing how to correct errors on these more and more complex systems is a challenge to making them reliable and resilient. Knowing how to ensure that time constraints (response time, etc) are met is a challenge to making them predictable, and thus safe. Security techniques (secure access mechanisms, blockchains, etc) have to be adapted to make CPS able to satisfy the privacy of their users. For example, blockchain can be used in IoT and smart sensors powered by battery or harvesting energy, require a large improvement in the efficiency of computing elements.

Because of their interaction with the physical world, CPS have extremely dynamic properties with numerous parameters possibly changing at runtime, sometimes discontinuously. The subsequently high number of scenarios makes modelling, simulating and implementing them really challenging.

CPS tend to offer increased autonomy – ACPS for Autonomous CPS - (autonomous cars, robots, home automation, etc.), which implies complex decision-making based on AI combined with high timing constraints as well as reliability, safety and security constraints.

This challenge of dependability is also present for HPC and server systems: as the number of components increases faster than their reliability, *system resilience* becomes the third challenge pole in Exascale system design: SMTBF is decreasing towards the range of 1h-10h and thus requires more efficient checkpoint/restart mechanisms together with Algorithm-Based Fault Tolerance, redundancy strategy, enforcement of real-time constraints for application reconfigured at runtime, real-time vote with no single point of failure. Technical improvements on this topic are expected to be manifold to include enhancement of both hardware and software reliability but also the development of fault resilient algorithms.

**The hardware challenges**
Today's distributed embedded systems (as exemplified by CPS) are built on a large number of distributed computational platforms that communicate with each other via a [wireless] network fabric and interact with the physical world via a set of sensors and actuators. To meet the increasing performance and flexibility demands, embedded systems leverage heterogeneous multi/many-core architectures optionally enhanced with hardware accelerators (e.g. GPU) to replace more and more µcontrollers and DSPs, to ensure real-time behaviour with partitioning and virtualisation technologies and to handle critical systems (e.g. independent certification of safety-critical components, separation of safety-relevant subsystem on the same processor, etc.).

Determining statically the Worst-Case Execution Time of such a complex system is an intractable challenge, and new (possibly dynamic) approaches are required to ensure that the system will fulfil its mission in due time. Processing time determinism is indeed often required in applications with safety-critical or hard real-time constraints. The solution can also be found with the design of dedicated architectures. When this is affordable, specific interconnection systems for multi/many-core processors can, for instance, be more effective and easier to implement than software approaches.

For the security aspect, trustable secure zones, enclaves, isolation techniques, specific modules for protection, cryptoprocessors, etc, have to be considered. The Open Source hardware (RISC-V, OpenPower, etc.) will allow white box design and the exploration of processor architectures by the community. Specification of many parts of the systems are generally not completely known or disclosed. This leads to black or grey boxes which have to be specifically considered. With most recent technologies, components reliability or performance variation may also require a specific approach to ensure good characteristics at upper layers. Edge systems are already made of small processing units (such as µcontroller) cooperating altogether (e.g. watch, phone, shoes). The battery requirement limits the possibility of integration. With the advent of autonomous energy sources, such as ambient RF energy harvesting, the design of ultra-low power and energy-aware processors for computation and communication may greatly improve this integration.

#### The software challenges

Software components are distributed throughout an embedded system and interact with one another across well-defined interfaces. At a feature level, they also collaborate via their shared interaction with the physical world. Two specific challenges are particular to collaborating embedded systems:

- Virtual System Integration: From a design perspective, challenges arise in the modelling (integration of models representing different formalisms, communication among hardware/software sub-models, etc.) and analysis of the design.
- Runtime System Adaptation: Reasoning and planning adaptation of a set of sub-systems via the maintenance of consistent information and management of inconsistencies and the usage of online model calibration.

Getting computers to work together with physical processes requires technically intricate, low-level design: embedded software designers are forced to deal with interrupt controllers, memory architectures, assembly-level programming (to exploit specialised instructions or to precisely control timing), device driver design, network interfaces, and scheduling strategies. The most critical systems (mission critical or even life critical) require a high verification level which can only be reached by a combination of formal methods and accurate timing analysis, trace analysis, monitoring with dedicated control algorithms, accurate profiling solutions, etc. The dynamicity of CPS implies systems in which the state space cannot be explored at design time. In spite of great progress in that domain, the end-to-end verification of complex hybrid systems is still a challenge. There is also a significant advantage to perform numerical stability property verification through formal methods of these systems. Improving the trade-off between communication availability, autonomy and real-time requires tightly cooperating hardware, platform, programming model (moving from task to event based) and application software.

### 9.3.2.5. Expected achievements

The expected achievements here are key development platforms and building blocks (hardware and software) to enable the design of trustable cyber-physical systems.

Moreover, “de facto” European standards for interoperable CPS systems will be a strong benefit to foster the development of competitive European products in that domain.

## 9.3.3. Making “intelligent” machines

**Towards autonomous systems**

### 9.3.3.1. Vision

Artificial Intelligence (AI) again became a very hot topic recently, mainly due to the practical success of Deep Learning on image classification, voice recognition and even in strategic games (AlphaGo from Deepmind/ Google beating the best human Go player, and Alpha Zero becoming the best player in chess and in Go within few hours, even beating its predecessor AlphaGo ). According to the “Hype Cycle for Emerging Technologies, 2017” by Gartner, Smart Robots, Virtual Assistants, Deep Learning, Machine Learning, Autonomous Vehicles and Cognitive Computing at the peak of the curve, while Artificial General Intelligence, Deep Reinforcement Learning and Neuromorphic Hardware are still on the rise. According to a report from Tractica (See figure 2 of chapter 0), the revenues generated from the direct and indirect application of AI software will grow from USD 1.4 billion in 2016 to USD 59.8 billion by 2025. These techniques will signify a big technological shift, and will have an overall impact. In the domain of Computing and storage, the consequences will be twofold:

- Europe should remain in the AI race and develop efficient solutions for IA systems, both at the hardware and software level. AI, and more especially Deep Learning, requires large amounts of computation (in the exaflop range) for the “learning” phase, and embedding AI solutions in edge devices will require low-energy accelerators. As previously seen, Europe’s place in CPS systems should drive it to the lead position in Autonomous Cyber-Physical Systems, adding “intelligence” to CPS.
- AI techniques can be used for the design of computing solutions, e.g. for selecting an optimal hardware combination (generative design), or for software generation. There are already researchers using Deep Learning for generating Deep Learning networks...

### 9.3.3.2. Scope and ambition

AI and especially Deep Learning require optimised hardware support for efficient realisation:

- For the learning phase, the large amount of relatively low precision computations (e.g. float16) requires accelerators with efficient memory access and large multi-compute engine structures. Access to a large storage area is necessary to store all the examples that are used during this phase,
- For the inference phase (e.g. on the edge), it will require low-power efficient implementation with closely interconnected computation and memory.
- A new emerging computing paradigm, using unsupervised learning like STDP (Spike-timing-dependent plasticity), might change the game by offering leaning capabilities at relatively low hardware cost and without the need to access a large database. Instead of being realised by ALU and digital operators, STDP can be realised by the physics of some materials, such as those used in Non-Volatile Memories. This could differentiate Europe from the learning accelerators for servers and HPC which require a huge investment, and solutions are already available, either open or closed, such as the NVIDA Volta GPU, Google’s TPU2, etc.

Developing solutions for IA at the edge (e.g. for self-driving vehicle, personal assistants and robots) is more in line with European requirements (privacy, safety) and knowhow (embedded systems).

Europe should also be at the forefront of emerging hardware and software solutions for AI, beyond classical Deep Learning, particularly in the use of AI-based solutions to improve the development of systems by selecting optimal solutions to complex problems, in various domains, including the development of new computing solutions.

Finally, hardware and software should be developed to support Self-X systems (self-repairing, analysing, managing, ...) to ensure more dependable systems.

#### 9.3.3.3. Competitive situation and game changers

AI techniques could change the way we interact with computers: instead of programming, i.e. telling the machine how to do things by giving it a list of instructions, we might move to a more declarative or parenting approach where we tell the machine what should be done (and not how it should be done), e.g. through examples. Typical computing models will be complemented with these new ones.

On the user side, AI techniques will allow more natural interaction, e.g. with language, and AI techniques will be key for a machine to recognise and analyse its environment, e.g. for self-driving cars. For safety, privacy and cost (reduction of the communication bandwidth with server), local intelligence (intelligence at the edge) needs to be developed, working harmoniously with the cloud, but exchanging data with it only when required. This will require more efficient processing capabilities at the edge, and an increase of local storage. In the coming years, the processing capabilities of the IBM Watson used for winning the jeopardy game could be affordable as a home server, and the compete Wikipedia encyclopaedia will fit in its local storage. Dedicated accelerators for Deep Learning and related techniques will allow the development of autonomous robots, intelligent personal assistant, safety systems and autonomous vehicle with the minimum need for accessing extra computing resources and storage.

Currently, IA and Deep Learning are mainly developed by the extended GAFA (Google, Amazon, Facebook, Apple, Microsoft, Baidu) and they make large investment in this domain by acquiring major players (both start-ups and known academics). They also have in-house the large databases required for the leaning and the computing facilities (even if they develop accelerators by themselves, for example Google and Apple). The US and Chinese governments have also started initiatives in this field to ensure that they will remain pre-eminent players in the field.

It will be a challenge for Europe to be in this race, but the emergence of AI at the edge, and its knowhow in embedded systems might be winning factors.

#### 9.3.3.4. High priority R&D&I areas

**System challenges and applications/architecture co-design**

As previously seen, managing the complexity of computing systems is an important challenge, and IA inspired techniques can be used to design more efficient hardware and software systems. Analysing the large space of configurations and selecting the best option with clever techniques allow the design of more efficient systems, taking into account a large number of parameters. It is still a research area, but in mechanical design it is already at the product level (*generative design tools*).

There are already experiments in this field to design efficient multi-core systems or generate more efficient code.

Techniques for self-analysing, self-configuration, discovery of the features of connected systems, self-correcting and self-repairing are also domains that need to be developed to cope with the complexity, interoperability and reliability of computing and storage systems.

### The hardware challenges

To efficiently support new AI related applications, for both the server and client (edge side), new accelerators need to be developed. For example, Deep Learning does not need a full precision floating point for its learning phase, only 16 bit floats. But a close connection between the compute and storage parts are required (Neural Networks are an ideal "compute in memory" approach). Storage also needs to be adapted to support IA requirements (specific data accesses, co-location compute and storage), memory hierarchy, local vs cloud storage.

Similarly, at the edge side, accelerators for AI applications will more specifically require real-time inferenced, especially to reduce the power consumption. For Deep Learning applications, arithmetic operations are simple (mainly multiply-accumulate) but they are done in very large numbers and the data access is also challenging (also clever schemes are required to reuse data in the case of convolutional neural networks or in system with shared weights). Computing and storage are deeply intertwined. And of course, all the accelerators should fit efficiently with more conventional systems.

Finally, new approaches can be used for computing Neural-Networks, such as analogue computing, or using the properties of specific materials to perform the computations (although with low precision and high dispersion, but the Neural Networks approach is able to cope with these limitations).

Over the years, a number of groups have been working on hardware implementations of deep neural networks. These designs vary from specialised but conventional processors optimised for machine learning "kernels" to systems that attempt to directly simulate an ensemble of "silicon" neurons, known as neuromorphic computing. The latter neuromorphic systems are more in line with what researchers began working on in the 1980s with an architecture modelled after biological neurons.

Recent achievements in this field are:

- the biologically inspired chip "TrueNorth" from IBM that implements one million spiking neurons and 256 million synapses on a chip with 5.5 billion transistors, and
- the neuromorphic chip developed by IMEC, capable of composing music by learning rules of composition (http://magazine.imec.be/data/83/reader/reader.html#!preferred/1/package/83/pub/89/page/5 ).
- The Neuram3 H2020 project, which just delivered a prototype chip with better performances than TrueNorth

Besides Deep Learning, the "Human Brain Project", a H2020 FET Flagship Project which targets the fields of neuroscience, computing and brain-related medicine, including, in its SP9, the Neuromorphic Computing platform SpiNNaker and BrainScaleS ( https://electronicvisions.github.io/hbp-sp9-guidebook/). This Platform enable experiments with configurable neuromorphic computing systems.

In the U.S. a report of a roundtable "Neuromorphic Computing: From Materials to Systems Architecture" of 2015 (https://science.energy.gov/~/media/bes/pdf/reports/2016/NCFMtSA_rpt.pdf) describes, amongst other things, the need for Neuromorphic Computing and identifies a number of open issues ranging from materials to systems. Early signs of this need appear with the emergence of machine learning based methods applied to problems where traditional approaches are inadequate. These methods are used to analyse the data produced from climate models, in a search of complex patterns not obvious to humans. They are used to recognise features in large-scale cosmology data, where the data volumes are too large for human inspection.

### The software challenges

The paradigm introduced by new AI techniques such as Deep Learning could promote more emphasis on *declarative* (or *statistical*) instead of imperative programming, "programming" by examples, where goals and constraints are given, but the system should determine by itself the best way to reach the goals. How this approach can be combined with "classical" systems, how to ensure that the solution is correct, etc, are new challenges. Validation, verification of systems and the ethical questions posed by systems that will determine themselves their choice in a more or less transparent way are also important challenges. This is also part of the more general challenge described in the previous paragraph consisting of determining whether a complex system, composed of white (we know the internals, how it works), grey (we know the specifications and interfaces) and black (we don't know how it works) boxes, will ensure the Quality of Service and objectives for which it has been designed.

The problem of interoperability and the complexity introduced with the new accelerators and how they can be combined with classical systems also need to be solved.

### 9.3.3.5. Expected achievements

In the domain of system challenges and applications/architecture co-design, the expected achievement is to provide a platform and tools that allow the complexity of systems to be managed and efficient solutions to be designed with the help of AI related techniques. It should help the partitioning of tasks onto various hardware and accelerators (including those for Deep Learning). Europe should be the leader in generative design tools for designing computing systems.

From the hardware point of view, new efficient accelerators for AI tasks should be developed for edge processing, allowing intelligence to be embedded near the user and limiting the use of remote accesses to ensure safety, privacy and energy efficiency.

From the software side, existing software environments should be extended to support declarative programming, and good coordination with AI related approaches to allow the smooth integration of various approaches.

A European run-time ensuring self-analysing, self-configuration, discovery of the features of connected systems, self-correcting and self-repairing should be developed to become the "de facto" European standard for interoperable and reliable systems.

Solutions should be developed, both at the technical, ethical and legal level to ensure that AI related techniques will be accepted in society, with a focus on the objectives and Quality of Service being correctly ensured.

## 9.3.4. Developing new disruptive technologies

Moore's Law has started to break down as the size of transistor has shrunk down to near atomic scale and alternative ways have been investigated to get more computing power, including quantum computing, neuromorphic computing, spintronic, photonic, biochemical computing, etc. for the longer term.

In the US alternative approaches to computing are being gathered under the name "Reboot Computing" including all aspects from materials and devices up to architecture. As it is not possible to cover all the different approaches explored on computing in this SRA due to length restrictions, a few of the promising approaches are selected as examples, but with the clear message that Europe should continue to invest to keep on par with the rest of the world.

### 9.3.4.1. Quantum computing

In 1982, R. Feynman sketched out roughly how a machine using quantum principles could carry out basic computations and, a few years later, David Deutsch outlined the theoretical basis of a quantum computer in more detail. Thanks to a large spectrum of follow-up research, it is nowadays known that Quantum Computing can theoretically contribute significantly to the resolution of problems that classical computing finds it hard to solve (e.g. Factoring, Cryptography, Optimisation, etc.). To move these algorithms from blackboard to concrete realisation, two main aspects require attention. The first is the need for a complete, scalable quantum computer. Indeed, if during the last three decades, quantum computing has progressed to proof-of-concept demonstrations of single- and multi-unit qubits (photons, electrons, quantum dots and other approaches), it is very much at the research stage with scientists competing on the manipulation of a handful of qubits. The second aspect requiring attention is the development of a unified set of methodologies and techniques to use and interact with such a physical quantum machine: at the logical level, how do we encode and test quantum algorithms? The lack of efficient general-purpose quantum computers (e.g. the D-Wave 2000Q System oriented towards Quantum Annealing) lead to a variety of meet-in-the-middle approaches by major actors, with the development of a variety of software-based emulators – including Atos/Bull Quantum Learning Machine, Microsoft's LIQUi|>, Google's Quantum Computing Playground - to assist in the research and development of quantum algorithms, independently from the hardware research activity. One thing can be learned from these approaches: A good computational paradigm for quantum computation is that of a quantum co-processor linked to a classical, conventional computer. Pre- and post-processing are done classically while the quantum co-processor targets the quantum-specific aspects of the computation. This will pose new challenges:

- There is no well-defined model of computation mixing classical and quantum computation, nor a complete compilation and software stack.
- The interfacing between the classical computer and the quantum computer will require new developments, both for the bandwidth, the errors and the fact that quantum machines currently work at very low temperature, where the behaviour of classical electronics is not well defined.
- The instability of quantum states, and interferences, will lead to errors, and error correction is therefore a challenge.

### 9.3.4.2. Neuromorphic computing

Neuromorphic computing is part of the previous challenge making "intelligent" machines, and is detailed in the part concerning the hardware challenges, but it has also its place here because in can be performed with different computing elements than ALUs and binary coding. For performing its operations, the information can be coded not only in a spatial way (like in binary code), but in a spatial and temporal way: for example, with "spikes" – the pulses similar to the ones that carry information in the brain – where the moment of emission of the pulse is an important element of the information. The processing can be done in an analogue manner, or using the physics of specific materials, as when implementing the STDP learning rule. These materials, storing the information of the neural network in "synapses", can be very small leading to the very dense and low-power realisation of Neural Networks that may also be compatible with the inference phase of Deep Learning approaches.

Reservoir computing can be seen as a kind of recurrent neural network where only the parameters of the final output are trained, while all the other parameters are randomly initialised and where some conditions are applied. It can be implemented with optoelectronics [35].

### 9.3.4.3. Optical computing

Optical computing has been an active topic of research for some decades and while it has not become mainstream, it is still alive today. It is not only university groups that study the issues of optical computing, in either hybrid or pure optical solutions, but also companies, one example being Hewlett Packard Labs which designed an all-optical chip that features 1052 optical components to implement an Ising machine (see: http://spectrum.ieee.org/semiconductors/processors/hpes-new-chip-marks-a-milestone-in-optical-computing ). This chip demonstrates that advances in all-optical information processing, including digital and analogue, classical and quantum as well as those based on Turing computation, are still being made.

We refrain from describing all possible and different approaches to optical computing in detail, as there are quite many, but it is clear that the topic is not dead and deserves to be considered as an alternative implementation to computing with far-reaching consequences. Although some considered the field of optical processing to have passed its peak, the 2010s have since seen a clear resurgence in activity, around new approaches in quantum and analogue mesh and phase-based computing.

### 9.3.4.4. Spin-based computing

Spintronics can be an alternative for new generation of AI hardware architecture providing small computing approaches and with ultra-low consumption [36]. Furthermore, magnonics (information processing via spin quanta, i.e., magnons) is considered one of the most promising Beyond-CMOS technology [37]. The importance of Spintronics for low-energy consumption is well documented in Europe and abroad. One example from IMEC [38] (Leuven, Belgium) compares a spin wave device with a 10nm FinFET CMOS technology; another example from Ohno's group (Tohoku University, Japan) shows a reduction of energy consumption of more than 80% when specific logic functionalities are addressed by spin-based solution [39].

Indeed, the core aspects of novel spintronic applications [40] are the building blocks for future CPSs: storing, sensing, computing and communicating. Novel approaches (e.g., skyrmions and all-optical switching) permit information to be stored and manipulated faster and with a smaller footprint towards a "universal memory"; spin-based devices (e.g., Tunnel Magneto Resistance) permits going beyond the performances of existing sensors to respond to the growing needs of automotive and IoT markets, together with the automation requested by Industry 4.0. Spin-based devices combining energy harvesting, simple front-end analogue treatments and communicating functionalities at varying frequencies of the EM spectrum (from MHz to THz), will provide novel solutions to sense, compute and exchange information with almost no energy consumption and weight, also useful for IoT or novel

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35 *L. Larger, M. C. Soriano, D. Brunner, L. Appeltant, J. M. Gutierrez, L. Pesquera, C. R. Mirasso, and I. Fischer, "Photonic information processing beyond Turing: an optoelectronic implementation of reservoir computing," Opt. Express 20, 3241-3249 (2012)*

→

36 *J. Grollier et al., "Spintronic Nanodevices for Bioinspired Computing" Proceedings of the IEEE, Vol 104, 2024 (2016) [http://ieeexplore.ieee.org/document/7563364/]*

37 *A. V. Chumak, V. I. Vasyuchka, A. A. Serga, B. Hillebrands, Magnon spintronics. Nature Physics 11, 453 (2015)*

38 *O. Zografos et al., "Design and benchmarking of hybrid CMOS-Spin Wave Device Circuits compared to 10nm CMOS" Proceedings of the 15th IEEE International Conference on Nanotechnology July 27-30, 2015, Rome, Italy [http://ieeexplore.ieee.org/document/7388699]*

39 *T. Hanyu et al., "Standby-Power-Free Integrated Circuits Using MTJ-Based VLSI Computing" Proceedings of the IEEE, vol. 104, 1844 (2016) [doi:10.1109/JPROC.2016.2574939]*

40 *SPINTRONICFACTORY (STF) (http://magnetism.eu/spintronicfactory)*

robotic systems. Indeed, the breakthrough R&D on spin-transfer torque oscillators and spin wave computing will nourish the future market of spin logic (Beyond CMOS) and give the relevant hardware solutions for neuromorphic computing.

Thus, implementing spin-based technology together with existing CMOS, will permit both challenges of low energy consumption and memory wall to be solved, providing a solution that is more compact, with reduced consumption and even autonomous in the long term.

#### 9.3.4.5. Scope and ambition

Shrinking transistors have powered 50 years of advances in computing, but now, for both technical and financial reasons, other ways must be found to make computing more capable. What's next will be more exciting: several new emerging technologies are expected to be available within the next five years such as quantum computers, which have the potential to be millions of times more powerful than current technology and neuromorphic computing, which provides chips that are thousands of times more efficient than current technology (see previous challenge), or using spintronic or photonic to compute and store information.

#### 9.3.4.6. Competitive situation and game changers

Even for those new emerging technologies, the starting line is not the same for all actors and hence a levelling in terms of investment is necessary in order to catch up with the original delay.

Europe is starting an action on quantum computing (a Flagship project) and a good synergy should be developed with ECS.

Concerning Neuromorphic Computing, Europe is still in the race, and the development of advance neuromorphic systems (and the supporting software and system integration) should be promoted and applied to industrial problems developed in this SRA, such as CPS and autonomous systems.

#### 9.3.4.7. High priority R&D&I areas

These new technologies require strong investments at all levels varying from hardware to software and integration with classical technologies. Indeed, in a first approach, new accelerator technologies combined with classical computing are being considered to solve specific classes of problem. The best strategy is still to adopt a "meet-in-the-middle" approach, working on many aspects (software, hardware, integration, algorithms) of those technologies at the same time until converging to exploitable solutions.

#### 9.3.4.8. Expected achievements

Within 5 years new acceleration solutions are expected to come from integrating those emerging technologies with classical computing platforms to effectively support specific industrial problems.

# 9.4. MAKE IT HAPPEN

## 9.4.1. Educational challenge

For both the medium (2020) and long (beyond 2020) terms, the [r]evolution in computing requires a complete flattening of methods and techniques in hardware design (scaled-up architecture, heterogeneity, size, etc.), software development (massive parallelism, new concepts, etc.) and applications (new modelling, mathematical background). This in turn creates major challenges in computing education in order to provide skills and competencies for the next generation of computing.

## 9.4.2. Organise the computing community

It is important to organise the computing community, and increase the exchanges between the application owner and computing and storage specialist, in order to actively drive the innovation. Inside the computing community, synergies should be increased between the High-Performance Computing and Embedded System communities, and also between the compilers and tools and the hardware architects. Initiatives are being taken in that field, mainly by CSA (Coordination and Support Action).

## 9.4.3. Standardisation

For the medium term, standardisation is on smart interfaces, communication protocols and programming models to support heterogeneous architectures and massive computing. For emerging technologies, such as quantum computing and neuromorphic computing, standards are still to be defined and adopted by the computing community.

## 9.4.4. Foreign export restriction

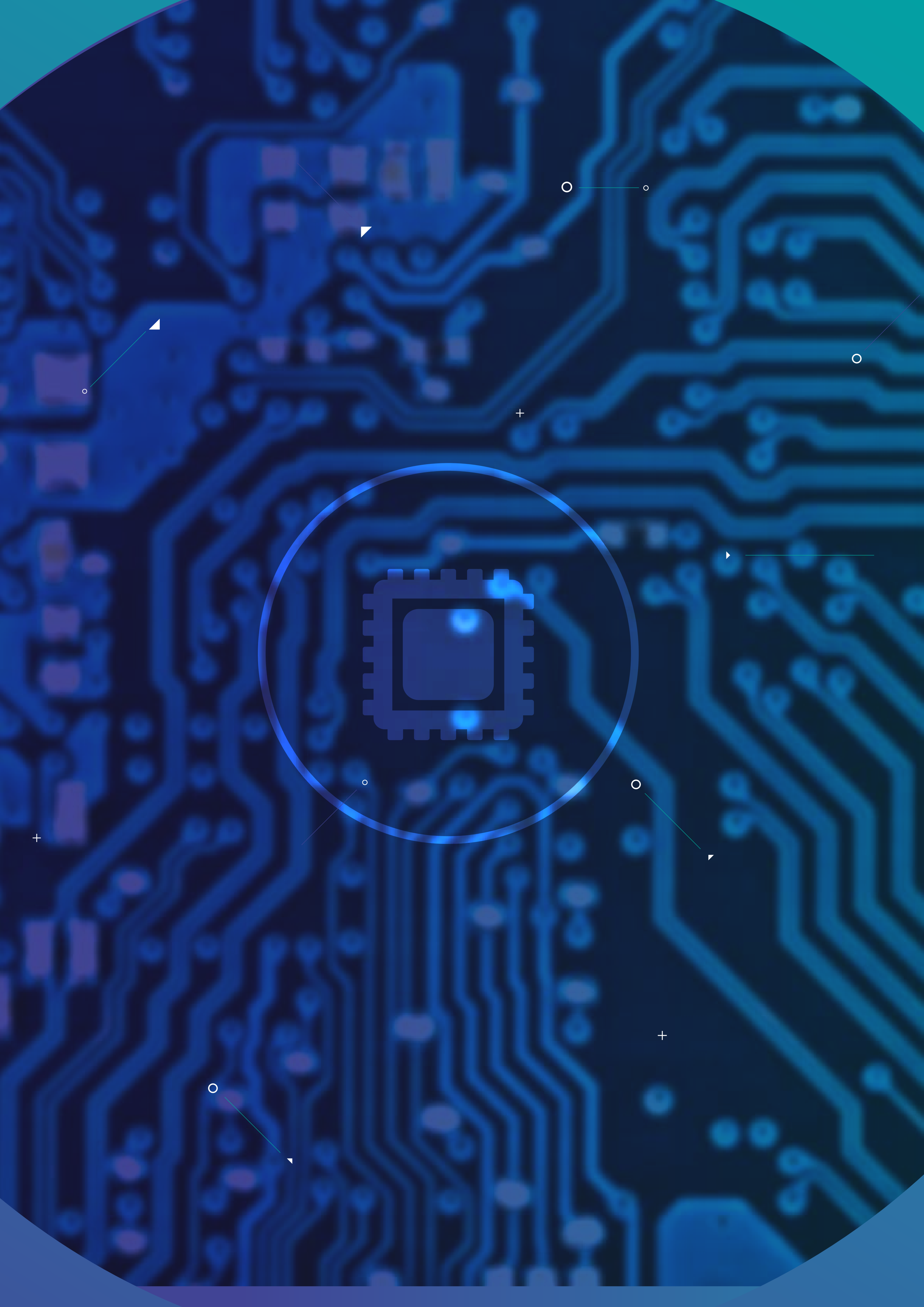
Export restriction can be a roadblock to making and selling European computing systems. Some key non-European components can be restricted or banned from re-export to some countries, even if the product using them is made in Europe. It is therefore a drive to have European technology for those components, which will give to European companies more freedom in the availability of key components and markets. US export restrictions (one of them is ITAR, see annex), were at the origin of the development by China of its own processor and HPC machine, which was at the top of the top500 in 2017.

# 9.5. TIMEFRAMES

The following table illustrates the roadmaps estimated for computing and storage.

| CHALLENGE | TOPIC | 2017 | 2020 | 2025 | 2030 |
|---|---|---|---|---|---|
| Computing Performance | HPC | Peta Computing<br>n105 cores, xPB memory<br>10-15 MW | | Exascale Computing<br>n106 cores, xEB memory<br>20-30 MW | |
| System Integration | CPS | Integrated Computing (MPSoc, n102 cores)<br>Expanded Autonomy<br>Security Architectures | | Autonomous Architectures (n103 cores)<br>Adaptable Systems | Pervasive Computing |
| | | Design Methodology<br>Feedback Systems CyberSecurity | | Edge Computing | |
| Disruptive Technologies | Quantum Computing | Simulation/Emulation<br>(5-50 Qubits) | | Universal Quantum Computer | |
| | Optical Computing | 160PF, 640Pb/s, 11pJ/bit | | 10EF, 40 Eb/s, 250 FJ/bit | |
| | Neuromorphic Computing | 4.00E+09 Neurons<br>1.00E+12 Synapses<br>4KW | | 1.00E+10 Neurons<br>1.00E+14 Synapses<br>1KW | |

**F.45** *Computing and Storage roadmap*



# 10

# *Electronics Components & Systems Process Technology, Equipment, Materials and Manufacturing*

# 10.1. EXECUTIVE SUMMARY

Technological challenges arise from future technologies such as Internet of Things, Big Data, 5G and beyond networks and Industry 4.0. These challenges require advances in Moore's Law (More Moore, MM), in additional functions (More than Moore, MtM), in optimising existing technology nodes, and in integration and manufacturing schemes, well into the next decade.

Furthermore, European industry in sectors such as healthcare, automotive, energy, smart cities and manufacturing strongly depends on the timely availability of highly specialised electronics devices enabling added value and new functionalities in their products.

Independent access to semiconductor technology for the manufacturing of function-critical Electronics Components and Systems (ECS), and their development and manufacturing in Europe are indispensable for meeting the challenges of the European society.

ECS manufacturing in Europe requires access to advanced materials and equipment and competitive manufacturing techniques. The latter are a self-sustaining sector of European importance and form the base of the ECS manufacturing value chain.

Consequently, the European position must be reinforced through leadership in all relevant technologies by driving the following Major Challenges:

- Developing advanced, logic and memory technology for nanoscale integration and application-driven performance;
- More than Moore and Heterogeneous System-on-Chip (SoC) Integration;
- Advanced smart System-in-Package (SiP) applications;
- Maintaining world leadership in Semiconductor Equipment, Materials and Manufacturing solutions.

# 10.2. IMPACT

The European semiconductor ecosystem employs approximately 250,000 people directly and is at the core of innovation and competitiveness in all major sectors of the continental economy. The semiconductor equipment and semiconductor materials sectors employ more than 100,000 individuals in Europe, the majority of them in jobs requiring a high level of education. The overall value chain of equipment, materials, system integration, applications and services employs over 2.5 million people in Europe. By launching new process and equipment technologies based on innovative materials, designs and concepts into pilot-lines, ECSEL projects will facilitate a strongly growing market share, increased employment and investments for innovative equipment, materials and for manufacturing of semiconductor devices and systems through European leadership positions in MM, MtM and SiP.

Whilst the manufacturing of electronic components and systems faces strong competition from East Asia and the US, the European semiconductor and smart system industry is able to keep its leading technological and commercial positions in domains in which Europe has an industry, for example in automotive, aircraft manufacturing, power generation and medical/healthcare. The goal should be to keep this industrial position. Europe can seize opportunities in these sectors for growth to provide electronic components and systems markets and help the European downstream industry to keep a leading global industrial position.

Europe's semiconductor manufacturing industry suppliers have a long history of successful mechanical engineering, tailor-made machinery, optical equipment, metrology, inspection and testing equipment, and chemical processing tools. In addition, there are suppliers of raw materials, ancillary materials and substrate materials in Europe that successfully export their products to global markets. This history of success has made Europe a world leader in several domains, foremost in lithography, metrology and silicon substrates, but also in thermal processing, deposition, cleaning, wafer handling as well as wafer assembly and packaging.

The path to Cyber Physical Production Systems will be significantly enabled by the early availability of innovative semiconductor, sensor and packaging technologies. Having a strong semiconductor portfolio "made in Europe" with early access for lead system suppliers is a winning competitive asset for Europe. The complete value chain must be covered to maintain the competitive situation of the European semiconductor process and integration technology. Ensuring the continuation of competitive manufacturing in Europe supported by a high level of excellence in manufacturing science and efficiency will reinforce the strong global positions of the downstream industry (security, automotive, aircraft manufacturing, power generation and medical/ healthcare). It will significantly contribute to safeguarding our strategic independence in critical domains and secure tens of thousands of jobs directly or indirectly linked to the semiconductor manufacturing.

Furthermore, through a traditionally strong and advanced educational system, and through the presence of world-leading research associations, Europe's R&D position throughout the whole stack of competencies is remarkable.

## 10.3. MAJOR CHALLENGES

Making process, integration and packaging technologies for advanced smart ECS (Electronic Components and Systems), and corresponding advanced equipment and materials and manufacturing techniques available, will address the increased demand for miniaturisation (repetition) and specialisation. This enables a strong technology-design-system-application interaction.

The following Grand Challenges have been identified:

1. Developing advanced logic and memory technology for nanoscale integration and application-driven performance;
   As already evidenced in the latest versions of IRDS (International Roadmap for Devices and Systems), device density and switching speed are no more the single performance indicator for logic devices. Low power (stand-by and operational) and high operating temperature are of greater importance for European critical applications like Health, IoT and Automotive/Industrial.

2. More than Moore and Heterogeneous System-on-Chip (SoC) Integration;
   The realisation of smart electronic components and systems for European critical applications requires complementing logic and memories with additional features, which are non-scalable with Moore's Law, to handle the functions of sensing, actuation, communication, data protection and power management. These heterogeneous functionalities can be integrated on the same System-on-Chip, such as for embedded memories, and for analogue and Smart Power, or realized as discrete components for SiP integration. Advanced technologies, processes and materials need to be developed for innovative More-than-Moore solutions. They enable innovative emerging applications, while leveraging synergies with processing and manufacturing technologies of More-Moore devices.

3. Advanced smart System-in-Package (SiP) applications;
   Advanced SiP technologies are required to deliver the functionality in meeting the demanding specifications and boundary conditions of major electronic component applications. The integration of more functionality in smaller volumes requires new assembly and packaging materials, compatible chip/package interfaces as well as heterogeneous integration of chips with different functionalities like MEMS/sensors, power chips, processors, or memory. The must be a special focus on electrical capabilities and temperature constraints to keep the applications robust and reliable.

4. Maintaining world leadership in Semiconductor Equipment, Materials and Manufacturing solutions.
   Defend and extend Europe's world leadership positions in Semiconductor Equipment, Materials and Manufacturing solutions.
   Supply European ECS manufacturing companies with 'best-in-class' equipment and materials, and flexible, agile and competitive semiconductor manufacturing solutions in the domains More Moore (MM), More than Moore (MtM) and System in Package, and thereby enable the European application sector to compete in world markets with top quality products.

### 10.3.1. Major Challenge 1: Developing advanced logic and memory technology for nanoscale integration and application-driven performance.

Semiconductor process technology and integration actions will focus on the introduction of materials, devices and new concepts, in close collaboration with the equipment, materials and modelling/simulation communities to allow for the diversity of computing infrastructure needed.

The applications range from high performance, over mobile and edge computing to ultra-low power data processing at IoT node level. This challenge includes three areas of attention at transistor level: (i) extensions of the scaled Si technology roadmaps (including FD SOI, FinFET/Trigate and stacked, Gate-All-Around horizontal or vertical nanowires, 3D integration), (ii) exploration and implementation of materials beyond Si (III-V, SiGe, Ge) and (iii) novel device, circuit and systems concepts for optimum power-performance-area-cost specifications, high energy efficiency and novel paradigms like neuromorphic computing. Long-term challenges also include Steep Slope Switches (Tunnel FET, FeFET, NEMS) and spin-based transistors, and alternative materials (2D, CNT, Ferroelectric, Magnetic, etc.).

New memory concepts will be targeted to support the correct memory hierarchy in the various applications. An example is the opportunity to push new memory concepts (RRAM, PCRAM, STT-MRAM) to the demonstration level in the IoT infrastructure (from server, over edge to nodes). These alternative memories need the development of advanced novel materials (magnetic, phase-change, nanofilament). A much closer collaboration between device teams and system architects is indispensable in the future. New markets will require storage class memory to bridge the performance gap between DRAM and NAND. Internet of Things applications will require low-power embedded devices and cloud computing with more mass-storage space. The standard memory hierarchy is challenged.

Simultaneously, advanced interconnect, SoC integration and packaging challenges will need to be addressed (cf also challenges 2 and 3), where innovative solutions to reduce the cost are required. The options to use advance 3D and Optical I/O technological solutions circumventing limitations of the traditional I/O's architectures are strengths to foster and build in Europe.

In order to maintain the European competencies in advanced design for integrated circuits and systems, a close link with a strong effort in semiconductor process technology and integration has to be maintained. Issues like the creation of standards for IoT, reliability for safety or mission-critical applications, security and privacy requirements need close collaboration among all actors to build leadership going forward in this coming generation of advanced and distributed computing infrastructure and diversified system performance.

#### Expected achievements

Maintaining competence on advanced More Moore technology in Europe to support leading edge manufacturing equipment development. Implementation of pilot lines for specialised logic processes and devices supporting European critical applications. Exploration of new devices and architectures for low-power or harsh environment applications.

### 10.3.2. Major Challenge 2: More than Moore and Heterogeneous System-on-Chip (SoC) Integration

This section covers More than Moore single chips (RF, bio, power, optical, etc.) and the integration of different functionalities like, CMOS logic, NVM, MEMS, Analogue, power etc on a single chip. Depending on the application, advantages of heterogeneous SoC technology can be size, cost, reliability, security and simpler logistics. Therefore, this technology is seen as a key enabler for the European industry. To maintain and strengthen Europe's position it is necessary to improve existing technologies and to integrate emerging technologies. All application domains addressed by the ECS agenda will benefit from components with very diverse functionalities.

Specific process technology platforms may be requested as in the case of biomedical devices for minimally invasive healthcare, or mission-critical devices in automotive, avionics and space.

Semiconductor process and integration technologies for enabling heterogeneous functionality will focus on the introduction of novel (nano-)materials and advanced device concepts. A non-exhaustive materials list includes wide bandgap materials, III-V and 2D materials, organic, ferroelectric, thermoelectric and magnetic thin films as well as packaging materials. At the functionality level, the introduction of innovative RF technologies, integrated logic and embedded NVM, photonics, 3D integration technologies, power devices, MEMS and sensor systems is looked for. The driver for their integration is always a clear demand from the application domain. To maintain Europe's position, the focus should be on emerging technologies as they come along as well as new developments in the equipment and materials industry, in which Europe has a leading position. Furthermore, the early generation of models and their initial validation for benchmarking and IP generation are required. More specifically the following challenges are identified (non-exhaustive).

Digital functionality is specifically treated in section 7.1, but it is evident that Heterogeneous System-on-Chip (SoC) Integration will require specific solutions for the following challenges:

- Embedded non-volatile memories for smart functional devices
- Energy-efficient computing and communication, including a focus on developing new technologies, architectures and protocols.
- Development of Ultra Low Power (ULP) technology platform and design.

Analogue functionality will be introduced in systems through:

- Integrated application-defined sensor technologies. With the recent success in mm-wave sensors and MEMS devices enabled by high-volume semiconductor manufacturing capabilities in automotive and consumer applications (acceleration, radar, microphones, environmental sensors) the progress will be on further integration, miniaturisation and packaging, surface conditioning, structuring and innovation in selectivity.
- New RF and mm-wave integrated device options, incl. radar (building on e.g. SiGe/BiCMOS, FD-SOI, CMOS).
- Photonics-enabled device and system options.

Analogue functionality is a domain where process technology exploration for functional integration of novel materials (e.g. TMDs, Thermal- and Piezo electric, Ferroelectric, Magnetic, 2D materials and organics, e.a.) for various applications is essential.

Moreover, power devices for energy and power management as well as energy-efficient components and systems are in high demand:

- Power electronics with a myriad of options such as higher power density and frequency, wide-gap materials, new CMOS/IGBT processes, integrated logic, uni- & bipolar; high voltage classes, lateral to vertical architectures
- Continuous research on performance, efficiency, power density and reliability aspects – either through further thinning of wafers, topologies and material compositions
- Energy harvesting, micro batteries, supercapacitors and wireless energy.

Also, packaging requirements, power budget restrictions and manufacturing conditions need to be taken into account specifically in defining the roadmaps of future generations of these components. There should be a special focus on chip-package interaction, e.g. with respect to stress, EMC, temperature and application specific environmental integrity.

Manufacturing specific elements for the More than Moore and Heterogeneous System-on-Chip (SoC) Integration requires specific focus:

- Cope with high volumes and high quality (for e.g. power semiconductors, sensors and MEMS devices)
- Enable flexible line management for high mix, and distributed manufacturing lines
- Productivity enhancements (e.g. wafer diameter conversions) for MtM technologies to significantly improve cost competitiveness

It will also require adapting factory integration and control systems to adopt industry 4.0 principles to the manufacturing environment in Europe, a clear area for synergy with the manufacturing challenge in this agenda.

#### Expected achievements

Implementation of pilot lines for integrated application-defined sensors, including packaging, the same for new RF and mm-wave device options including radar, photonics options as well as packaging solutions and power electronics. Initiation of the creation of process technology platforms for biomedical devices for minimally invasive healthcare applications and packaging. Exploration of functional integration of novel materials.

### 10.3.3. Major Challenge 3: Heterogeneous System-in-Package (SiP) integration

This chapter covers the integration of chips of different functionalities like CMOS logic, NVM, MEMS, Analogue, etc into a SiP. Depending on the application heterogeneous SiP technology can provide a better compromise between functions available, performance and time to market.

Therefore, this technology is also seen as a key enabler for the European industry. To maintain and strengthen Europe's position it is necessary to improve existing technologies and to integrate emerging technologies. All application domains addressed by the ECS agenda will benefit from innovative system-in-package components.

Integration of the above functionalities in miniaturised (sub-)systems in a package requires fundamental insight into application needs and system architecture. Process technology to realise this integration is part of the third major challenge and is essential for Europe's prominent role in supplying solutions for the various application domains.

Compared to chip technology, assembly and packaging are becoming more important. Today in many cases assembly and packaging costs are higher than the chip cost. To tackle this trend, we must focus on SiP process technologies that take into account all the level; chip, package and board/system, and find the optimum trade-offs between function, cost, power, reliability, etc.

To remain economically sustainable and globally competitive a toolbox must be set-up which includes process technologies that provide cost-effective and outstanding system-in-package integration, such as 3D interconnect technologies, fan-out technologies. .....

As for System-on-Chip integration, due to the miniaturisation and increasing functional density of SiPs, it is important to consider chip package interaction, e.g. Power, Thermal, Mechanical, Stress, EMC, etc. In addition, the interfaces to the system/board need to be considered. For example, a MEMS device which requires a carefully designed package for optimum performance.

At macro-scale level, a system can be seen as consisting of a collection of large functional blocks. These functional blocks have quite different performance requirements (analogue, high voltage, embedded non-volatile memory, advanced CMOS, fast SRAM, …) and technology roadmaps. Therefore, for many applications it is of increasing interest to split the system in heterogeneous parts, each to be realised by optimum technologies at lower cost per function, and assembled parts using high-density 3D interconnect processes. It is clear that 3D integration in electronic systems can be realised at different levels of the interconnect hierarchy, each having a different vertical interconnect density. Different technologies are therefore required at different levels of this 3D hierarchy.

Research and development priorities are on:

- Innovative interconnect technologies that allow vertical as well as horizontal integration. This includes process technologies for vertical interconnects like Through Silicon Via (TSV), Through Encapsulant Via (TEV) technologies and microbumps as well as process technologies for horizontal interconnects like thin film technologies for redistribution both on chips and on encapsulation materials. A technology base is needed for 3D stacking as well as horizontal interconnecting of dies.
- Encapsulation technologies, handling carriers as well as panels which on the one hand protect dies, and on the other hand allow optimum electrical performance. Chip embedding technologies like chip embedding in mould material (e.g. fan-out WLP or eWLB technologies) and chip embedding in laminate material, for both of which Europe already has a strong capability, must be sustainably supported to prepare the next generation.
- Process technologies for integration of additional functionality like antennas or passive devices into a system-in-package. This additional functionality will be an enabler for new applications.
- High integration density and performance driven 3D integration (power/speed). For this category, denser 3D integration technologies are required: from the chip I/O-pad level 3D-SIC, to finer grain partitioning of the 3D-SOC and the ultimate transistor-level 3D-IC (See Section 7.1 for the 3D landscape).
- Reliability and quality. For this a close consideration of the chip/package interaction, but also of the interaction of chip/package to the board is required. Research and development in this area need a strong link especially with materials and their compatibility, also taking into account the heat dissipation challenges. In the last 10 years nearly all assembly and packaging materials have changed and in the next 10 years it is expected they will change again. Also, a close link with the design chapter is crucial.
- Chip-Package-Board co-design. This will be of utmost importance for introducing innovative products efficiently with short time to market and this work is closely linked to the work described in Chapter 6 of this SRA.
- System integration partitioning: The choice of the 3D interconnect level(s) has a significant impact on the system design and the required 3D technology, resulting in a strong interaction need between system design and technology.

System requirements and semiconductor device technology (Challenge 1 and 2) will evolve at the same time, creating momentum for further interconnect pitch scaling for 3D integration technology platforms. Hence, the timelines of all 4 challenges of this chapter are strongly connected.

**Expected achievements**

Keep SiP manufacturing in Europe through research and development of proper processes e.g. parallel processing similar to front-end technologies and wafer level processing, as well as with increasing automation and logistics. Special care should be taken to address reliability and quality.

Process technology development for multi-chip embedding and flexible substrates. Process technology for heterogeneous chip integration. Continuous improvement of materials aspects and thermal management, including high temperature package characterisation and modelling.

### 10.3.4. Major Challenge 4: Maintaining world leadership in Semiconductor Equipment, Materials and Manufacturing solutions

The equipment, materials and manufacturing sector in Europe is a standalone sector providing the world market with best-in-class technologies to enable manufacturing of miniaturised Electronics Components. As this field and sector covers such a wide range of process technologies, this major challenge is divided into 3 sub-challenges:

- More Moore (MM): Develop European knowhow for advanced equipment, materials & processes for sub-10nm semiconductor devices & systems manufacturing
- More than Moore (MtM) and SiP: Strengthen European competitiveness by developing advanced MtM equipment, material and manufacturing solutions for front-end-of-line (FEOL) and back-end-of-line (BEOL) wafer processing and device (including SiP and SoC) as well as assembly and packaging (A&P)
- Manufacturing Technologies: Develop new fab manufacturing and appropriate equipment & manufacturing solutions that support flexible, agile and competitive semiconductor manufacturing in Europe and supply the worldwide market with correspondingly ‘best-in-class’ hardware and software products.

#### 10.3.4.1. More Moore

This sub-challenge targets the development of new equipment and material solutions for sub-10nm semiconductor technologies that enable high-volume manufacturing and fast prototyping of electronic devices in CMOS and beyond CMOS technologies, and therefore will allow the world market to be supplied with technology leading, competitive products. The overarching goal of the equipment and material development is to lead the world in miniaturisation techniques by providing appropriate products two years ahead of the shrink roadmap of world’s leading semiconductor device and components manufacturers. Internationally developed roadmaps such as the IRDS (International Roadmap for Devices and Systems) will also be taken into consideration.

Accordingly, research and development is needed to facilitate innovations for, among others:

- Advanced lithography equipment for sub-10nm wafer processing using DUV and EUV, and corresponding sub-systems and infrastructure, and mask manufacturing equipment for sub-10nm mask patterning, defect inspection and repair, metrology and cleaning.
- Advanced holistic lithography using DUV, EUV and Next Generation Lithography techniques such as e-beam and mask-less lithography, DSA and Nano-Imprint.
- Multi-dimensional metrology (MDM) and inspection for sub-10nm devices which combines holistic, hybrid, standalone setups (of Optical, fast AFM, E-Beam, scatterometry, X-Ray and STEM technologies) for mapping the device material and dimensional properties and defectivity, with productivity aware design (PAD) techniques such as: recipe automation, fleet management, ‘close-

to-process' monitoring and support big data management with predictive methodologies.

- Thin film processes including thin film deposition, such as (PE)ALD and PIII for doping and material modification, and corresponding equipment and materials.
- Equipment and materials for wet processing, wet and dry etching, thermal treatment, laser annealing, and wafer preparation.
- Si-substrates, Silicon on Insulator substrates, SiC, III-V materials, advanced substrates with multifunctional layer stacking (e.g. highly dense 3D), including insulators, high resistivity bulk substrates, mobility boosters, corresponding materials, manufacturing equipment and facilities.

**Expected achievements**

The European E&M industry for advanced semiconductor technologies is keen to lead the world in miniaturisation by supplying new equipment and new materials approximately two years ahead of the volume production introduction schedules of advanced semiconductor manufacturers. The main focus will be on equipment and materials for lithography, metrology and wafer processing including the respective infrastructure for sub-10nm technologies.

#### 10.3.4.2. More than Moore

More-than-Moore (MtM) technologies will create new technological and business opportunities and demand new skills and knowhow in areas such as 3D heterogeneous integration and advanced system-on-chip (SoC) solutions. The overall goal for European E&M companies is to enable semiconductor manufacturing companies to produce More than Moore Electronics Components and Systems, such as sensors and sensor systems, MEMS (Micro-Electro-Mechanical Systems), advanced imagers, power electronics devices, automotive electronics, embedded memory devices, mm-wave technologies, and advanced low-power RF technology.

For MtM, which is a definite European strength, 200 mm as well as 300 mm technologies will be the main focus. For system integration equipment capable for combining chips from both wafer technologies is required.

In the coming years, 3D integration and SoC manufacturing will add complexity to the global supply chain and generalise the concept of distributed manufacturing. This will require the development of new concepts for Information and Control Systems (see Major Challenge 3). The interfaces and handovers between wafer technologies and A & P need to be clearly defined and require innovative equipment.

MtM technologies will require working more closely together, combining front-end wafer equipment and assembly and packaging (A&P) equipment. Technologies and methodologies well established for Si wafers will partially be reused and adapted for A&P.

New materials and equipment will be required for future A&P, creating new R&D challenges and business opportunities. Over the last decade, nearly all assembly and packaging materials have been replaced by more advanced materials - a process that is expected to continue. This will have a strong impact on future processes and equipment.

More-than-Moore and heterogeneous SoC and SiP integration will pose significant challenges and therefore requires R&D activities in a multitude of fields. Equipment and material research must drive the general technology trends in respect to miniaturisation and integration of more functionality into a smaller volume and with higher efficiency. Application dependent reliability and heat dissipation are very important. Examples for necessary research on equipment and materials are:

- 3D integration technologies (e.g. chip-to-wafer stacking),
- Chip embedding technologies (e.g. fan-out WLP),
- Substrates for RF and power electronics devices
- Vertical (e.g. TSV or micro flipchip bumping) and horizontal interconnects (e.g. RDL, thin film technology),
- New processes (e.g. reliable die attach, thinning, handling, encapsulation) for reliable as well as heterogeneous system integration technologies
- Failure analysis in-line and off-line
- Metrology for SiP devices

**Expected achievements**

More-than-Moore processes and E&M can be partially sourced from previous-generation CMOS infrastru ctures. However, new technology generations will also require capabilities which are not yet available in advanced CMOS fabs.

Today's More than Moore equipment is typically designed for high-volume continuous production in a More Moore environment, which requires major modifications or re-design. The performance of any future MtM production tools must be enhanced for smaller batch production providing high flexibility and productivity at low Cost-of-Ownership (CoO).

Furthermore, the similar trend in MtM solutions of ever-decreasing feature size, with ever-increasing number of features, and interconnects packed onto an IC, puts strong demands on product validation and verification methodologies and on test methodologies and respective equipment.

#### 10.3.4.3. Manufacturing technologies

The sub-challenge 'Manufacturing' focuses on research and development in E&M to enable highly flexible, cost-competitive, 'green' manufacturing of semiconductor products within the European environment. The overarching goal is to develop fab management solutions that support flexible and competitive ECS manufacturing in Europe, as well as the world market.

For that, aspects of digitalisation including Industry4.0 need to be incorporated, with a focus on resilient and sustainable manufacturing, and the move from "APC-enabled" equipment to cyber-physical systems. The developed solutions should include innovations for resource saving, energy-efficiency improvement and sustainability, without any loss of productivity, cycle time, quality or yield performance, and at reduced production costs. Furthermore, it will be key to adapt workflows to new, data-driven manufacturing principles adopting Artificial Intelligence, Big Data and deep learning methods.

Solutions for manufacturing will have to address related challenges, respecting Industry4.0 principles, and are similar for both manufacturing domains: Innovative solutions are required to control the variability and reproducibility of leading-edge processes. This implies that domains traditionally seen as disconnected (for example, Statistical Process Control (SPC), Fault Detection and Classification (FDC), process compensation and regulation, equipment maintenance and WIP (Work in Progress) management) will have to become tightly data driven and interconnected. Moreover, the blurring of the frontiers between these domains will require considerable consolidation of knowledge capitalisation and exchange of knowledge. Factory Integration and Control Systems will have to become modular and virtualised, allowing information to flow between factories in order to facilitate rapid diagnostics and decision-making, also through BYOD (Bring Your Own Device) concepts. Enhancing the data security in the fab environment is of increasing importance.

The focus of high-mix/low-volume manufacturing will be on flexible line management for high mix, and possibly distributed manufacturing lines as well as on reliability and quality. New manufacturing techniques combining chip and packaging technologies (e.g. chip embedding) will also require new manufacturing logistics and technologies (e.g. panel moulding etc.).

### Expected achievements

Future innovations should address new automation techniques and automation software solutions as well as innovative man-machine solutions. Furthermore, also new environmental solutions (e.g. in terms of energy consumption, chemical usage) and in this regard new materials (for example, in terms of quality, functionality, defectivity) will be needed.

Generic solutions are required for current and future fabs that allow high-productivity manufacture of variable size, and energy-efficient, sustainable, resource-saving volume production. The introduction of big data based control system architectures, making use of high-performance computing systems, should allow for fab digitisation, including predictive yield modelling and holistic risk and decision mastering. This requires the integration of control methods and tools and knowledge systems.

Focal topics should include factory operation methodologies, data acquisition and analysis concepts, factory information and control systems, materials transport as well as local storage and fully automated equipment loading/unloading.

Further opportunities will emerge from the drive towards "Industry 4.0" in other industrial branches: cross-fertilisation is expected between solutions for semiconductor manufacturing and other manufacturers of high-value products, especially in the area of data-driven manufacturing optimisation (including big-data, machine learning, prediction capabilities, etc.).

## 10.4. STRATEGY

Focused projects in the TRL 2 to 5 are needed as technology push to enable new applications. Technologies will drive the realisation of industry roadmaps in MM, MtM and SiP. The required efforts include further CMOS scaling and related equipment development, power electronics, III-V and 2D materials, RF technologies, integrated logic, photonics, 3D integration technologies, MEMS and sensor systems, interlinked with key application challenges. Similarly, to enable the development and production of future generations of SiP hardware in Europe, world-leading research is needed to prepare the proper system integration technologies, Furthermore, attention will be given to emerging technologies and materials, and to new developments in the equipment and materials industry, in which Europe has a leading position.

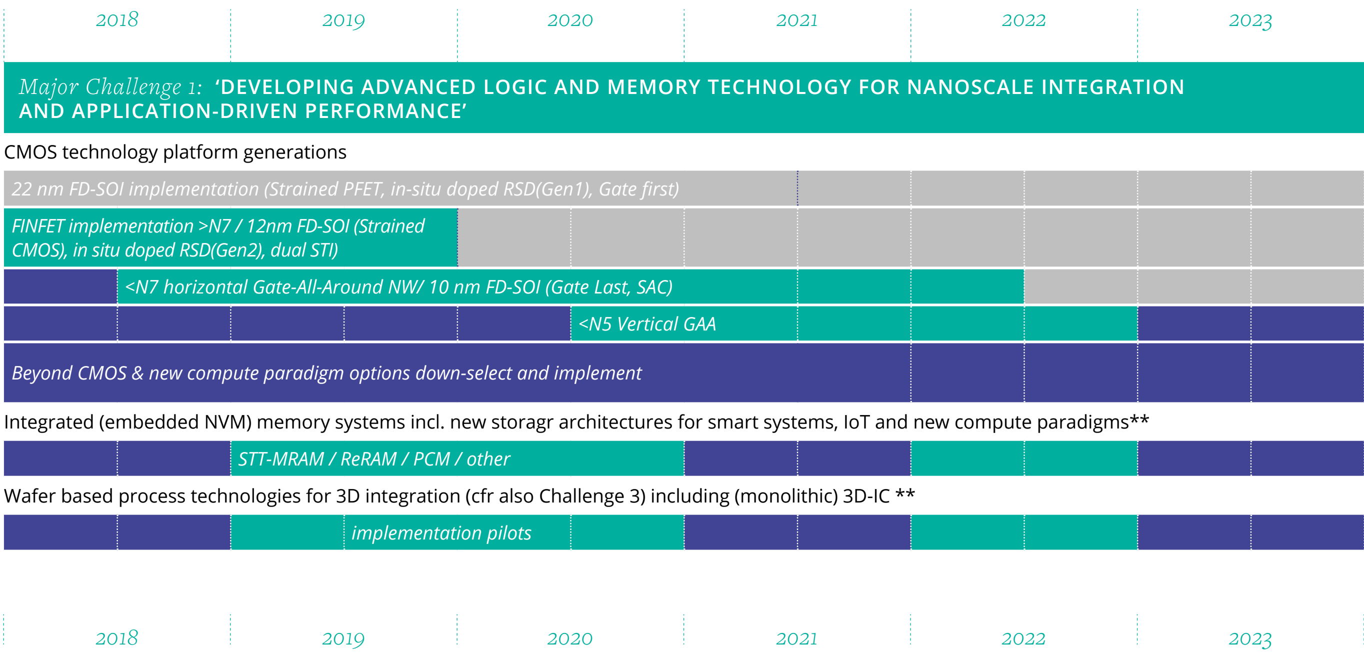
Extended projects will aim at pilot lines with an emphasis on TRL 4 to 8 to deliver industry-compatible flexible and differentiating platforms for strategic demonstrations and in order to sustain manufacturing competence, and on pilot lines for SiP hardware demonstration. Research and development on processing (front-end technologies, wafer level processing, assembly and packaging as well as automation and logistics), is a prerequisite to set up and to keep SiP manufacturing infrastructure in Europe.

Other TRL 4-8 project need to target test-beds and demonstration for emerging applications domains like IoT infrastructure, Industry 4.0, sustainable mobility, incorporating the advanced technologies, also under the umbrella of flagship projects.

More advanced R&D activities, at level 2-5 can be included also in pilot lines and test-bed projects at higher TRLs, to provide the fundaments to enable EU companies to set up their dedicated technology capability, and to prepare for next generation products in a sustainable way. This safeguards Europe's competitive position and will keep high-quality jobs in Europe.

A specific requirement of the European semiconductor manufacturing industry is the ability to cope with high volumes and high quality while enabling flexible line management for high-mix and distributed manufacturing lines. Therefore, manufacturing science projects and demonstrations at high TRLs are needed for the validation of new technologies and equipment, and for mastering cost-competitive semiconductor manufacturing in Europe, including packaging and assembly, while achieving sustainability targets (resource-efficiency and "green" manufacturing). It will require a productivity aware design (PAD) approach with focus on predictive maintenance, virtual metrology, factory simulation and scheduling, wafer handling automation and digitalisation of the value chain for artificial intelligence based decision management. In addition, attention should be given to big data based control system architecture: viz. predictive yield modelling, and holistic risk and decision mastering (integrate control methods and tools and knowledge systems).

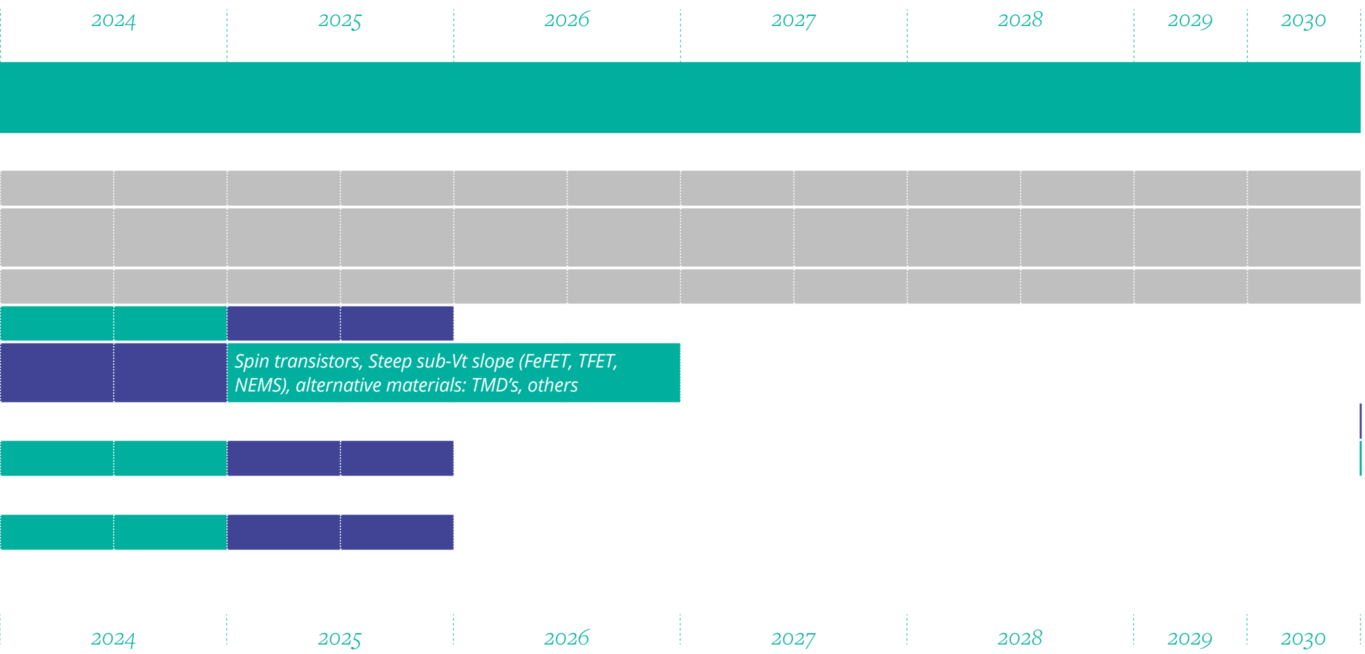
Attention should be given to university education in close collaboration with the industry in the above fields, for example by means of joint (Academia and Industry) courses, traineeships, and other support actions (incl. EC grants).



10.5.
# TIMEFRAMES

All leading European industry and research actors align their activities with international roadmaps and timelines. Roadmap exercises are being conducted in various projects and communities like NEREID and the recently announced IEEE IRDS in which European academia, RTOs and industry participate. For system integration also the iNEMI and the new Heterogeneous Integration Roadmap activities are considered The European R&D priorities are to be planned in synchronisation with the global timeframes and developments, which are under continuous adaptation. The timelines below are high-level derivatives from these global evolutions and follow the structure of the four major challenges described above:

1. Developing advanced, logic and memory technology for nanoscale integration and application-driven performance;
2. More than Moore and Heterogeneous System-on-Chip (SoC) Integration;
3. Heterogeneous System-in-Package (SiP) integration;
4. Maintaining world leadership in Semiconductor Equipment, Materials and Manufacturing solutions.



| 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|

## *Major Challenge 2:* 'MORE THAN MOORE AND HETEROGENEOUS SYSTEM-ON-CHIP (SOC) INTEGRATION'

Technology platform for integrated application defined sensors, including packaging **

*implementation pilots*

Process technology platforms for new RF and mm-wave integrated device options, incl. radar (SiGe/BiCMOS, FD-SOI, CMOS), photonics options, as well

*implementation pilots*

Process technology platforms for biomedical devices for minimally invasive healthcare **

*implementation pilots*

Process technology platforms for power electronics **
e.g. higher P density & freq., wide-gap, new CMOS/IGBT processes, integrated logic, uni-& bipolar, higher V-classes, lateral to vertical arch as well as packaging

Process technology exploration for functional integration of novel materials (e.g. Graphene, TMD's, FerroElectric, Magnetic, e.a. ) implemented in

*implementation pilots*

## *Major Challenge 3:* 'HETEROGENEOUS SYSTEM-IN-PACKAGE (SIP) INTEGRATION'

Process technology for multi-chip embedding (molded, PCB, flexible substrate, silicon) **

*Multi-die embedding (molded, la* — *implementation pilots* — *next gen systems /*

*... in flexible substrates* — *implementation pilots* — *next gen*

Process technology for heterogeneous and (2.5 & 3D) SiP integration **

*wafer level, interposer (Si), various technologies, e.g. GaN, SiC, Logic & power embedding, intelligent power modules, optical interc.*

*SiP Technologies (thin wafer/die handling, dicing, stacking)* — *next gen systems / new applications*

*Si interposer (TSV), passive, RF-SiP (glass) and sensor integration* — *next gen systems / new applications*

Continuous improvement of (i) Materials aspects, (ii) Thermal management
(iii) high temperature package (iv) Characterization & modleing, (v) Reliability & failure analysis & test

*continuous improvements* — *continuous improvements*

*iv) Characterization & modleing, (v) Reliability & failure analysis & test, but needs parallel ongoing basic reseach*

## *Major Challenge 4:* 'MAINTAINING WORLD LEADERSHIP WITH SEMICONDUCTOR EQUIPMENT, MATERIALS AND MANUFACTURING SOLUTIONS.'

More Moore: Equipment & Materials for sub-10nm semiconductor devices & systems manufacturing

*Equipment & materials for 7nm node °*

*Equipment & materials for 5nm node °*

*Equipment & materials for 3nm node °*

*Metrology & inspection equipment for 7nm node*

*Metrology & inspection for 5nm node*

*Metrology & inspection equipment for 3nm node*

*Equipment , Materials, Metrology & inspection for Beyond CMOS & new compute paradigm options*

More than Moore and Heterogeneous SoC & SiP integration equipment and materials

*Equipment enabling Heterogeneous Integration*

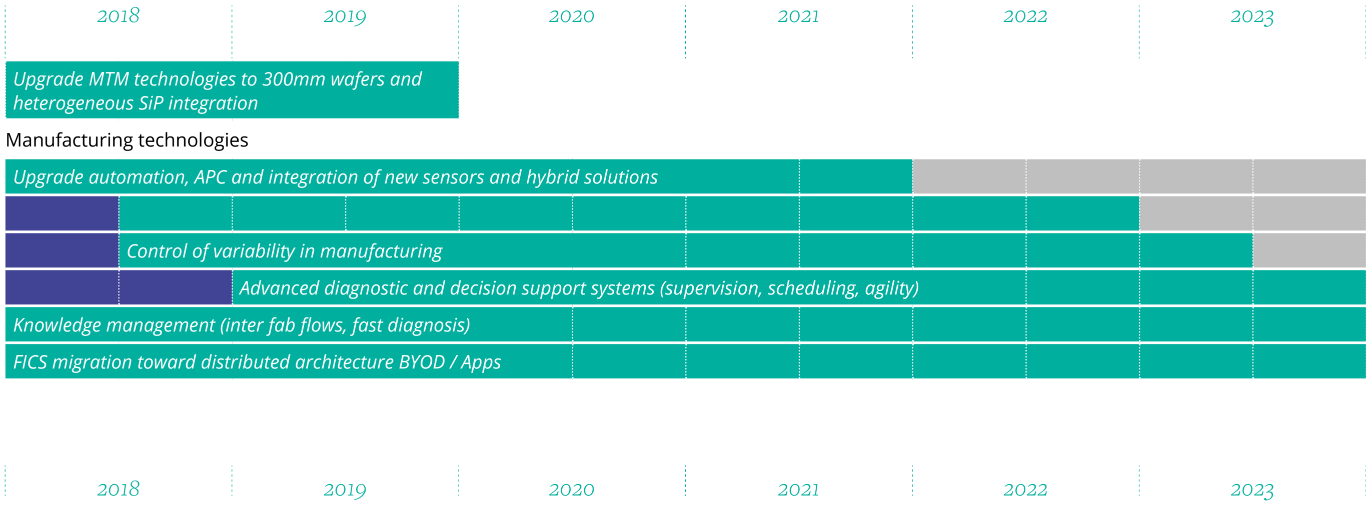
*Innovative materials enabling Heterogeneous Integration*

*Specific equipments and materials enabling innovative MTM devices and heterogeneous integration*

*E&M for further miniaturization and higher functional density for MTM*

| 2018 | 2019 | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|


2024
2025
2026
2027
2028
2029
2030
as packaging **
existing pilot line
new applications
systems / new applications
Equipment & materials for sub 3nm node °
Metrology & inspection equipment for sub 3nm node
(on chip & package level)
2024
2025
2026
2027
2028
2029
2030




° *Mask technology always 1.5 years ahead wafer technology*

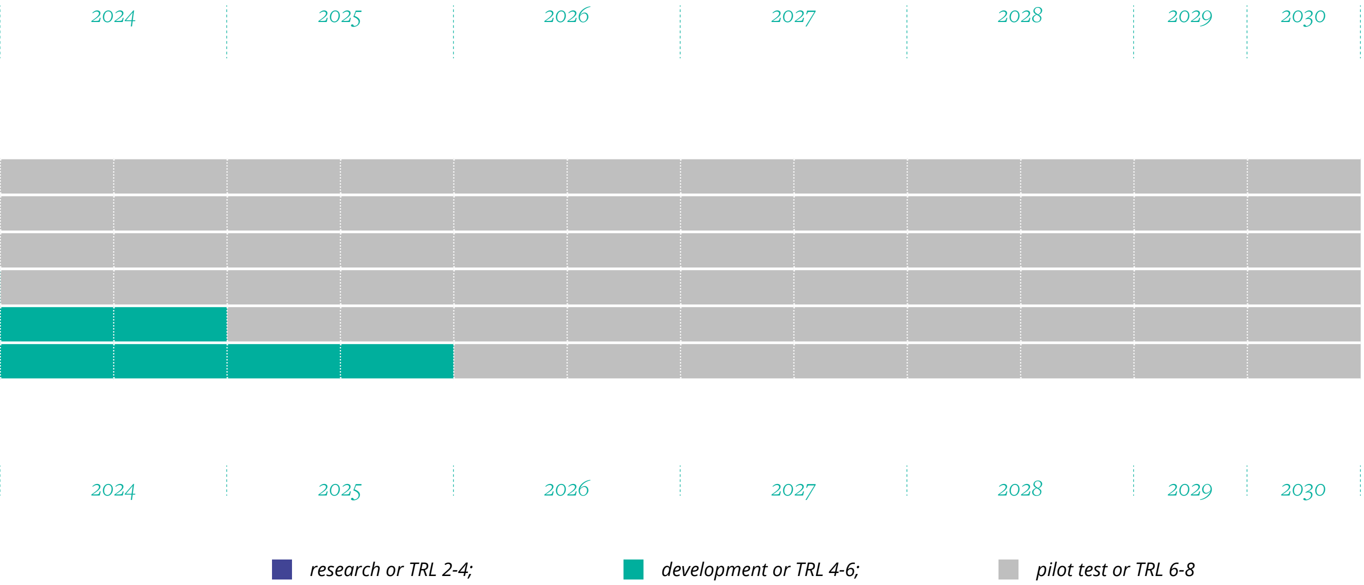
** *Multiple TRL cycles needed to work towards solutions for the challenges*

*VM - Virtual Metrology, PdM - Predictive Maintenance, BYOD - "Bring Your Own Device", FICS - Factory Information and Control System; Logic nodes definition*

For Challenge 1 the roadmap for process technology and device/system integration presents relatively clear timelines, although economic factors determine the speed of adoption in industrial manufacturing. Dedicated process technologies (e.g. low-power and high-operating temperature) will follow feature scaling with some delay, focusing on other performance indicators. Areas where the roadmaps are less clear (e.g. new computing paradigms) are introduced at low TRL levels although timelines are not very clear. Digitalisation of the European ECS value chains lacks well behind Asia and US. It needs attention and effort now to gain competitive advantages.

For Challenge 2 and Challenge 3 the timeline of the implementation of new technologies largely depends on the needs and roadmaps of the systems and will result from the interaction within application driven projects and test-bed initiatives. The timing of new Equipment & Manufacturing solutions for these challenges should be derived from the schedules of the major European semiconductor manufacturers. This includes roadmaps for key future semiconductor domains, such as automotive, health care, safety and security, power, MEMS, image sensors, biochips, lighting, etc. Fast implementation and modification of these new device technologies will pave the way for the technologies of tomorrow.

Firstly, the development of sub-10nm solutions in terms of equipment and materials as part of Major Challenge 4 needs to be 2-3 years ahead of mass adoption and are of critical importance to maintain European leadership. Secondly, new Equipment and & Materials solutions should be developed in line with the needs defined in the roadmaps of challenge 1 to 3. Lastly, improving manufacturing efficiency, and enhancing yield and reliability are ongoing tasks that need to be performed in accordance with the needs of the 'More Moore' and 'More-than-Moore' domains. Fundamentals of 'manufacturing science' will concern projects at rather low TRL levels (typically 3 to 5), whereas implementation in pilot lines and full-scale manufacturing lines will contemplate higher TRL level projects (typically 7 to 8). For most of the Manufacturing Science projects, the execution will be spread along medium to long-term time span, though shorter-term impact, such as improving uptime of equipment thanks to productivity aware design or the improvement of robustness of the manufacturing processes, will get due attention to enhance competitiveness.



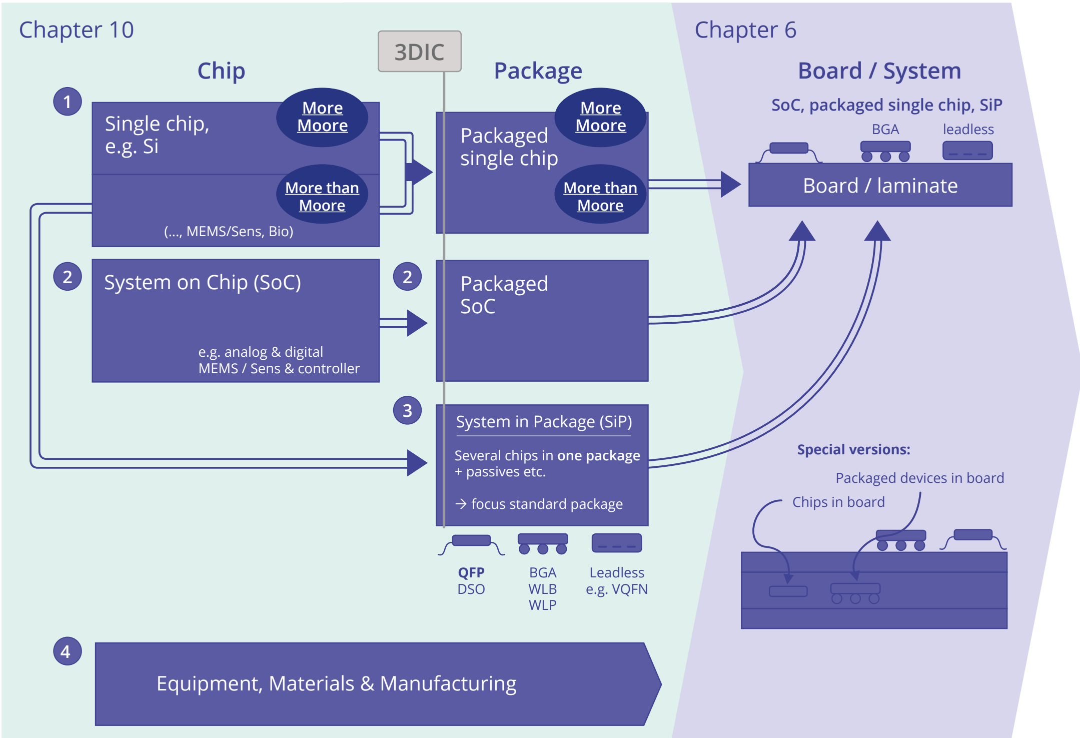

*Roadmap timeline for Process Technology, Equipment Materials and Manufacturing*

**F.46**

## 10.6.
## CROSS REFERENCES & SYNERGIES

Europe needs leadership throughout the value chain from process, materials and equipment to production of devices, systems and solutions and deployment of services to leverage Europe's strong differentiation potential and to drive its competitiveness.

System-Technology co-optimisation is key to all leading-edge innovations (see figure 47). Specific actions include: specification of technology and product roadmaps for the planning of future products, advanced access to new technologies for prototyping, cooperation on the development of dedicated technologies, advanced access to test-beds and markets.
The impact of technology choices on the application and vice versa is becoming very large and decisive in successful market adoption. This is true for all application fields but especially so where the communication, computing and sensing technology is key to deliver the expected (quality of) service or function, e.g. Industry, Automotive, Health. In this respect, one of the most important challenges ahead for Europe is the broad and deep implementation of IoT in the industry, together with so-called 'exponential technologies', jointly named "Industry 4.0". In order to meet the related challenges, the integration of the whole system must be considered. Therefore, the scope should not be restricted to semiconductor devices only; instead, research must be combined in all key domains of which the Industry 4.0 is composed and the importance of a consolidated effort cannot be overemphasised.




**F.47** *Close connection between electronics component development in this chapter with next level heterogeneous system integration in chapter 6*

## Collaboration with the design community

While there is traditionally a close link to the design community (Design - Technology co-optimisation is a well-known trend), these ties need to be further reinforced. The number of technology options, each with its own challenges, is exploding. Early and quantitative assessment of the gains, issues and risks is key to maximising the value of a technology for a given application. Likewise, technology development faces the same challenges to deliver a technology that suits the purposes of designers. Specific focal areas include: building, sharing and incorporating physical models of components, device electrical characteristics, models of degradation effects, data on parameter variability and dispersion. In response, there will be design solutions generated for process variability and process reliability, as well as for in package device integration with the modelling of thermal, mechanical and EMI effects. Use of advanced SW tools with well-calibrated physical parameters of electro-thermal models for the identification of critical issues, and for the generation of new devices with optimised properties.

These process technology and integration developments will be closely synergised with design efforts, and as such offer opportunities for building unique European IP to establish leadership in applications for global markets. This responds to the growing need for co-design efforts for security, energy efficiency, data management, distributed computing, etc.

# 11

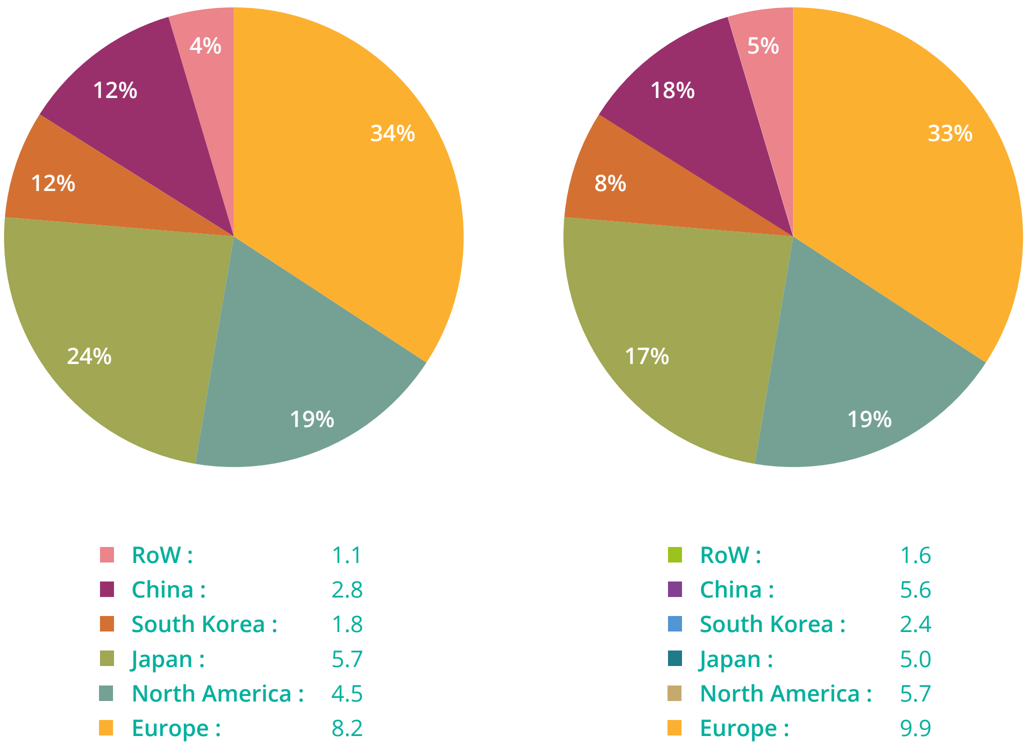
# *Appendix to Chapter 1*

## 11.1.

# COMPETITIVE SITUATION OF AUTOMOTIVE INDUSTRY IN EUROPE

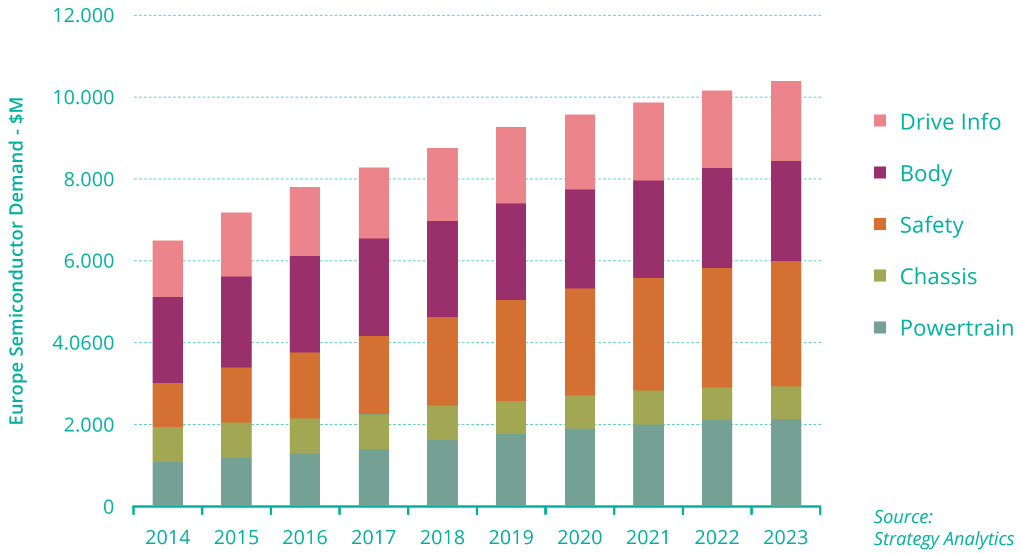
More specifically, the European Union is home to 15 international car manufacturers producing around 20 million vehicles per year. It is also home to world-leading automotive electronics semiconductor, embedded software and system suppliers.

Automotive semiconductor revenues in Europe reached EUR 4.0 billion in 2012, representing more than 30% of the world market. According to Strategy Analytics1, automotive semiconductor revenues are expected to grow 7% (CAGR) over the five-year forecast period.




*Automotive Revenues by Regions (USD billions)* *Source: (Analytics, 2013)* **F.48**

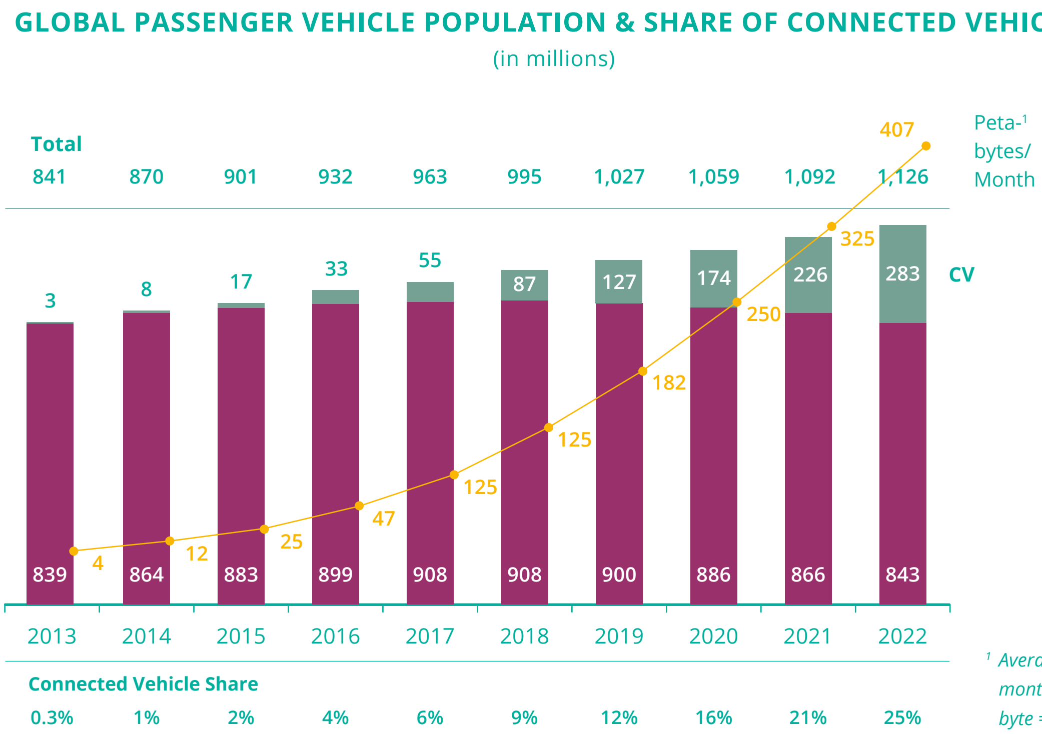
The revenues in Europe are split over the following market segments:




*Source: Strategy Analytics*

**F.49** *Automotive Revenues by Market Segments (USD millions)*

Of all the cars sold, more and more of these cars will be connected in the future. According to CISCO, 25% of all cars will be connected in 2023.




[1] *Average of 1.5 GB/month/vehicle, 1 Petabyte = 1,048,576 GB*

**F.50** *Global Passenger Vehicle Population* *Source: CISCO 2011*

## 11.2.
# DETAILS CONCERNING HIGH PRIORITY R&D&I TOPICS FOR MAJOR CHALLENGE 2 IN APPLICATION SECTION OF THE CHAPTER TRANSPORT & SMART MOBILITY

### Environment recognition

- New trusted integrated sensors also for harsh conditions (cameras, radar, lidar, ultrasonic, …), including their SW for real-time data acquisition management
- Sensor fusion, video data analysis and annotation
- Methods to evaluate, reproduce, overcome and validate fault (and/or degraded) behaviour for exceptional situations in environment perception
- Lifetime, reliability, robustness
- Quality attributes of sensors; ageing of sensors; influence of environment to sensor quality; handling of quality attributes of sensors in software; electromagnetic compatibility
- Redundancy concepts
- Traffic scene interpretation (also for different countries); scenario categorisation; catalogue of safety relevant scenarios; scenario description language, system context modelling; tools and methods required for scene interpretation
- Scene and object recognition
- Driver health/emotion/intention recognition
- Support and harmonisation of object lists, identifications, attributes, sensor protocols; open platforms for scenarios

### Localisation, maps and positioning

- Crowd-sourced or shared data acquisition of mapping data
- Situation-aware, turn-by-turn navigation
- Reliable, accurate and high-precision localisation, GNSS Galileo & GPS, lane-level resolution positioning
- Combination and fusion of different available data sources (stationary/infrastructure-based, dynamic data, cloud data…)

### Control strategies

- Transport system level: optimisation of throughput and safety of all traffic in a larger area (e.g. city, motorway section…). Provides system data and recommendations to the lower levels such as speed limits, personalised re-routing
- Cluster-of-vehicles level: strategies to optimise the flow and safety of a group of closely-spaced, temporarily connected vehicles, perhaps travelling together (possibly forming a platoon) or approaching an intersection
- Individual-vehicle level: control strategy for optimisation of safety and speed of individual vehicle, based on available data at each of the level. This is the ultimate decision and responsibility level.

- Framework for scene interpretation, environment object handling to separate sensing from control strategies
- Mission-oriented automated system SW: Mapping and routing, online mission verification, emergency control SW, fail operational strategies
- Technical goal-oriented collaborative automated system: Mapping and routing, control strategies & real time data processing; ADAS functions, ADV functions
- Fault-tolerant control strategies & real-time data processing
- Distributed control (network of control units, multi-core, multi-processor, cloud-based)
- Human-vehicle interaction (e.g. handover scenarios, VRUs interaction)

#### HW and SW platforms for control units for automated mobility and transportation (including also support for artificial intelligence)

- Artificial intelligence (AI) - intelligence versus deterministic response
- New methods, tools, HW and SW for development of AI-based systems
- Efficient and safe use of resources in multi-core/many-core processor architectures
- Test procedures for AI enabled components, standardization of test procedures
- Bring AI towards industrialization
- Disruptive applications for AI in mobility and transportation

#### Communication inside and outside vehicle

- Dynamically reconfigurable networks (“Drive-by connectivity”)
- Networks that support real-time, mixed criticality, availability, dependability
- Big-data handling and data-governance inside vehicles and between vehicles and the environment
- Seamless integration and cooperation of multiple communication platforms (amongst others: V2X, Radar, DAB / digital audio broadcasting, 5G, eLicense Plates, NFC, Bluetooth, 802.11p, etc.)
- Safe and secure communication (e.g. built-in data security and privacy)
- Intelligent in-vehicle networking (wire-based and wireless)
- Secured high-speed in-vehicle networks
- Multi-layered privacy protecting and secure elements in architectures and components
- Standards and interoperability

#### Testing and dependability

- Test methods for connected, cooperative, automated mixed-criticality systems
- Methods and tools to support virtual approval (shift towards virtual homologation)
- Functional safety along life cycle
- Model-centric development and virtualisation of testing by digitalisation
- Sensor, actuator, communication test infrastructure and tools (including deep learning sensor algorithms)
- Test methods for AI-based systems
- System validation and non-regression testing from real-world data
- Large-scale field tests of secure highly automated vehicles, field operational tests (FOT), naturalistic driving studies (NDS)
- Software tools for automatic validation
- Contemporaneous logging and secure, reliable and privacy protected data retention for incident reconstruction
- Continuous cross-industry learning processes for the development of highly automated transport systems are established enabling fast take up of new features and capabilities mandated from analysing fleet data with the objective to continuously enhance system safety and performance.

- Alignment of test procedures/scenarios/methods of test-fields/labs for connected, automated operation
- Cost-effective usage of test infrastructure validation of fail-operational concept for unknown environments
- Training methods for automated driving functions (e.g. compare open loop ADV functions with manual driver reactions)

### Swarm data collection and continuous updating

- Check field operational data and derive scenarios of it, approval of scenarios for further validation usage
- Learning process for automated vehicles (including necessary online SW update-infrastructure), SW improvement cycle using field data / big data analysis
- Safe and secure over-the-air SW update
- Reliable and temper-free black box recorder for near incident data (including dependable communication and near incident scenario evaluation, definition of minimal data set)

### Predictive health monitoring for connected and automated mobility

- Self-aware systems guaranteeing that the risk produced by highly automated transport systems is reduced to an acceptable minimum.
- On-board diagnostics for automated transport systems
- Methods for self-assessment / self-diagnosis of health state, degradation, system state, system condition across all ECS levels
- Methods and tools (development of ECS but also in-vehicle usage) to cope worst-case scenarios

### Functional safety and fail-operational architecture and functions (sensors, electronics, embedded software and system integration)

- A common evolvable fault-tolerant system architecture, including onboard and infrastructure, is standardised to enable the necessary innovation speed and allow affordable validation efforts
- Strategies for HW and SW redundancy
- Fail-silent and fail-safe systems
- Development frameworks to design fail-operational ECS
- Service-oriented distributed dynamically reconfigurable HW/SW architecture
- Strategies for safe operation / safe stop / safe actuation in emergency situations
- New generation technologies for automated driving based on competitive consumer electronics

# 12

# *Appendix to Chapter 6*

This appendix gives a detailed list of topics in each R&D&I Area of every Challenge of Chapter 6 Systems and Components: Architecture, Design and Integration.

## 12.1.
# MAJOR CHALLENGE 1: MANAGING CRITICAL, AUTONOMOUS, COOPERATING, EVOLVABLE SYSTEMS

Major Challenge 1 topics are collected in three categories (high priority R&D&I areas):

### Models, model libraries and model-based design technologies

- Re-usable, validated and standardised models and libraries for
  - system contexts (use cases, scenarios)
  - environment (including different environment factors and conditions)
  - human behaviour (as operators, users, cooperation partners)
  - for system behaviour, including
    - environment/situation perception (incl. sensor models)
    - situation interpretation and prediction
    - self-awareness, -management and -healing (incl. reconfiguration)
    - handling of uncertainty, inaccuracy and faults
- Advanced modelling techniques for future ECS
  - combining rigorous (functional, physical and data based) behavioural and property modelling and measurement/observation-based modelling
  - supporting V&V of heterogeneous ystems,
  - supporting alteration management and model transformation
  - for learning and adaptive systems
- Model-based design methods and interoperable tool chains for critical systems, supporting constraint driven requirements (including standards like ISO26262, EAL6+), and (incremental) certification and homologation
- Extended specification capabilities (including requirement engineering, mission profiles, use cases, architectural design, transition of informal to formal specification …) to enable executable and consistent specifications of all design aspects and in all stages of development

### Verification and Validation (V&V) and Test for critical systems: Methods and Tools

- Model-based verification, validation and test methodology and interoperable tool chains and platforms for critical systems,
  - supporting heterogeneous systems
  - starting from high levels and spanning different levels of abstraction
  - including coverage, error mode analysis, generation of HW/SW V&V from models and connection of model-based design and verification
- Automated derivation of verification procedures and tools from requirements and models, back annotation of verification results, interface between requirement engineering and V&V environment

- V&V and test methods including tool support
    - for lifecycle and in-service phase, including support for
        - monitoring systems' state of health and exception conditions
        - reconfiguration, adaptation, handling of faults and ageing
        - upgrades in the field and evolvability
        - maintainability
        - special situations (start-up, power-down,...)
    - for adaptive, cognitive and learning systems, including V&V for strategy synthesis
    - for Human-Machine Interaction, collaborative decision-making, cooperation strategies and activities, etc., including human (health) state and intention prediction
    - for autonomous systems including (a) environment/situation perception (incl. sensor models), (b) situation interpretation and prediction, and (c ) handling of uncertainty, inaccuracy and faults
- Methods for the hierarchical verification of the whole system (incl. reuse of already verified components, scene and environmental analysis, connection of formal and simulative methods, incremental verification)
- Concepts and procedures for the evaluation of functional safety, robustness and reliability (hierarchical management of requirements, criteria and system characteristics / functions, determination of errors and failure probabilities, ...)

### (Virtual) Engineering of Electronic Component and Systems (ECS)

- Collaboration concepts and methods, platforms and interoperable tools for interdisciplinary, holistic virtual engineering of ECS covering the whole value chain, spanning organisations, engineering domains and development activities
- Methods and interoperable tools for virtual prototyping of complex, networked systems with a large number of components (e.g., IOT systems)
- Engineering support (libraries, platforms, interoperable tools)
    - for evolvable and adaptable systems including adaptation to human needs and capabilities, to changing and unknown environments/situations/contexts, enabling upgradability while ensuring functional, structural and semantic integrity during runtime, all embedded within holistic lifecycle management
    - for the design and operation of Open-World Systems (distributed control loops, cognitive systems, handling of unreliable information, safe fall-back strategies, legacy systems/ components, monitoring, self-awareness and self-healing, fault tolerance layers, etc.)
    - for the design and operation of cognitive, cooperating systems (sufficient observability of the environment, handling of unknowns, on-line synthesis of (cooperation) strategies, reasoning engines, value governance, learning...)

12.2.
# MAJOR CHALLENGE 2: MANAGING COMPLEXITY

Major Challenge 2 topics are grouped in four categories (high priority R&D&I areas):

### Systems architecture

- Extended methods for architectural design: Support for
  - systems with thousands of components
  - metrics for functional and non-functional properties
  - early architectural exploration, considering use cases and application context, enabling evaluation of design alternatives (e.g. centralised vs. decentralised…) and consistency checking
- Design methods and architectural principles, platforms and libraries supporting
  - V&V, Test, and Life-Cycle-Management of complex, networked ECS: Modular Architectures and platforms supporting compositional and incremental V&V and Test, Adaptability, Upgradability, Evolvability, Maintainability)
  - Self-Management, Self-Awareness and Self-Healing (including monitoring and diagnosis on hardware and software level in real-time, self-assessment, support for re-configuration, redundancy, down to integrated DFT/BIST tests)
  - cognitive and adaptive systems (support for cognitive computing, adaptive algorithms, artificial intelligence, machine learning, neuromorphic architectures…)
- Model-based system architecture, including models representing requirements and specifications in dynamic and executable architectures, to ensure, among other things, preservation of consistency of architectures throughout the design process and lifecycle

### System design

- Hierarchical Concepts and Standards for IP Modelling (component-based design, reusable components on all levels, extended analysis techniques, coverage and error mode analysis, architecture and system models for Soft-IP)
- Methods and Tools for Model Driven Engineering, supporting model creation and transformation (incl. model extraction and model learning), model languages (incl. Domain Specific Languages), model management, and scalability of model-based approaches
- Methods and Tools for component based HW/SW Co-Design for complete products incl. heterogeneous systems, embedded cores, software blocks, digital and analogue IP, subsystems, (possibly unknown) system environment and (fast) changing application context
- Methods and Tools for efficient virtual prototyping (fast simulation/emulation of embedded platforms, early software integration and validation, adaptive, re-configurable real-time platforms, co-simulation of heterogeneous modelling paradigms, cloud-support, cognitive computing)
- Design and Analysis methods for multi-/many-core systems, including support for complex software stacks and DSLs, and for migration of legacy software)

### Methods and tools to increase design efficiency

- Seamless and consistent design and tool chain for automated transfer of abstract (system level) descriptions into functional HW/SW blocks (High-Level synthesis, Generator-based design, Co-Simulation of heterogeneous models) with inclusion of design checking and consideration of simultaneous technology and product development.
- Strong support of package, board and sensor/MEMS (co-)design including die-embedding and 2.5/3D integration (design exploration, mixed discipline modelling, multi-criteria evaluation of functional and non-functional properties, optimisation, and integrated DFT development
- New methods and tools to support new design paradigms: multi-/many-core architectures, increased software content, NoCs (Network on Chips), GALS, neural architectures, design knowledge acquisition, artificial intelligence, big data methods, machine learning, etc.
- Support of new technologies: FD-SOI, graphene, nanotubes,..., <7nm technology
- New approaches to handle analogue/mixed signal design (capturing and formalising designer knowledge, guided design, automatic generation of blocks, synthesis of analogue blocks)

### Complexity reduction for V&V and test

- V&V methods to prove safeness and soundness of real-time complexity reduction in situational representation and situational prediction
- Hierarchical system verification using already verified components and verification process reuse
- Methods and tools to support scenario based V&V and Test, including scenario analysis, scenario selection, combination of formal proof, simulation and test techniques,
- Virtual platform in the loop: Enabling the efficient combination of model-based design and virtual platform based verification and simulation
- Methods and tools for V&V automation and optimisation including test optimisation and test system generation, including handling of product variability

## 12.3.
## MAJOR CHALLENGE 3: MANAGING DIVERSITY

The main R&D&I activities this challenge 3 are grouped in four categories (high priority R&D&I areas):

### Multi-objective optimisation of components and systems

- Integrated development processes for application-spanning product engineering along the value chain (modelling at different abstraction levels, management of constraints in different domains, multi-criteria, cross-domain optimisation, standardised interfaces)
- Consistent and complete Co-Design and integrated simulation of IC, package and board in the application context (integration of communication systems, mechatronics components and their interfaces)
- Modular design of 2.5 and 3D integrated systems (reuse, 3D IPs, COTS and supply chain integration, multi-criteria design space exploration for performance, cost, power, reliability, etc...)

### Modelling and simulation of heterogeneous systems

- Hierarchical Approaches for Modelling on System Levels (consistent models at different abstraction levels, model simplification and order reduction, model transformation and adaptive models with automatic adjustment of abstraction level, accuracy and complexity)
- Modelling methods to take account of operating conditions, statistical scattering and system changes (application-specific loads, variations in production, commissioning and operation, degradation and ageing effects)
- Methods and tools for the modelling and integration of heterogeneous subsystems (analogue, digital, RF, antennas, power, memory, buses, optics, passive components)
- Methods for hardware software co-simulation of heterogeneous systems at different abstraction levels (co-simulation of software and sensors and different modelling paradigms, hardware-in-the-loop simulation, heterogeneous simulation (from FEM to inaccurately described systems in one environment)
- Modelling methods and model libraries for learning, adaptive systems
- Models and model libraries for chemical and biological systems

### Integration of analogue and digital design methods

- Metrics for testability and diagnostic efficiency (including verification, validation and test), especially for AMS designs.
- Harmonisation of methodological approaches and tooling environments for analogue, RF and digital design (reuse of analogue IP on system level, synthesis and verification for analogue and RF components and heterogeneous systems considering the package)
- Automation of analogue and RF design (high-level description, synthesis acceleration and physical design, modularisation, use of standardized components)

### Connecting digital and physical world

- Advanced simulation methods (environmental modelling, multi-modal simulation, simulation of (digital) functional and physical effects, multi-level/multi-rate simulation, emulation and coupling with real hardware, connection of virtual and physical world)
- Novel More than Moore design methods and tools (design exploration, automated variant generation and evaluation, synthesis approaches for sensor components and package structures)

## 12.4.
## MAJOR CHALLENGE 4:
## MANAGING MULTIPLE CONSTRAINTS

R&D&I activities in this challenge are grouped in three categories (high priority R&D&I areas)

### Ultra-low power design methods

- Advanced methods for ultra-low-power design (efficiency modelling, low-power optimisation taking into account performance parameters)
- Design methods for (autonomous) ultra-low-power systems, taking into account application-specific requirements (function and performance, safety and security, communication, energy demand profiles / energy recovery, system life, boundary conditions for energy harvesting and storage)

- Method for comprehensive assessment and optimisation of power management and power consumption (normal operation, switching on and off, behaviour in the event of a fault) including the inclusion of parasitic effects (substrate couplings, etc.)

### Efficient modelling, test and analysis for reliable, complex systems considering physical effects and constraints

- Hierarchical modelling and early assessment of critical physical effects and properties (ESD, substrate coupling, latch-up, EMC, thermal-electrical interactions, thermo-mechanical stress, power and signal integrity) from SoC up to system level
- Design and development of error-robust circuits and systems (methods for monitoring and fault detection, adaptation strategies, intelligent redundancy concepts, adaptive algorithms)
- Production-related design techniques (modelling, characterisation, variability and reliability analysis, yield optimisation, lithography friendliness, measurement and prognosis of yield losses)
- Consistent methods and new approaches for (multi-level) modelling, analysis, verification and formalisation of ECS's operational reliability and service life (comprehensive consideration of operating conditions and dependencies between hardware and software, detection and evaluation of complex fault failure probabilities and dependencies)
- Consistent design system able to model and optimise variability, operational reliability (including degradation/aging), yield and system reliability (including the consequences for the qualification), considering dependencies
- Analysis techniques for new circuit concepts and special operating conditions (Voltage Domain Check, especially for Start-Up, Floating Node Analysis …)
- Advanced test methods (test generation for analogue and RF design, baseband testing with massive BIST usage, hierarchical production test (including diagnostics, online test troubleshooting or error correction), intelligent concepts for test termination, automated metrics/tools for testability and diagnosis, extraction of diagnostic information)
- Methods and tools for monitoring, diagnostics and error prediction for ECS (online and real-time monitoring and diagnostics, intelligent self-monitoring of safety-critical components, life expectancy)

### Safe systems with structural variability

- Architectures, components and methods for adaptive, expanding systems (self-) monitoring, diagnostics, update mechanisms, strategies for maintaining functional and data security, lifecycle management, adaptive safety and certification concepts)
- Design methods and tools for adaptive, expanding systems (realisation of real-time requirements, high availability and functional and IT security, evaluation of non-functional properties, analysis of safety and resilience under variable operating conditions)
- Novel simulation approaches for the rapid evaluation of function, safety and reliability (real-time simulation and simulation of mixed virtual real systems, approximate computing, approaches for mixed criticality)
- Security concepts for highly connected and adaptive, expanding systems (self-monitoring, environmental analysis, ageing-resistant chip identification techniques, ensuring functional safety through robustness guarantees).

# 12.5. MAJOR CHALLENGE 5: INTEGRATING MINIATURISED FEATURES OF VARIOUS TECHNOLOGIES AND MATERIALS INTO SMART COMPONENTS

The main R&D&I activities in the three identified categories (high priority R&D&I areas of Major Challenge 5 are:

**Activity field 1: Functional features**

- Selective gas (CO, $CO_2$, $NO_x$, VOC, etc.) sensing components
- Low-power wireless architectures
- PMICs with high efficiency at very low power levels and over a wide range of input voltages (AC & DC)
- Selective detection of allergens, residues in food/water, atmospheric particles, etc.
- Disease monitoring & diagnostics (at home, POC, animal health)
- Bio-sensors and bio-actuators
- MOEMS and micro-optics
- Various sensors and systems in package for autonomous cars, industrial robots, smart energy applications, etc.
- Component-level features for self-diagnosis (PHM detectors)
- Harvesters and storage devices (e.g. microbatteries, supercapacitors), including 2D, 3D and solid-state for feeding low or zero power devices
- Hardware solutions for security and privacy

**Activity field 2: Materials**

- Surface coatings for multi-functionality on the same base structures
- High-efficiency photonic materials
- New / alternative organic and bio-compatible materials
- New materials and features for sensing (CNT, Graphene, Nitrogen voids, etc.)
- Low quiescent/leakage power material/devices for sensors
- Materials for low power, fast responding gas sensors and occupancy sensors
- Non-toxic, scalable, high-density feature materials for energy-harvesting sources (thermoelectrics, piezolectrics, triboelectricity…) and better performing electrodes and electrolytes for improved capacity and conductivity of energy storage devices
- Rare earths replacement, e.g. for magnetics
- Heterogeneous integration of new materials, sensors, actuators for miniaturised chips (also for high temperature and photonics)

**Activity field 3: Integration technologies and manufacturing**

- 2D and 3D printing technologies for heterogeneous system integration and rapid manufacturing
- Robust integration of multi-component systems (sensors, actuators, electronics, communication, energy supply (includingfluidics and photonics)
- Key technology areas (printing, etching, coating, etc.)
- Manufacturing & health monitoring tools (including tests, inspection and self-diagnosis) for components
- Quantum sensors and associated integration

# 12.6. MAJOR CHALLENGE 6: PROVIDING EFFECTIVE MODULE INTEGRATION FOR HIGHLY DEMANDING ENVIRONMENTS

The main R&D&I activities in the three identified categories (high priority R&D&I areas) of Major Challenge 6 are:

**Activity field 1: Functional features**

- Board-level signal processing and control features for self-diagnosis and self-learning
- Smart power (mini-) modules for low-power sensing/actuation and efficient power transfer
- Low-power sensor nodes for real-time data processing
- High-performance signal quality in harsh environmental conditions
- Protective housing and coating features (e.g. against chemicals)
- Photonics features like optical sources, paths and connectors integrated into PCB
- Advanced and active cooling systems, thermal management
- EMI optimised boards
- 3D board & module design
- Board level high-speed communication features

**Activity field 2: Materials**

- Heterogeneous integration of new materials for miniaturised sensor & actuator modules
- Recycling and repair of modules
- Transducer materials (e.g. CMOS compatible piezo, e.g. flexible solar panels) that can be integrated into SiPs
- Materials for flexible devices
- Materials for coatings, potting and overmoulding
- New thermal interface materials
- New substrate materials on board level

**Activity field 3: Integration technologies and manufacturing**

- Transfer printing of heterogeneous components on various substrates
- Heterogeneous 3D integration of sensors, actuators, electronics, communication, and energy supply features for miniaturised modules
- Highly miniaturised engineering and computer technologies with biochemical processes
- Bio-mimicking (bio-hybrids, fluidics)
- Manufacturing & health monitoring tools (including tests, inspection and self-diagnosis) for components
- Direct manufacturing and rapid prototyping
- Automation and customisation ('towards I4.0') in module manufacturing
- Flexible and stretchable devices and substrates
- Chips, passives and packaged components embedded in board
- 3D printing of IC components on top of PCBs

12.7.
# MAJOR CHALLENGE 7: INCREASING COMPACTNESS AND CAPABILITIES BY FUNCTIONAL AND PHYSICAL SYSTEMS INTEGRATION

The main R&D&I activities in the three identified categories (high priority R&D&I areas) of Major Challenge 7 are:

**Activity field 1:** Functional features
- Effective and reliable energy generation, harvesting and transfer
- Efficient computing architectures for real-time data processing in sensor nodes
- In-situ monitoring in automation, process industry and medical application
- Biomedical remote sensing
- System integration of wide bandgap semiconductors
- System health management based on PoF models (and not statistical)
- Perception techniques
- Sensor fusion and cyber-physical systems
- Data and system safety, security and privacy
- Low power RF architectures for asset tracking and low data rate communication (e.g. UWB, LoRA)
- Modularity and compatibility across development generations (interface definition, standardisation)
- Thermal management on system level

**Activity field 2:** Materials
- ICT for diverse (material) resources monitoring and prognosis
- Recycling and repair of systems
- New materials and concepts for humidity transport into and out of the (sensing) systems
- New materials for improved thermal management

**Activity field 3:** Integration technologies and manufacturing
- Volume reduction (per lot due to customisation) in system manufacturing
- Improved signal integrity (EMC)

# 13

# *Appendix to Chapter 9*

### More details on foreign export restrictions:

One of the most well-known export restrictions is known as ITAR:

The ITAR term is often used as a shortcut for 'US Export Control Laws', which restrict exports of designated goods and technology. These federal laws are implemented by the US Department of Commerce through its Export Administration Regulations (EAR—trade protection), by the US Department of State through its International Traffic in Arms Regulations (ITAR—national security), and by the US Department of Treasury through its Office of Foreign Assets Control (OFAC—trade embargoes). The ITAR is concerned with items that are designed or modified for military use. The EAR regulates items designed for commercial purposes that can have military applications such as computers, pathogens, etc.

Any product that includes or is bundled with US-origin items is subjected to US Export Control Laws, **irrespective of the licensing conditions of these items**. US origin is assumed for any item (commodity, technology, or software) contributed from a US national anywhere in the world, or from a foreign national on US territory. Items physically or virtually located in the US including artefacts in data centres are also considered as US origin. Because of the extra-territorial application of US Export Control Laws, **these become a re-export control** of products from one country to another. If an item is of US origin and subject to US Export Control Laws, it remains so regardless of how many times it is re-exported, transferred, or sold. In particular, an export license is required for any re-export or in-country transfers of US-origin items or non-US made items subject to the EAR, unless the exemptions below apply.

The main exemption to the requirements to obtain an export licence according to US Export Control Laws is for items in the 'public domain'. Public domain items do not have an identified copyright owner. Fundamental research performed by academic institutions is also assimilated to 'public domain', but only as far as no access restrictions existed on the grant agreements that funded this research. Access restrictions that remove the 'public domain' exemption of fundamental research include publication content controls or specific treatment of non-US nationals in the contribution to or dissemination of research results. See for instance https://www.umass.edu/research/sites/default/files/documents/export_controls_and_universities_information_and_case_studies.pdf

The second exemption to the requirements to obtain an export licence applies only to EAR, when the value of US-origin items in a product is below a percentage based on 'de minimis' guidelines. The 'de minimis' guidelines set the percentage threshold based on: (1) Export Control Classification Number (ECCN); (2) the ultimate destination of the item; (3) the end-user and end-use of the item. However, the 'de minimis' exemption does not apply in 'except' cases, such as: specific countries of destination (except #1); certain components of high performance computers, and encryption commodities and software (except #2). Further details are available from https://www.bis.doc.gov/index.php/licensing/reexports-and-offshore-transactions/de-minimis-guidelines/18-licensing and https://www.bis.doc.gov/index.php/documents/pdfs/1382-de-minimis-guidance/file

# 14

# *Further reading*

## 14.1.
# FURTHER READING FOR CHAPTER 4

- 5G white papers, info graphics
  - https://networks.nokia.com/innovation/5g
  - https://apps.networks.nokia.com/5g/index.html
- AI will change field service: http://www.7wdata.be/enterprise-software/4-ways-ai-will-transform-the-field-service-industry/

## 14.2.
# FURTHER READING FOR CHAPTER 5

Several relevant documents are mentioned that provide suggestions for further elaboration:

- AIOTI strategy document, online at https://aioti.eu/

- IERC: the European Research Cluster on the Internet of Things
  "Internet of Things beyond the Hype", online at: http://www.internet-of-things-research.eu/

- The future of cities; Scenarios that show how people may experience cities in 2035, Philips Lighting. Online at:
  http://www.lighting.philips.com/main/systems/connected-lighting/connected-lighting-for-smart-cities/city-scenarios

- Wearable technology and the IoT, Ericsson, online at:
  https://www.ericsson.com/en/networked-society/trends-and-insights/consumerlab/consumer-insights/reports/wearable-technology-and-the-internet-of-things#thedemographicdivide

- Edelman-Digital-Trends-Report 2017, online at:
  https://edelmandigital.com/wp-content/uploads/2016/12/2017-Edelman-Digital-Trends-Report.pdf

- State of the Media Industry 2017, Ooyala, on line at:
  http://go.ooyala.com/rs/447-EQK-225/images/Ooyala-State-of-the-Media-Industry-2017.pdf

# 15

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# 16

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## CHAPTER 1 – TRANSPORT AND SMART MOBILITY

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# 17

# *Acronyms used in the document*

| Acronym | *Meaning* |
|---|---|
| 3D-IC | *3-Dimensional Integrated Circuit* |
| 5G | *5th Generation wireless communication network* |
| AC/DC | *Alternating current to Direct Current* |
| AD | *Automated Driving* |
| ADAS | *Advanced Driver Assistance System* |
| AI | *Artificial Intelligence* |
| AIOTI | *Alliance for Internet of Things Innovation* |
| AR | *Augmented Reality* |
| AUTOSAR | *AUTomotive Open System Architecture* |
| BCI | *Brain Computer Interface* |
| BIST | *Build-In Self-Test* |
| CMOS | *Complementary Metal Oxide Semiconductor* |
| CNT | *Carbon Nano Tubes* |
| COTS | *Components of the Shelf* |
| CPPS | *Cyber Physical Production Systems* |
| CPS | *Cyber-Physical System* |
| DC/AC | *Direct Current to Alternating current* |
| DDoS | *Distributed Denial of Service* |
| DfR | *Design for Reliability* |
| DfT | *Design for Test* |
| DfX | *Design for X, where X can stand for Manufacturing, Reliability, etc...* |
| DoE | *Design of Experiment* |
| DRAM | *Dynamic Random-Access Memory* |
| DRM | *demand/response management* |
| DSL | *Domain Specific Language* |
| DSP | *Digital Signal Processor* |
| DUV | *Deep Ultra Violet* |
| ECS | *Electronic Component and System* |
| EDA | *Electronic Design Automation* |
| EE | *Electric and Electronics* |
| EMC | *Electro-Magnetic Compatibility* |
| EMI | *Electromagnetic interference* |
| ESD | *Electrostatic discharge* |
| ETSI | *European Telecommunications Standards Institute* |
| EUV | *Extreme Ultra Violet* |
| EV | *Electric Vehicles* |

| | |
|---|---|
| **eWLB** | *Embedded Wafer Level Ball grid array* |
| **FD-SOI** | *Fully Depleted Silicon-On-Insulator* |
| **FPGA** | *Field-programmable gate array* |
| **GALS** | *Globally asynchronous locally synchronous* |
| **GaN** | *Gallium nitride* |
| **GDP** | *Gross Domestic Product* |
| **GPS** | *Global Positioning System* |
| **GPU** | *Graphics Processing Unit* |
| **GSM** | *Global System for Mobile Communications* |
| **HMI** | *Human Machine Interface* |
| **HPC** | *High-Performance Computing* |
| **HPU** | *Holographic Processing Unit* |
| **HW** | *Hardware* |
| **HW/SW** | *Hardware / Software* |
| **IC** | *Integrated Circuit* |
| **ICT** | *Information and Communication Technologies* |
| **IEA** | *International Energy Agency* |
| **IERC** | *the European Research Cluster on the Internet of Things* |
| **IGBT** | *Insulated-Gate Bipolar Transistor* |
| **III-V** | *Chemical compound of materials with 3 and 5 electrons in the outer shell respectively* |
| **IoT** | *Internet of Things* |
| **IP** | *Intellectual Property / Internet Protocol (depending on context)* |
| **IRDS** | *International Roadmap for Devices and Systems* |
| **ITAR** | *International Traffic in Arms Regulations* |
| **ITRS** | *International Technology Roadmap for Semiconductors* |
| **ITU** | *International Telecommunication Union* |
| **LAE** | *Large Area Electronics* |
| **LE** | *Large Enterprise* |
| **LED** | *Light-emitting diode* |
| **LV** | *Low Voltage* |
| **M2M** | *Machine to Machine* |
| **MC** | *Major Challenge* |
| **MDM** | *Multi-Dimensional Metrology* |
| **MEMS** | *Micro Electro Mechanical Systems* |
| **MEPS** | *minimum energy performance standards* |
| **MIL** | *United States Military Standard* |
| **ML** | *Machine Learning* |

| | |
|---|---|
| MM | *More Moore* |
| MMI | *Machine to Machine Interface* |
| MNBS | *Micro Nano Bio System* |
| MOEMS | *Micro-Opto-Electro-Mechanical System* |
| MR | *Mixed Reality* |
| MtM | *More than Moore* |
| MV | *Medium Voltage* |
| NAND | *Negative-AND is a logic gate which produces an output which is false only if all its inputs are true* |
| NEMS | *Nano Electro Mechanical Systems* |
| NIS | *Network and Information Systems* |
| NVM | *Non-Volatile Memory* |
| OEM | *Original Equipment Manufacturer* |
| OSAS | *Obstructive Sleep Apnea Syndrome* |
| PAD | *Productivity Aware Design* |
| PCRAM | *Phase Change Random Access Memory* |
| PE-ALD | *Plasma Enhanced Atomic Layer Deposition* |
| PFSI | *Physical and Functional Systems Integration* |
| PHM | *Prognostic Health Management* |
| PMIC | *Power Management Integrated Circuit* |
| PoC | *Point of Care* |
| PoF | *Physics of Failure* |
| PSD2 | *The revised European Payment Services Directive* |
| PV | *Photo Voltaic* |
| R&D&I | *Research and Development and Innovation* |
| RF | *Radio Frequency* |
| RRAM | *Resistive Random-Access Memory* |
| Safety | *Protecting from any malfunction that might occur* |
| S/C | *Semiconductor* |
| SCM | *Storage Class Memory: A non-volatile memory technology that is capable of replacing hard disks.* |
| SDN | *Software Defined Network* |
| Security | *Protection from the negative influences of the outside world* |
| SiP | *System in Package* |
| Si-Photonics | *Silicon-Photonics is the study and application of photonic systems which use silicon as an optical medium.* |
| SME | *Small and Medium Enterprise* |
| SMTBF | *System Mean Time Between Failures* |

| | |
|---|---|
| **SoA** | *Safe operating Area* |
| **SoC** | *System on Chip* |
| **SoS** | *System of Systems* |
| **SSI** | *Smart System Integration* |
| **STDP** | *Spike-Timing-Dependent Plasticity* |
| **STEM** | *Science, Technology, Engineering and Mathematics / Scanning Transmission Electron Microscopy (depending on context)* |
| **STT-RAM** | *Spin-transfer torque random-access memory* |
| **SW** | *Software* |
| **TAM** | *Total Available Market* |
| **TEV** | *Through Encapsulant Via* |
| **TIM** | *Thermal Interface Materials* |
| **TRL** | *Technology Readiness Level* |
| **TSV** | *Through Silicon Via* |
| **UCTE** | *European Network of Transmission System Operators for Electricity* |
| **ULP** | *Ultra-Low Power* |
| **V&V** | *Verification and Validation* |
| **VC** | *Venture Capitalist* |
| **VOC** | *Volatile Organic Compounds* |
| **VR** | *Virtual Reality* |
| **VRE** | *variable renewable energy* |
| **WBG** | *Wide Bandgap Semiconductors* |
| **WLP** | *Wafer Level Packaging* |

ECS