STRATEGIC AGENDA

Guideline for Pan-European R&D&I
Co-Operation in the Electronics Value Chain

Aeneas

PREFACE

The association AENEAS promotes research, development and innovation (R&D&I) in the field of micro- and nano-electronics-enabled components and systems in order to strengthen the competitiveness of European industry across the electronics value chain. Its members are industries (large enterprises and SME) and research organisations active in European R&D&I partnerships.

The AENEAS Strategic Agenda describes the ambitions of the AENEAS members in co-operative R&D&I activities, together with the anticipated contributions in resolving societal challenges and creating economic value for Europe. It builds on the Vision, Mission and Strategy on R&D in European Micro-and Nanoelectronics, issued previously by AENEAS together with CATRENE.

The AENEAS Strategy Agenda is prepared and maintained in a structured and open process by a broad group of experts from across the European industrial and scientific community.

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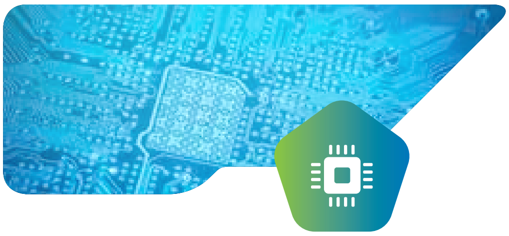

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EXECUTIVE SUMMARY

Solutions for societal challenges are increasingly depending on contributions from micro- and nano-electronics-enabled components and systems. Europe is home to world-leading industries and scientific institutes in this field. Knowledge intensity in the domain is very high. Many companies sustain R&D&I investment levels far above the industry average, including SME. Micro- and nano-electronics-enabled components and systems constitute a value chain from base technology supply to end-user applications. Collectively, the European value chain is approaching a worldwide revenue of 1 trillion euros. The AENEAS Strategic Agenda addresses high priority R&D&I areas providing key technological contributions in solving societal challenges and creating economic value. In doing so, it helps Europe in building regional autonomy along the electronics value chain.

The AENEAS Strategic Agenda focuses on three main areas with opportunity for high demand growth that have a good fit with European strengths and skills. These areas are (1) markets where Europe is strong and there is above average growth in electronic content, (2) new high growth areas, such as the Internet of Things, where industry in Europe is well positioned to benefit from emerging 'Smart-X' markets, and (3) markets where opportunities can be captured through Industry 4.0. Global societal challenges double as lead market drivers for the value chain in each of these main areas.

In the highly competitive landscape outlined by the opportunity areas and the societal challenges, the AENEAS Strategic Agenda targets nine interlinked themes for Europe. These themes are (1) Automotive and Transport, (2) Connectivity and Digital Networks, (3) Energy Efficiency, (4) Health and the Ageing Society, (5) Safety and Security, (6) Design Technologies, (7) Process Technology and Integration, (8) Equipment, Materials and Manufacturing, and (9) Production Technologies. Each of these themes addresses a mix of technologies and applications along the value chain, and includes descriptions of competitive value and societal benefits, high priority R&D&I areas, and timeframes for roadmaps until 2030.

The AENEAS Strategic Agenda provides essential roadmaps for Europe to address important societal challenges, to compete worldwide with innovative products and services, and to strengthen the competitiveness of European industry along the electronics value chain. As such, the Agenda is a Pan-European guideline for implementing public-private R&D&I partnerships. This includes giving direction to the EUREKA Cluster PENTA, the ECSEL Joint Undertaking, the H2020 program, in particular LEIT, as well as national and regional instruments. At the same time, access to such co-operative R&D&I programs is a key condition for success for realizing the ambitions of this Agenda.

Vision and Ambition

Solutions for global societal challenges are increasingly depending on contributions from micro- and nano-electronics-enabled components and systems. Europe is home to world-leading industries and scientific institutes in this field. Their innovations and their precompetitive co-operation lead to innovative products and services that are in high demand on the world market.

Knowledge intensity in the micro- and nano-electronics-enabled components and systems domain is very high. Many companies sustain R&D&I investment levels far above the industry average, and many operate internationally, also the small- and medium-sized enterprises. Because of the high demand for advanced knowledge, firm linkages with research and technology organisations are essential.

Micro- and nano-electronics-enabled components and systems constitute a value chain from base technology supply to end-user applications. In Europe, large enterprises, small- and medium-sized enterprises, and research and technology organisations co-operate along this value chain, and engage with regional, national and European public authorities in addressing societal challenges.

Collectively, the European value chain of micro- and nano-electronics-enabled components and systems is approaching a worldwide revenue of 1 trillion euros. In the value chain, the economic footprint increases steeply when moving closer to end-user applications, while the relative R&D&I investment is typically highest at the technology supply side.

Many companies across the world are competing vigorously in many of the existing and emerging markets. To keep Europe ahead in global markets, a solid understanding of the rapidly changing needs is essential. Such needs create opportunities that increasingly require intense cooperation along the value chain.

Co-operative R&D&I projects in public-private partnership offer the pre-competitive environment to create confidence, maintain an ecosystem and build the alliances necessary to take advantage of these opportunities. The AENEAS Strategic Agenda provides continuous guidance to such R&D&I projects and partnerships throughout the micro- and nano-electronics-enabled components and systems ecosystem.

The AENEAS Strategic Agenda addresses high priority R&D&I areas providing key technological contributions in solving the European societal challenges. In doing so, the AENEAS Strategic Agenda helps Europe in building regional autonomy along the value chain. At the same time, the alliances in the ecosystem are instrumental to capture access to worldwide growth markets.


APPLICATIONS
SYSTEMS
CHIPS
ARCHITECTURE
EQUIPMENT
DESIGN TOOLS
MATERIALS

VALUE CHAIN

Focus Areas

The AENEAS Strategic Agenda focuses on three main areas of opportunity for high demand growth that have a good fit with European strengths and skills in micro- and nano-electronics-enabled components and systems:[1]

1. Areas where Europe is strong and there is above average growth in the electronic content, e.g., automotive, energy, industrial automation and security.

2. New high growth areas, in particular Internet of Things (IoT), where industry in Europe is well positioned to benefit from the development of 'Smart-X' markets, including e-Health.

3. Markets in the changing landscape of mobile convergence which constitute opportunities to be captured, e.g., by securing leadership in industry digitalisation through Industry 4.0.

Global societal challenges double as lead market drivers for the value chain in each of these main areas. 'Smart, green and integrated transport', e.g., creates demand in electric and automated driving, and 'Secure, clean and efficient energy' pushes requirements for power electronics and cybersecurity.

INTERNET OF THINGS

As enabler of a future hyper-connected society, the Internet of Things (IoT) is a set of sensors, actuators, smart objects, data communications and interface technologies that allow information to be collected, tracked and processed across local and global network infrastructures.

The IoT is recognised as the next step of disruptive digital innovation. With the IoT, any physical and virtual object can become connected to other objects and to the Internet, creating a fabric of connectivity among things and between humans and things.

Moreover, the IoT is gathering pace and unleashing a very disruptive potential. A recent study estimates that the IoT market (hardware, software and services) in Europe will exceed one trillion euros by 2020[2].

Europe has state-of-art knowledge on all building blocks of the IoT, hosting scientific and industrial leaders in both the technologies and the applications where the IoT will be implemented, e.g., smart transport, smart grids, and smart cities. By mobilizing the full value chain, in a mind-set of open and innovative co-operation, Europe has all opportunities to grab a major part of this new market.

[1] as recommended in ec.europa.eu/digital-single-market/en/electronics-roadmap-europe
[2] ec.europa.eu/digital-single-market/en/news/definition-research-and-innovation-policy-leveraging-cloud-computing-and-iot-combination

INDUSTRY 4.0[3]

The First Industrial Revolution used water and steam power to mechanize production. The Second used electric power to create mass production. The Third used electronics and information technology to automate production. Now a Fourth Industrial Revolution, Industry 4.0, is surfacing, in a fusion of technologies blurring the lines between the physical, digital, and biological spheres.

The possibilities of billions of people connected by mobile devices, with unprecedented processing power, storage capacity, and access to data, are unlimited. With Industry 4.0, these possibilities are multiplied by breakthroughs in artificial intelligence, robotics, the IoT, autonomous vehicles, 3-D printing, nanotechnology, biotechnology, materials science, energy storage, and quantum computing.

Impressive progress has been made in artificial intelligence, enabled by exponential increases in computing power and data availability. Engineers and architects are combining computational design, additive manufacturing, materials engineering, and synthetic biology to pioneer a new symbiosis between microorganisms, our bodies, the products we consume, and the buildings we inhabit.

Like the earlier revolutions, Industry 4.0 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 unpreceded as it will be unpredictable.

SOCIETAL CHALLENGES[4]

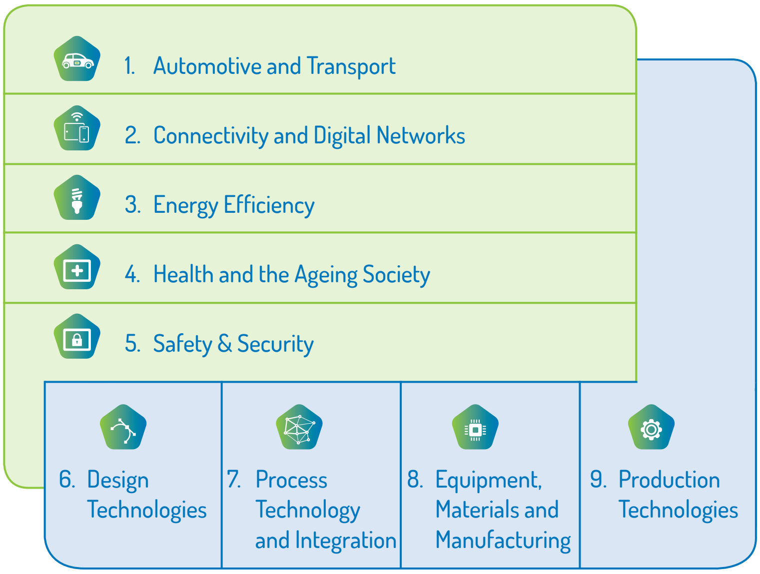
1. Health, demographic change and wellbeing
2. Food security, sustainable agriculture and forestry, marine and maritime and inland water research, and the bio-economy
3. Secure, clean and efficient energy
4. Smart, green and integrated transport
5. Climate action, environment, resource efficiency and raw materials
6. Europe in a changing world - inclusive, innovative and reflective societies
7. Secure societies - protecting freedom and security of Europe and its citizens

[3] adapted from foreignaffairs.com/articles/2015-12-12/fourth-industrial-revolution
[4] as listed in ec.europa.eu/programmes/horizon2020/en/h2020-section/societal-challenges

Roadmaps

In the highly competitive landscape outlined by the main areas of opportunity and the societal challenges for Europe, the AENEAS Strategic Agenda targets nine themes to define the roadmaps in the field of micro- and nano-electronics-enabled components and systems. Each theme addresses a mix of technologies and applications along the value chain.

THEMES



In the above diagram, themes 1 through 5 are closer to end-user applications, while themes 6 through 9 are closer to the technology supply side. Safety and Security (theme 5) takes a special position in the first group, because its content has direct impact in all applications and technologies. Similarly, Production Technologies (theme 9) is special in the second group, underpinning all others.

The above themes are detailed in separate chapters, created and maintained by partners from industry and science in an open bottom-up process. 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 specific conditions for success in the theme, high-level timeframes for the relevant roadmaps until 2030, and main synergies with other themes. Presence of well-educated people and access to co-operative R&D&I programs are generic conditions for success in all themes.

FUTURE AND EMERGING TECHNOLOGIES

The AENEAS Strategic Agenda is based on a broad and constantly moving portfolio of technologies, where new options emerge frequently. At the same time, technologies in operation are also continuously improving. Which future technologies will be picked up and translated into solutions in market- and society-driven applications is hard to predict.

Quantum technology, the newly announced H2020 flagship initiative, can be a game changer in the field of micro- and nano-electronics-enabled components and systems. But other novel paradigms in computing may also be ready for adoption within the timeframe of the AENEAS Strategic Agenda, e.g., photonic integrated circuits, resistive computing and neuromorphic computing.

The AENEAS roadmap community is aware of these opportunities and uncertainties, keeping an open eye on the low side of the Technology Readiness scale, while executing R&D&DI at the medium and high side. Next editions of the AENEAS Strategic Research Agenda will take into account the latest development in the nursery of future and emerging technologies.

Implementation

The AENEAS Strategic Agenda provides essential roadmaps necessary for Europe to address important societal challenges, to compete worldwide with innovative products and services and to strengthen the competitiveness of European industry along the electronics value chain. As such, the AENEAS Strategic Agenda is a pan-European guideline for public-private partnership programs on research, development and innovation in the field of micro- and nano-electronics-enabled components and systems at European Union, intergovernmental, national and regional level. This includes guidance to the EUREKA Cluster PENTA, the ECSEL Joint Undertaking, the H2020 program, in particular LEIT, as well as national and regional R&D&I support instruments.

The PENTA program focuses on topics selected from the AENEAS Strategic Agenda, seeking co-operation and alignment with the other EUREKA clusters, with the ambition to contribute to a possible 'Cluster of Clusters' in ICT within EUREKA.

In ECSEL, the AENEAS Strategic Agenda blends in with the roadmaps of AENEAS' fellow Private Members in the Joint Undertaking, ARTEMISIA and EPOSS, seeking for synergies and strengthening of the European value chain across technologies and applications.

On the application side, the AENEAS Strategic Agenda provides input to the materialization of Lighthouse initiatives in ECSEL, targeting platform formation driven by market pull, with a potential reach far beyond the ECSEL programming, and including when needed de-facto standards and regulatory measures.

On the technology side, the AENEAS Strategic Agenda supports the European Commission IPCEI concept, in which national authorities may fill the investment gap to overcome market failures. This concept can boost the realisation of supply push initiatives emerging from preceding ECSEL projects into full technology and manufacturing readiness.

The AENEAS Strategic Agenda roadmaps will also be the technological basis for the AENEAS community in facilitating networking and organising the Market Place between SME and larger companies, together with industry sectors and clusters, and providing mentoring to SME throughout the process of public-private partnering.

THE HUMAN FACTOR

With the emergence of the Fourth Industrial Revolution, society will also become dependent on services from ubiquitous IoT-based systems, as in automated driving, smart cities, and e-health. A blackout, be it by technical failure, natural causes or hackers, let alone terrorism, may leave society helpless and vulnerable.

In the meanwhile, public policy and decision-making still dwells in the realm of the Second Industrial Revolution, when there was time to study issues and develop responses in a linear and mechanistic fashion. With the rapid pace of chance and broad impacts in the IoT-age, legislators and regulators must adopt agile responses, and think across borders of cities, regions, and nations.

Therefore, innovations in the field of micro- and nano-electronics-enabled components and systems should be accompanied by deep studies in socio-economic sciences and humanities on the consequences of IoT and Industry 4.0 for individuals and communities. These should aim at solutions and options to cope with the changing landscape and guide human society toward the future.

01

1 EXECUTIVE SUMMARY

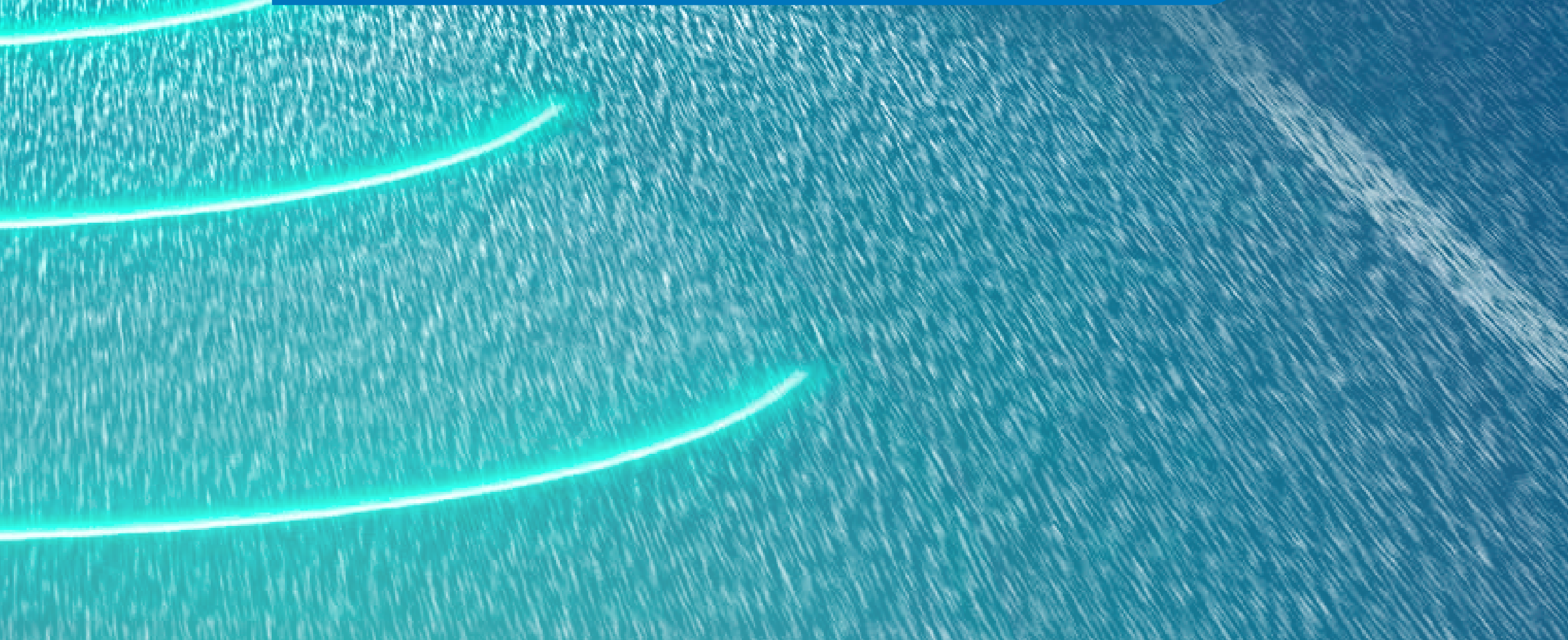
This chapter introduces and describes three Grand Challenges that have been identified for the European Research and Development community over the next five years in the Automotive & Transport sector.

These Grand Challenges in Automotive & Transport are:

Grand Challenge 1	Connected & Automated Driving
Grand Challenge 2	Highly secured & privacy protecting vehicles in the IoT
Grand Challenge 3	Sustainable & Affordable Electrified Vehicle & Infrastructure

These three Grand Challenges aim to keep Europe in the lead for innovations throughout the automotive value chain and to broaden the RDI-horizon so that future research and innovation focus more on holistic, cross-domain and IoT-based sustainable mobility solutions for all the main transportation domains (Automotive, Railway, Aviation and Shipping). Key aspects to cover throughout the 3 challenges are security, privacy protection features, safety, sustainability, affordability, human interaction and societal acceptance. Important is also to study the impact on revised or even complete new business models for the automotive industry.

The defined Automotive and Transport 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.



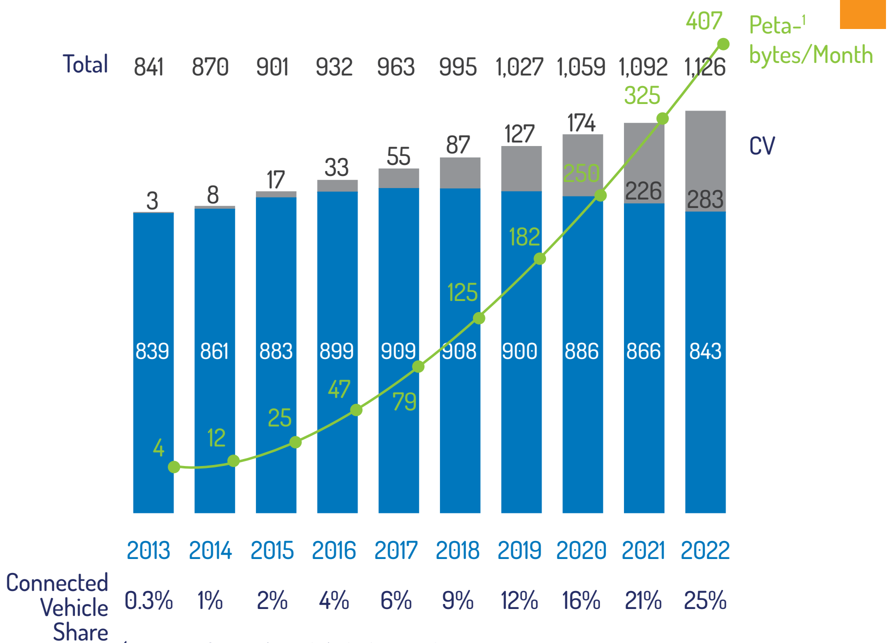
2.1. Competitive value

Mobility is not only a visible expression of Europe's economic and societal prosperity; it is also an important source of that prosperity. 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 and system suppliers.

Automotive semiconductor revenues in Europe reached €4.0 billion in 2012, representing more than 30% of the world market.

According to Strategy Analytics[5], automotive semiconductor revenues are expected to grow year on year, by 5% in 2013 and 7% (CAGR) over the five-year forecast period.

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.

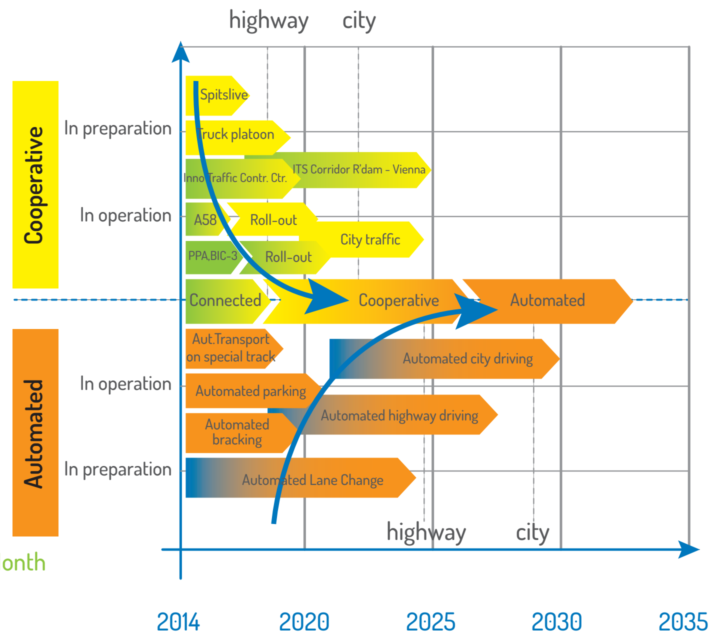


¹Average of 1.5 GB/month/vehicle, 1 Petabyt = 1,048,576 GB

Sources: Cisco IBSG, 2011, based on data from U.S. Department of Transportation, iSupply, McKinsey & Company

Connected cars are the first step towards highly automated and autonomous cars. Connectivity will be based on multiple protocols and standards, as e.g. camera's, vision systems, radar, lidar, C2X 802.11p, NFC, 5G, etc. Connectivity in cars will also be of crucial importance towards connecting the car and the vulnerable road user.

The timeline is the following:



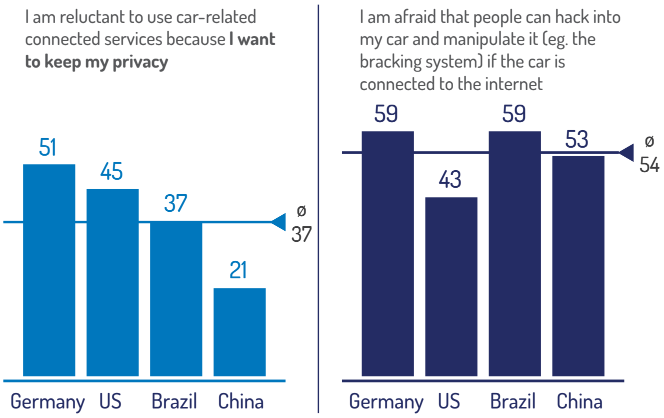
SOURCE / *Gear 2030 Discussion Paper – Roadmap on Highly Automated Vehicles*

[5] Source: Strategy Analytics, Automotive Semiconductor Demand Forecast 2011-2020, July 2013

A key area of research for realizing the connected car is the aspect of security and privacy protection of the car owners and users. Defending the car against hacking from the outside world is a must-have towards societal acceptance of the connected car.

New-car buyers are broadly concerned about data privacy and the possibility of hacking when it comes to car connectivity.

% of new-car buyers that (strongly) agree with the statement



SOURCE / *McKinsey's Connected Car Consumer Survey, 2014*

Automated driving requires a broader view beyond the vehicle aspect itself, including the requirements for the physical and digital road infrastructure, the integration in the IoT, links to connectivity aspects and traffic management and aspects linked to the road users, not least the road safety dimension. The societal (e.g. driver acceptance, data issues, interaction driver/vehicle/other users, ethical issues, environmental issues, social inclusion) and economic issues (impact on economic activities) should also be looked at.

Micro-electronics, nano-electronics and embedded systems will be key enablers for leveraging the integrated transport systems (e.g. road, rail, air and waterways) that are projected to be at the heart of future freight transport systems, as well as contributing significantly to passenger traffic by the year 2020. It will be the fundamental base to come to a fully automated multi-modal transport system throughout Europe.

In the area of electrified vehicles, the main challenge is the transition from niche market products to mainstream products. In order for a tsunami of electrified vehicles to come on the market, three things must happen:

- there must be a massive reduction in cost,
- effective energy storage solutions must be developed (progress in battery technology),
- an intelligent and strengthened power distribution infrastructure needs to be put in place.

In addition, a big challenge will be on how to ramp up the volume production of electrified vehicles rapidly enough and how to manage the complete lifecycle. Smart grids and nano-electronics will be key areas of innovation in the field of electric mobility.

Finally, innovation in microelectronics and nanoelectronics should lead to standardization initiatives and de-facto standards. Current examples include ASIL for safety, BroadReach for in-vehicle communication, IEEE802.11p for Car2X, 5G for future IoT-networks, and AUTOSAR for a standardized modular software-stack in automotive applications.

The roadmaps and priorities of the 3 grand challenges will also be aligned with a number of European initiatives, as e.g. GEAR2030 and AIOTI.

2.2. Societal benefits

Integrated mobility systems already play a key role in the transportation of people and goods in local, regional, national, pan-European and international contexts. On the downside, however, they represent a major cause of energy consumption and human casualties.

For example, road transportation alone accounts for 21% of Europe's fossil fuel consumption and 60% of its oil consumption. In relation to the casualty toll, 28 thousand people were killed in road traffic accidents in the EU in 2012 - equivalent to three road casualties every hour. Road traffic accidents are the main cause of death in Europe's under-45 age group. The ambitious target to halve the number of traffic deaths in Europe between 2001 and 2010 was not reached. Consequently, improvements in road safety through the use of electronics-based driver-assist systems remain a high priority. One of the factors affecting the increasing need for such systems is Europe's aging population, which despite growing old has the expectation of maintained mobility. Driver-assist and driver-alert systems that mitigate age-related cognitive or physical impairment will increase security for all road users, and at the same time extend the mobility and independence of the elderly. Ultimately they form the base for fully automated and connected cars. Autonomous driving is expected to gain increasing importance in improving traffic flows, safety and driving comfort.

The addressed enabling technologies are aimed at increasing both passive and active traffic safety and providing greater comfort, as well as radically reducing overall emissions and primary energy usage. An integrated approach that links different modes of transport (road, rail, air and waterways) is essential for guaranteeing the sustainable competitive transport solutions needed to make a visible and positive difference for Europe, its citizens and its industry.

Mobility, safety, security & privacy protection are clear societal needs for the future intelligent car and road infrastructure.

E-mobility based on sustainable & affordable electric vehicles will be the key element in maintaining individual mobility.

3.1. Challenge 1: Connected, progressing to Autonomous Driving

3.1.1. Vision

Autonomous & zero-accident driving based on highly reliable and affordable electronic systems & components. Technologies for new ways of interacting between driver and car.

3.1.2. Scope and ambition

As the proportion of electronics and software as a percentage of the total construction cost of a vehicle increases, so does the demand for the safe, secure, reliable and un-hackable operation of these systems. In addition, privacy protection is a key element for car owners and drivers. These requirements ask for technologies that deliver intrinsically safe operation and fail-safe fall-back from component to subsystem and interaction with the cloud. This requires new developments in terms of multi-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.

In terms of qualification of connected and highly automated vehicles, today's status is that many thousands or millions of km on roads need to be driven to "qualify" a system or a new sensor (Radar, Imager, ...). Even with careful selection of roads and situations at some point this is a probabilistic approach, very time consuming and where non-regression testing is difficult to impossible. A fast progress is not possible with such a test approach. It will thus be necessary to find new ways to perform fast and repeatable validation and non-regression tests independent from driving on roads.

3.1.3. High priority R&D&I areas

- System validation and non-regression testing from driving on the road – software tools for automatic validation in Highly Automated Driving
- Artificial intelligence for autonomous cars, intelligence versus deterministic response
- Multi-layered privacy protecting and Secure Elements in architectures and components
- Efficient and safe use of resources in multi-core processor architectures
- New trusted integrated sensors in harsh conditions
- Low cost materials and structures for highly reliable electronics
- Secured high-speed in-vehicle networks
- New generation technologies for automated driving based on competitive consumer electronics
- New interaction between driver and car
- Big-data handling and data-governance inside cars and between cars and the IoT
- Large scale field tests of secure highly automated vehicles
- Reliable and high-precision localization
- Strategies for safe operation / safe stop / safe actuation in emergency situations
- Contemporaneous logging and secure, reliable and privacy protected data retention for incident reconstruction

3.1.4. Competitive situation

Especially in European countries, the automotive industry plays a central role for the internal market as well as for export markets. According to Europe's car manufacturers and transporters, they employ around 12 million people (approximately 2.2 million directly and 10 million indirectly) and contribute 16 per cent of the European Union's GDP. However, competition is getting fiercer. Since 2013, China has overtaken Europe in number of cars produced. It will be the first time this has happened. European Car manufacturers are also competing in a worldwide race toward vehicle automation and connectivity with newcomers from the IT sector (e.g. Google, Apple, Tesla). The value is being reshuffled across the value chains. According to some studies, 30 to 40 per cent of the value in the automotive value chain will pass through digital platforms, in the near future. Whilst the market behaviour of digital platform providers is subject to the existing competition policy instruments, it will be important to assess in addition what role the EU could have in ensuring the free flow of data and undistorted access to the relevant platforms. 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 good market position by developing innovative and effective safety features, many jobs in the automotive, aeronautics and railway industries will be preserved.

3.1.5. Expected achievements

The impact of automated and connected vehicles could be huge. It could help to drastically reduce road fatalities as 90% of road accidents come from human error. 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. Drivers 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 behavior and urban development. It could also result in new business models, such as shared mobility which could have an impact on the number of vehicles on our roads. Connected and automated vehicles also bring new challenges for regulators concerning road safety, security, traffic law, access to data, protection of personal data, financing, etc. which need to be addressed.

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

- interacting information systems for secure connection between vehicles and between vehicles and infrastructure, also enabling intelligent urban & metro area traffic management systems
- intelligent on-board traffic management and navigation systems to achieve maximum efficiency and driving range
- innovative advanced driver-assist systems for fully automated and autonomous vehicles
- energy harvesting sensor & actuator systems in harsh conditions
- next generation multi-core based architectures
- safe fallback vehicle autonomous sensing and actuation systems
- high precision low cost localization platform for civil (automotive, industrial, agricultural) use

Development of such systems will be accomplished through the use of innovative new components and standards (e.g. sensors, multi-cores, actuators, communication protocols, etc.), new system-in-package technologies, and new design/verification methodologies.

3.2. Challenge 2: Highly Secured and Privacy Protecting Vehicles in the IoT

3.2.1. Vision

Cars will become IoT devices and will connect with other IoT-devices, as e.g. road infrastructure, buildings, other cars, other modes of transport (train, metro, ships, planes, etc.), vulnerable road users, etc.... A key challenge will be the protection of the privacy of the driver and the security aspects when a car becomes an element in the cloud.

3.2.2. Scope and ambition

This grand challenge aims to elevate the efficiency, predictability and reliability of traffic and transportation systems to a higher level by using data from different sources and by full integration within the IoT. These sources will include cellular networks, wired and wireless broadband networks and broadcast systems (commercial downlink channels), navigation systems, vehicle-to-vehicle communication systems, as well as other data sources. Distributed sensor networks, communicating through RF and broadband information buses will have to be analyzed according to their deployment in automotive and transport systems. Appropriate multi-access / multi-standard gateways for seamless interaction with other domains will need to be developed. Of particular interest will be the pan-European standardization of interfaces between components from different suppliers.

3.2.3. High priority R&D&I areas

- real-time traffic information (up- and down-link), for example, using cars as moving sensors (uplink) and digital radio (downlink)
- intelligent traffic flow management targeting the efficient use of energy resources and time
- pro-active communication on accidents, road blocks, dangerous situations, availability of charging stations, active route planning
- appropriate multi-access/multi-standard communication gateways
- intelligent high-performance data processing and secured data distribution
- reliable electronics for security and privacy protection
- monitoring of technical status of the vehicle for preventive maintenance
- energy-harvesting sensor/actuator technologies
- IoT (Internet of Things) - technologies, distributed control systems
- embedding of traffic infrastructure systems into a broader context of smart grid, smart city concepts etc.

3.2.4. Competitive situation

European industry is in a clear leadership position in terms of developing complex embedded systems. New standards for electronic vehicle architectures (AUTOSAR), communication (V2VC) and co-operative traffic management concepts (e.g. the EU projects Safespot, CVIS and Coopers) have been developed. These developments will enable a holistic approach to Intelligent Traffic Systems, enhancing safety for vehicles and vulnerable road users, improving the efficiency of traffic flows and ensuring low energy consumption (including electric vehicles and grid management). The European industry's strong position in nanoelectronics and embedded system technology will be a major enabler of breakthroughs in this area.

The implementation of multiple bus systems and distributed electronic control units (ECUs), for example, CAN, LIN, Flexray and MOST, was driven by European OEMs. Future requirements will lead to partial networking (distributed intelligence and stand-by of transceivers and processors) and higher bandwidth communication systems such as Open Alliance for 100 Mbit/s and RTPE/IEEE for 1Gbit/s. These in-car networks will interact with the environment and will collect data for upload streams and/or distribute download streams within the vehicle.

3.2.5. Expected achievements

Innovative new concepts, such as co-operative traffic management systems that interact with systems in other application domains (for example the Internet or logistics) are expected. Such systems will strongly support improvements in the efficiency of traffic movements by reducing traffic jams, reducing energy consumption and pollution, and reducing journey times for public transport and the multi-modal transport of goods. Extending in-car networks to the wider community of road users will offer new features. Intelligent traffic management systems, automatic emergency call systems and road tax systems for all vehicles will require safe, reliable, interactive telematic modules, which will become part of the automotive architecture, including smart driver interfaces. These innovations will enable time savings and reductions in energy and $CO2$ emissions due to traffic jams and road congestions, while also saving lives.

3.3. Challenge 3: Sustainable & Affordable Electrified and Non-Fossil Powered Vehicles

3.3.1. Vision

Needs-based, user-friendly, affordable & sustainable electric vehicles embedded in a flexible and smart mobility infrastructure satisfy the need for individual mobility. Need for non-fossil-powered vehicles and different technologies to reduce the CO2 footprint. Nanoelectronics and embedded systems will provide essential features.

3.3.2. Scope and ambition

The ambition is to cover all available electric drive concepts, not only fully electric drive-train systems but also hybrid drive-train technologies (e.g. parallel hybrid, plug-in hybrid, serial hybrid and range-extender concepts). It should also cover other types of vehicle such as electric trains, electric ships and aircraft. Furthermore, it should encompass smart battery management and optimized connection to the grid.

3.3.3. High priority R&D&I areas

- energy-efficient electronics to control and connect advanced storage technologies (applied to innovative battery cells, hybrid batteries and fuel cells)
- new energy-saving architectural concepts
- efficient power electronics - e.g. for inductive charging technologies
- deployment of multi-core processor technology for real-time control in mixed- criticality systems
- heterogeneous system integration, inclusive of thermal & battery management
- smart connections to smart grids
- scalable drive train solutions for different category of vehicles
- integrated low-weight drive train components for light electric vehicles

3.3.4. Competitive situation

At present, European automotive companies enjoy the number-one market position in the market for conventional cars and number-three position for electric cars. Regarding the semiconductor component of cars, Europe has three players in the global top five: ST, NXP and Infineon. Bearing in mind the European automotive industry's leading position in the worldwide market for combustion engine vehicles (in terms of car manufacturers as well as component suppliers) it is extremely important for Europe to not only maintain this position but also to match it for electric vehicles, especially in relation to integrated e-mobility systems (vehicle and infrastructure integration for hybrid and electric vehicles). Full market penetration not only has the potential to stabilize employment in Europe, it also has the potential to increase it. However, worldwide competition in electromobility is fierce and Europe is already in danger of falling behind new competitors, especially those in the Far East.

Fully electric vehicles will create an estimated world-wide market in the multi-billion Euro range. By 2015, it could be around 50 billion Euros per year, and by 2020 around 100 billion Euros per year.

Recent market trends suggest the rapid introduction of e-bikes and e-cycles in order to get end-users on the e-mobility learning curve and pave the way for mass introduction of e-cars.

3.3.5. Expected achievements

Well-recognized economic and ecological reasons will drive the introduction of intelligent electric vehicles. A significant CO2 emission reduction from today's >120g/km to around 45g/km is expected, leveraging the fact that electrical energy is increasingly being generated from low carbon sources.

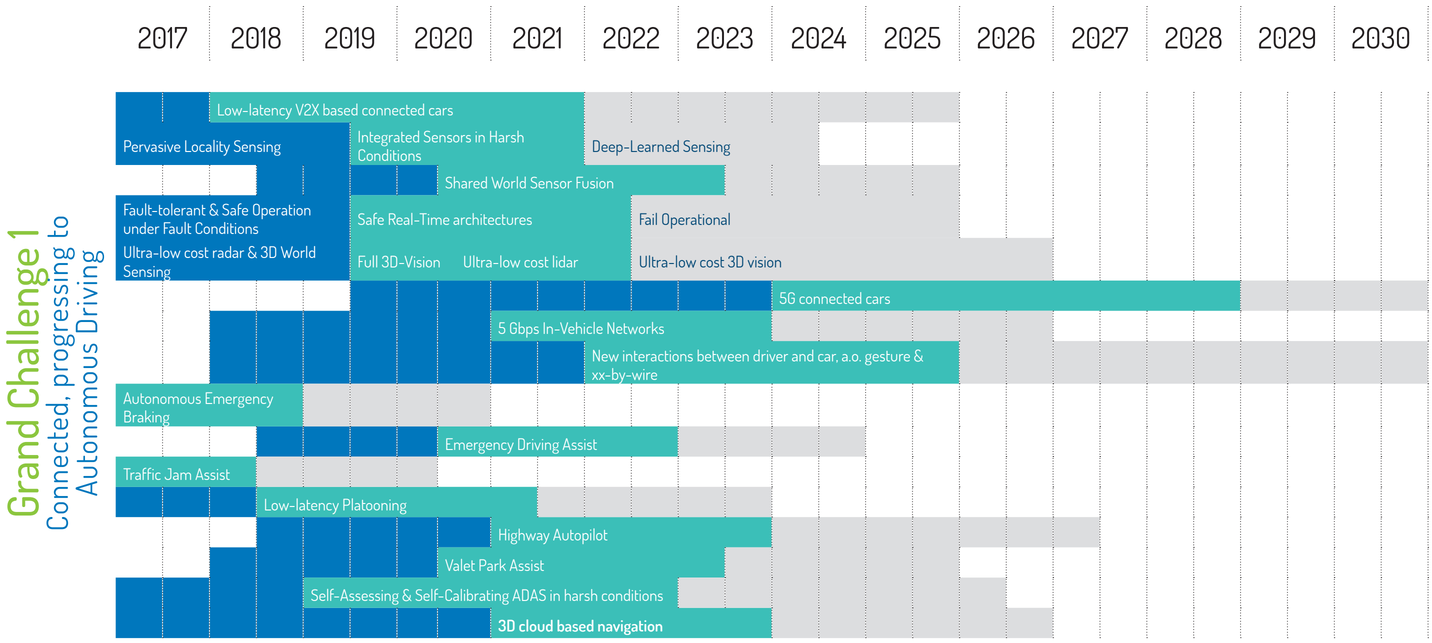
Microelectronics and nanoelectronics based solutions are expected to trigger significant progress in the fields of energy efficiency, devices reliability and lifetime at reasonable cost.

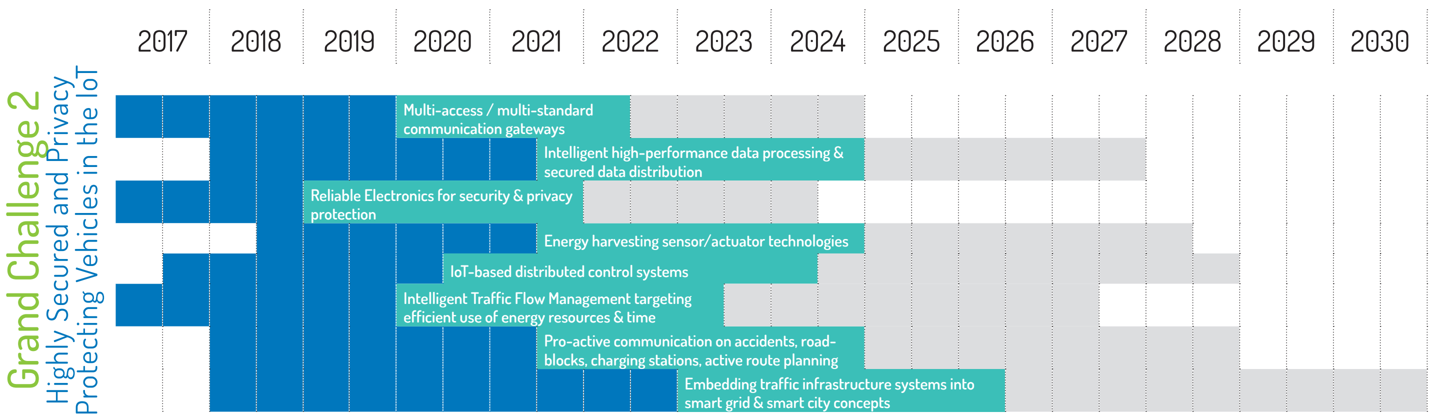
Furthermore, this will lead to improved driver experience of electric vehicles by intelligent and innovative (light) electric vehicle solutions.

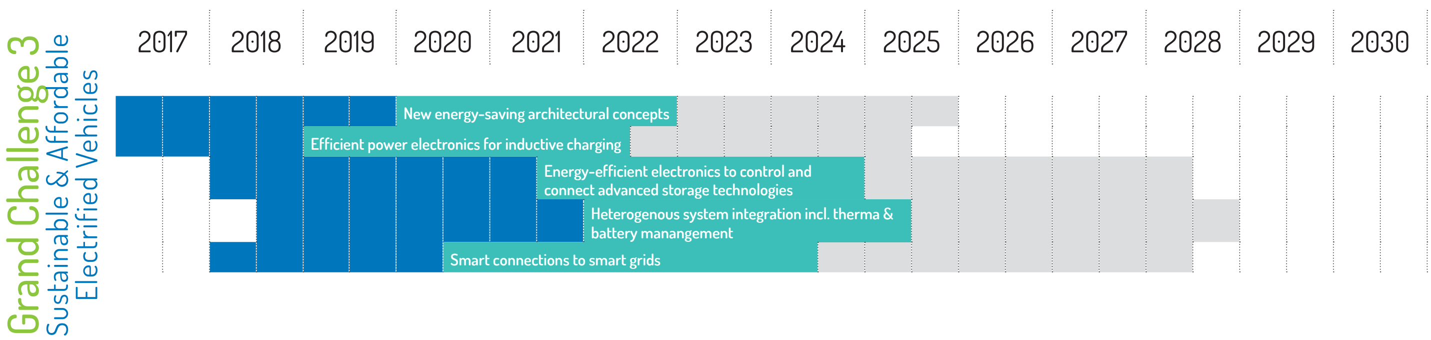
4 CONDITIONS FOR SUCCESS

AENEAS is 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. 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 forms and business models of mobility.

5 TIMEFRAMES







TRL 2-4 Technology Readiness Level; applied research – validation in laboratory environment

TRL 4-6 validation in laboratory environment – demonstration in relevant environment

TRL 6-8 demonstration in relevant environment – prototyping in an operational environment qualified

6 SYNERGIES WITH OTHER THEMES

Vehicles and multi-modal transport is becoming a core element in the IoT and in the cloud. Therefore, a clear synergy will exist between mobility & transport and the IoT program, which is part of the chapter for "Connectivity & Digital Networks". 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. Seamless connectivity, interoperability and privacy protection therefore become more and more important. This should be supported by cross-domain use of Design Technologies, Semiconductor Process, Integration Technologies, Connectivity & Digital Networks.

In contrast to other domains, Automotive & Transport applications are characterized by stringent real-time requirements and severely limited energy resources. To meet these requirements, robust technologies and domain-specific implementations of the same functionality are needed. Another specific characteristic of Automotive & Transport is the different significance of non-functional aspects such as Safety and Security or Energy Efficiency in comparison to other application domains.

02

1 EXECUTIVE SUMMARY

The communication network of 2020 will be infinitely more complex than the one of today. On one hand we are witnessing an explosion in data demand, almost doubling yearly, mainly driven by video streaming (higher content demand combined with higher resolution devices), VR (virtual reality) and AR (augmented reality). New developments in both the wireless (5G) and wired arena are mandatory to cope with this continuous increase of average and peak data rates.

On the other hand, the IoT (Internet of Things), the 3rd wave of internet will connect around 20 billion devices by 2020 according to Gartner, not only tablets and smartphones, but also new types of devices, indispensable building blocks to create Smart Homes, Smart Cities, Smart Transport, Smart health and Smart industry. This enormous network of connected devices exchanging information unfolds across geographical, industrial and technological borders. This requires advanced and application/service-agile networks supporting low latency, high robustness, high throughput, universal coverage (in & out-door), agile deployment and energy-efficient operation.

Standardization is an enabler to guarantee interoperability (compatibility amongst devices), at the level of connectivity there is a major standardization in place, more recently also standardization in the different Smart domain areas is taking place and the next step is to cover cross-domain standardization.

Security is a key issue, E2E (End to End) security is a must to guarantee confidentiality and integrity of data communications as well as the privacy of human beings.

Advanced silicon and packaging technologies are needed for the industry to introduce fast and powerful IoT solutions.

CONNECTIVITY AND DIGITAL NETWORKS

2 RELEVANCE

2.1. Competitive value

With a highly developed telecommunications market, Europe is both a major producer and a consumer of networking technologies and services. The telecommunications industry expects an average yearly growth of 3% for the period of 2015-2019, growing from $1.55 trillion in 2015 to $1.74 trillion in 2019 (source IDC). The semiconductor market in 2016 is forecasted at $367 billion, a 4% growth versus last year (source IC Insights) out of which communication being the biggest contributor (38%). The global economic impact of IoT is estimated at $11 trillion by 2025. There is a need to properly address the infrastructure of the network that will be needed to cope with the challenge of unprecedented data growth and changed performance characteristics (IoT). Europe must take this golden opportunity to drive the changes and position European vendors, service providers and innovative SME's in new markets.

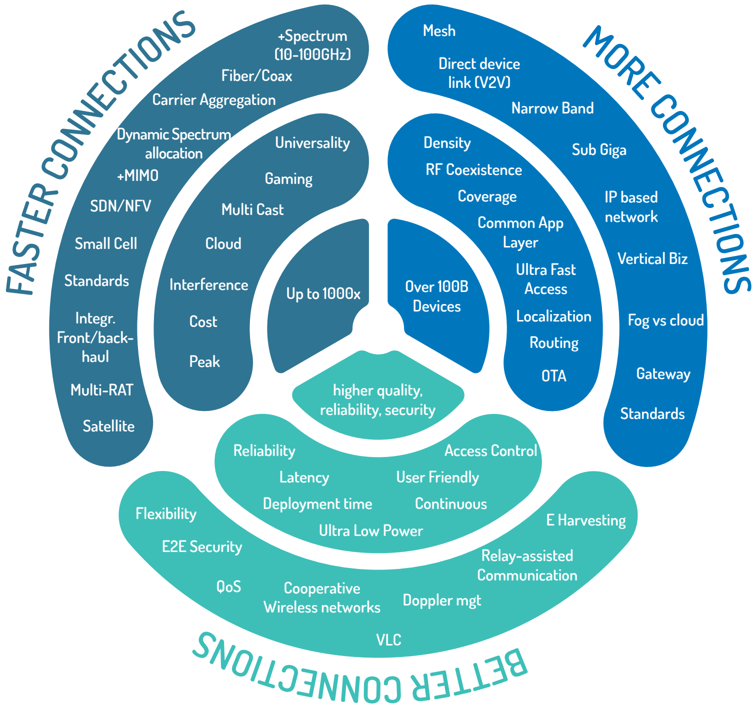
2.2. Societal Benefits

The large-scale implementation of IoT devices will transform many aspects of the way we live. Connected cars, intelligent traffic systems with sensors embedded in roads (Smart Cities), will help minimizing congestion and reducing energy consumption and pollution. Wearable fitness and health monitoring will transform the healthcare services. Thanks to automation components and energy management devices, home energy efficiency and security will improve. Numerous vertical domains in the industry, distribution and agriculture will benefit from the information originating from networked sensors available throughout the value chain.

3 GRAND CHALLENGES

In order to address all the technical issues associated with the connectivity and network requirements in the most efficient way, R&D activities should be organized around the following three Grand Challenges.

- **Faster connections:** up to 1000 times
- **More connections:** over 100 Billion devices
- **Better connections:** higher quality, reliability, security



3.1. Challenge 1: Faster connections: up to 1000 times

3.1.1. Vision

Coping with a data traffic demand doubling every year will require by 2020 a 1000-fold increase of the mobile data volume, a 100-fold increase of the peak data rates, and a latency of a few ms or less at a comparable end user cost level and overall energy consumption.

3.1.2. Scope and ambition

The increase in the data demand is driven by the ever growing number of data apps, smart phones, tablets and other connected devices. Much of this data will be dedicated to services and applications based on ultra-high resolution video and 3D audiovisual content for virtual and augmented reality. Data storage and computation in the cloud will contribute to the increase in bandwidth, especially because this big data will be accessible from an amazing number of devices to a large number of end-users.

The challenges

Data rates and latency

Future communication networks are expected to serve a diversity of applications and services, each requiring specific data rates, latencies and security. Social media applications for example, feature regular accesses to the network with moderate average data rate, but require high peak rates when up/down-loading a video stream. Such applications are typically less latency critical, in contrast to real-time critical services for factory machine controlling and autonomous cars. Future networks should support and manage this diversity of data rates and latency in an efficient way. This includes classification and scheduling based on the criticality of the data and network load, and to trade-off the data rate with the quality of experience for the user.

Heterogeneous mobile networks

To support growing data rates and number of connected devices in urban environments, mobile networks are increasingly dense and heterogeneous in cell-size and radio access technologies (multi-RATs (Radio Access Technology)). Future networks should resolve the interference between the different cells and radiations and develop new management models to control roaming and exploit the co-existence of the different cells and radio access technologies. It will be beneficial to deploy new management protocols to control the user assignment to cells and technologies in the mobile core network as it will increase the efficiency of accessing the network resources. Satellite communications should also be considered as a potential radio access technology, especially in rural areas.

Wireless backhauling is an important asset for fast deployment and network extension, but the backhauling technologies should support the very high aggregated throughput and be self-configurable and self-maintainable. Moreover, the backhaul and front haul should be better integrated to uniformly manage and service them from the network.

Cloud

Both traditional and novel network architectures like C-RAN (Cloud-Radio Access Networks), NFV (Network Functions Virtualization) and SDN (Software-defined networking) exploit the potential for data storage and processing in the cloud. Leveraging the cloud allows to reduce the complexity of IoT devices, as the main processing and data storage is performed in the network. Future networks should however implement cloud utilization mechanisms to maximize the efficiency in terms of latency, security, energy efficiency and accessibility. A weighting factor should be applied to trade-off the different criteria; company-confidential data for on-site usage should be treated differently than public movies.

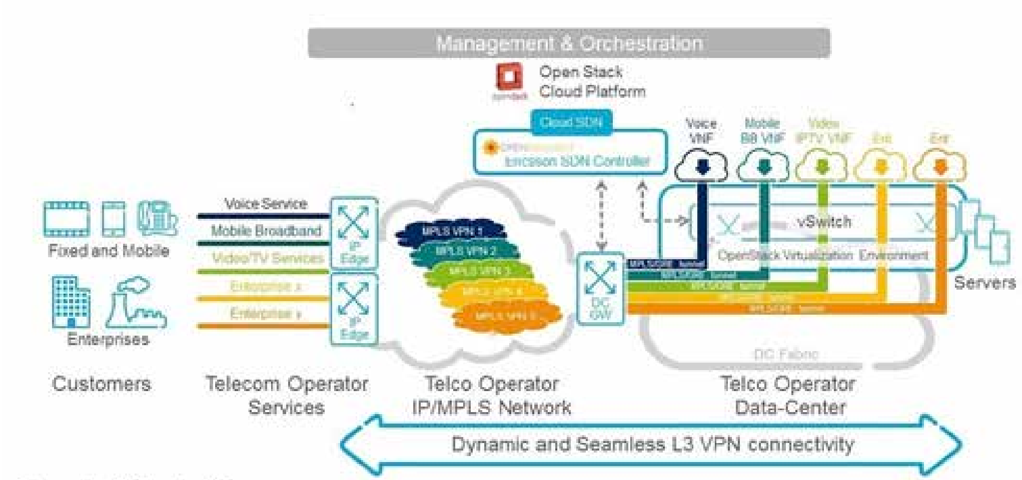
The Solutions

Radio access technologies

The substantial increase of the throughput requires an extension of the spectrum towards 100GHz and beyond, offering more data capacity due to the larger available bandwidths. Technologies like WiGig and NG60 (802.11ad and 802.11ay) are being developed to be applied in different high-throughput applications such as cell backhaul, point-to-point or point-to-multipoint communication. One of the drawbacks of these frequencies is however the large propagation loss and atmospheric absorption which requires large antenna arrays with beamforming and short-distance line-of-sight communications. This brings new perspectives in terms of multi-/massive-MIMO technologies. The wide bandwidth offers new opportunities for intra-band, inter-band and TDD-FDD carrier aggregation to optimize the usage of the network resources adequately to the instantaneous need.

Advanced radio access technologies and waveforms will enable dynamic and efficient spectrum allocation enabling scaling of network capacity, low latency, radio flexibility, spectrum and energy efficiency, and high reliability far beyond the capabilities of 4G LTE-A. This will enable the network and the connected devices to optimize the used spectrum based on priorities such as power, instantaneous throughput, MIMO configuration etc. Moreover, an advanced user/control separation based on multi-RAT heterogeneous network offers dedicated technologies which can be overlaid to coordinate the cellular network. This can reduce the user plane delay handover process and will contribute in minimizing latency and signaling overhead. It will also increase the spectral efficiency and reduce interference. Finally, standardization of the radio access technologies and service interfaces within the equipment is required to be capable of deploying sustainable and cost effective network solutions which allows seamless configuration and application portability.

Network architectures



Ericsson cloud SDN for telco NFV

Future networks will have to offer higher network flexibility by combining cloud technologies with SDN and NFV, as this enables network flexibility to integrate new applications and to configure network resources adequately (sharing adequately computing resources, split of data, security rules, QoS parameters, mobility, etc.…). An example of implementation is given in the figure above. These cloud technologies should be balanced, secure and user friendly. Applications making use of cloud computing, and those using edge computing will have to co-exist and will have to securely share data. The right balance needs to be found between cloud and edge computing to optimize overall network traffic and latency. Local gateways can be involved in this optimization to maximize utility, reliability, and privacy and minimize latency and energy expenditures of the entire networks. Such a smart home can be driven from a local gateway with a minimum of data transfer to the cloud.

Future networks will also be very heterogeneous with dense small-cell deployment, as more and more clusters with heterogeneous networking technologies will emerge. Connecting static or mobile clusters to the network will require advanced and secure gateways or backhaul. The integration of the wired/wireless front-haul, back-haul and access will allow to seamlessly connect the wireless IoT and mobile devices, optimizing the networking equipment and functions and supporting the network scalability. Such integration supports the network evolution and maintains the latency and QoS. In addition, network security is improved as it limits the thread to well defined elements.

Wired and wireless technologies

Multiple technologies will be developed to support the increased throughput. On one hand, the quality of wired network will be improved. Fiber in the core network is a well-supported and consolidated technology for network providers. The implementation of fiber technology enables services to benefit from a major increase of throughput. Copper fiber (e.g. coax) remains an interesting alternative, especially when applying protocols like MoCA2.5. On the other hand, novel communication means and alternative radio technologies will be developed. New wireless / optical technologies, for example, might be developed to cover the need of emerging applications like safety car application or car to infrastructure communication.

3.1.3. Expected Achievements/ Innovation Foreseen

- Development/deployment of the technologies needed to extend the spectrum in to the 10-100GHz and unlicensed band
- Development/deployment of advanced multi-/ massive-MIMO technologies.
- Deployment/extension of Cloud technologies with SDN and NFV.
- Advanced Automation of network and service operation.
- Development/deployment of platforms allowing a balanced, secured and user friendly Cloud / edge network architecture
- Integration of wired/wireless front-haul, back-haul and access
- Advanced wireless technologies and waveforms for dynamic and efficient spectrum allocation
- Advanced user/control separation based on multi-RAT heterogeneous networks
- Development/deployment of a network environment able to integrate and deploy dense small-cells
- Wireless optical technologies

3.2. Challenge 2: More connections: over 100 Billion devices

3.2.1. Vision

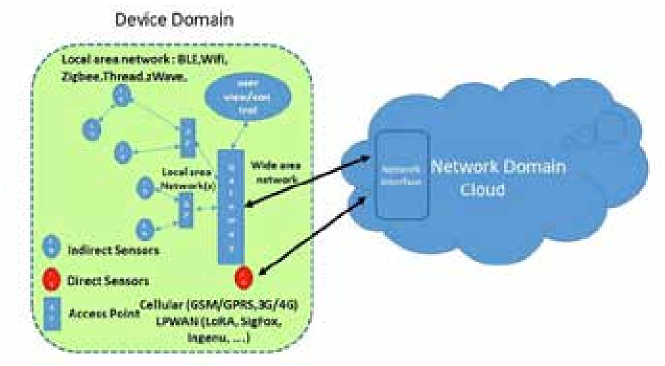
The creation of a network able to connect 20 billion devices by 2020, will require the increase of the number of connections per km2, extend the network coverage to non-urban areas and in-house, and create solutions for ultra-low power consumption (allowing IoT devices to sustain multiple years on a battery). Security is a key issue throughout the whole communication chain (End to End). Furthermore, costs for deployment and maintenance of the network should be minimized in order to create a sustainable business model for the operators.

3.2.2. Scope and ambition

Internet of Things represents a major opportunity for the electronics industry, the increasingly complex IoT solutions require advanced communication platforms that facilitate seamless integration of devices, networks and applications. The development of advanced semiconductor components, integrating sensors/actuators, multi-protocol circuits and electronic systems suited to large scale IoT is a key factor for sustaining E2E IoT ecosystems.

The challenges

Multiple networks will coexist in the house, car, office and factories. None of them will be capable of fulfilling all needs, and the use of separate optimized sub-networks will probably persist. WI-FI connected devices (tablets, phones), Bluetooth connected audio devices, Z-Wave/ Thread/BLE/WI-FI connected sensor and controlling devices will still be present for some time. However, these wireless connectivity solutions are still too power consuming to enable the widespread use of IoT and this competition might be modified by the emergence of new radio technologies and by new standards. Some of them are already deployed, or likely to be deployed: UNB (Ultra Narrow Band) by SigFox, CSS (Chirp Spread Spectrum) by LoRa, Weighless, and RPMA (Random Phase Multiple Access) by Ingenu. Europe is very well positioned in the emergence of these new standard LPWA (Low Power Wide Area) technologies.



Some machines will communicate through a direct network, e.g. V2V (vehicle to vehicle), vehicle to city sensors, as the risk of network unavailability in some areas is not affordable.

The need for gateways will persist to connect the different devices, support multiple connectivity standards, perform some edge processing through downloadable apps and connect to the cloud for big data processing through cable/ WIFI internet connection or wireless connection (4G/5G, NB IoT, LoRa, Sigfox, Weightless, etc.).

The IoT business is opening the door for complete new business models, operators can go vertical by offering smart security remote automation, or they can focus on data management for IoT. New services distributed ledgers will allow to get charged for what you use.

The goal is to enable rapid development and lower costs by offering standardized and multi-functional components that can be shared across multiple solutions in many industry verticals. Scalable IoT electronic systems require diversity in terms of functionality, application areas and need to address important issues such as security protections, customer demand, marketplace consolidation, standards, and technology barriers.

The Solutions

The network Infrastructure for IoT devices goes through a shift from anticipated number of devices to context-aware sense and respond. E.g. a truly context-aware phone could move from one profile to the next as a user drives a car, arrives home, or enters a restaurant.

Connecting many edge devices that are small, low cost and with increased functionality require applying the following innovation pathway:

- Integrate ubiquitous connectivity by using low cost, context based speed, pervasive network connectivity, through licensed and unlicensed wireless services and technology.
- Adopt and apply IP-based networking to provide a common platform of software and tools that is incorporated into a large base of devices easily and inexpensively.
- Combine More Moore with More than Moore to achieve computing economics requirements for delivering multi-protocol communication, computing power, low cost low power consumption and sensing/ actuating capabilities.
- Miniaturization to allow advanced computing and communications technology to be incorporated into very small size devices with sensing capabilities for various IoT applications.
- Edge computing advancement, which leverages remote, edge networked computing resources (i.e. intelligent gateways, communication micro servers, etc.) to process, manage, and store data, allowing edge and distributed devices to interact with a distributed communication, analytics and control/ monitoring capabilities.

The deployment of billions of devices requires network agnostic solutions that integrate mobile, NB IoT (Narrow Band IoT), IoT LPWA (Low Power Wide Area) networks, (LoRA, Sigfox, Weightless, etc.), and high speed wireless networks (Wi-Fi), particularly for applications spanning multiple jurisdictions; and to address IoT product, services and techniques to improve the GoS (Grade of Service), QoS (Quality of Service) and QoE (Quality of Experience) for the end users. Customization-based solutions, are addressing industrial IoT while moving to a managed wide-area communications system and ecosystem collaboration.

These different approaches show that device interoperability and open standards are key considerations in the design and development of internetworked IoT systems.

Ensuring the security, reliability, resilience, and stability of Internet applications and services is critical to promote the concept of trusted IoT based on the features and security provided of the devices at various levels of the digital value chain.

3.2.3. Expected Achievements/ Innovation Foreseen

- Development and deployment of context aware network infrastructures
- Integration of mobile, NB IoT and IoT LPWA networks
- Development and deployment of smart nodes and gateways, able to perform edge computing.
- Development and deployment of ultra-low power, low footprint and low cost IoT devices

3.3. Challenge 3: Better connections: higher quality, reliability, security

3.3.1. Vision

Future networks will require some vital services imposed by the new market and application requirements. The first aspect is the overall improvement of the quality and the reliability of the network. Several applications, as in the domain of M2M connections, require latencies down to 1ms, 99.999% network reliability, and global coverage including non-urban zones, highly autonomous operation and redundancy of data sources. For example, a cloud-controlled self-driving vehicle needs correct operation instructions within the right timeframe wherever the car is driving. More and more devices are used in high speed moving objects; hence the requirement of sustaining communication at speeds up to 1200km/hr (hyperloop).

The network-based "hop-by-hop" security approach, used today to secure the path between communicating parties, is not sufficiently efficient to build differentiated E2E security for mission critical services. We need to guarantee the trustworthiness and reliability of information that is processed and gathered through sensor networks. Complementary security layers (including at application level) are required to enabling data protection from source to destination. This topic is however covered in more detail in chapter 5 Safety and Security of the AENEAS Strategic Agenda.

Power reduction and Energy Harvesting is another critical network property for future and current networks. This is described in the chapter 3 Energy Efficiency of the AENEAS Strategic Agenda.

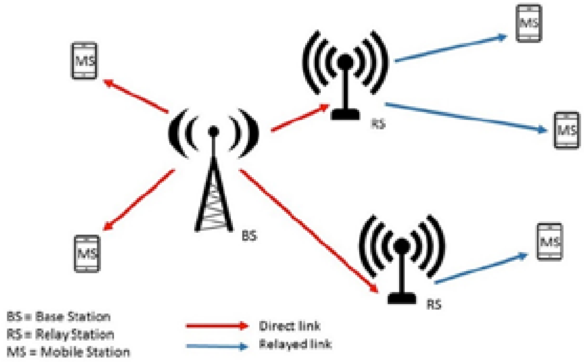
3.3.2. Scope and ambition

The Challenges

The distribution of high resolution multimedia content, the deployment of immersive interactive services or the transmission of next-generation real-time control flows are some of the business segments which will be given a lot of attention in the next decade, and the fulfillment of the QoS requirements of these services set new communication quality and reliability goals. These services are usually very sensitive to packet loss, delay and jitter effects among others, and hence user experience is immediately degraded when link quality is not optimum. The deployment of next generation services is very dependent on the quality and reliability of the communication channel, and the distribution of these services is still an open problem.

Mobile communications will need to provide better support to applications requiring high speed mobility. Furthermore, many of the connected things will be installed on (fast) moving objects. Deployment of massive communication and cluster of communication will need to provide an answer in the architecture to efficiently maintain networking connectivity with the infrastructure. In addition, deployment of communication with airplanes, vehicles for safety and autonomous driving will need massive investment in the infrastructure and the technology (new gateway generation, new wireless technology, etc.…)

The Solutions



One promising strategy for improving network data reliability and quality is to apply relay-assisted communication. Deploying intermediate nodes in the region between a transmitter and its intended receiver, improving communication by receiving a transmitted message, processing it and relaying the processed output to the receiver. These relay aided and cooperative schemes do still have a broad chance of improvement, providing dual-homing communications and redundant communication channels.

Cooperative wireless networks based on location and context awareness enables to predict the movements and data consumption of the mobile users. This information should be exploited to dynamically optimize the network functionality in terms of e.g. resource scheduling, and to facilitate inter- and intra-cell mobility. In cooperative networks, the predicted inter-cell mobility should be leveraged to enable efficient cellular hand-over and roaming across operators or radio access technologies.

SDN provide new tools to dynamically manage the networks resources and rapidly deploy new schemes. These new schemes may easily provide alternative routes under time varying network conditions.

Introduction of Smart Gateways able to communicate with the different IoT sensor nodes and perform local processing before sending the minimum of data over the network to the cloud, will further reduce network requirements like bandwidth and latency, and improve to overall reliability and quality. However, this approach is not the optimum solution towards global power saving, and creates new challenges for deployment, maintenance and updating of applications. A good balance needs to be found.

Optical wireless communications technologies such as VLC (Visible Light Communication) provide an alternative means of communication with very different properties from electromagnetic radio based wireless networks. This implies advantages that can be crucial for certain mission critical application e.g. in case the EMC spectrum is disturbed (accidentally, or 'jammed' on purpose). The evermore widespread availability of LED-based lighting (that can be modulated in high frequency) and cheap cell phone cameras enable ubiquitous availability of VLC (possibly as a secondary means of communication). Moreover, indoor positioning systems can be based on VLC.

3.3.3. Expected Achievements/ Innovation Foreseen

- Improvement and deployment of relay-assisted communication
- Development and deployment of (IoT) Edge calculation platforms (gateways) and applications, able to reduce the overall network and data center bandwidth.
- Improvement and deployment of SDN and network virtualization
- Development and deployment of VLC based communication and localization networks

3.4. High Priority R&D&I areas

The success of the different grand challenges will require special attention to be given to several high-priority research areas, including:

- Extend frequency spectrum to the 10-100GHz band for high speed local networks
- Advanced multi-/massive-MIMO technology and small-cell developments
- SDN and network virtualization with focus on flexibility and reduction of latency
- Coexistence, interference and co-working of heterogeneous devices and networks
- Integration of the wired/wireless front-haul
- Relay-assisted communication
- Edge computing by sensor nodes and smart gateways
- Optical wireless communications technologies such as VLC
- E2E embedded security with strong encryption, authentication and identification management at the edge devices levels.
- Long term autonomous operation of network nodes, which in turn calls for high reliability and zero or ultralow power consumption.

3.5. Competitive Situation

Europe broadband communication networks are very advanced; 75% of its population is connected to the internet. Most of European countries have more than three commercial operators offering wired and/or wireless connectivity, and some of these operators are contributing to the development of future communication technologies and implement new business models to sustain the cost of the exploitation. The European telecom infrastructure vendors Ericsson and Nokia Networks are still world leading companies (in terms of revenue), and it is key for them to invest in the development of 5G infrastructure. However, the European leadership in telecom chip manufacturing and application development has been strongly reduced over the last decade. Although Europe hosts world leading research institutes and academia in the field of future telecom networks and technologies, their collaboration with European industry is strongly reducing over the last years.

In order to strengthen its leadership in 5G and beyond, Europe should drive the complete value chain, enhance collaboration between European industry and institutes and invest in the development of technologies for 5G and beyond. This huge investment is crucial to enhance the European leadership and technological independence.

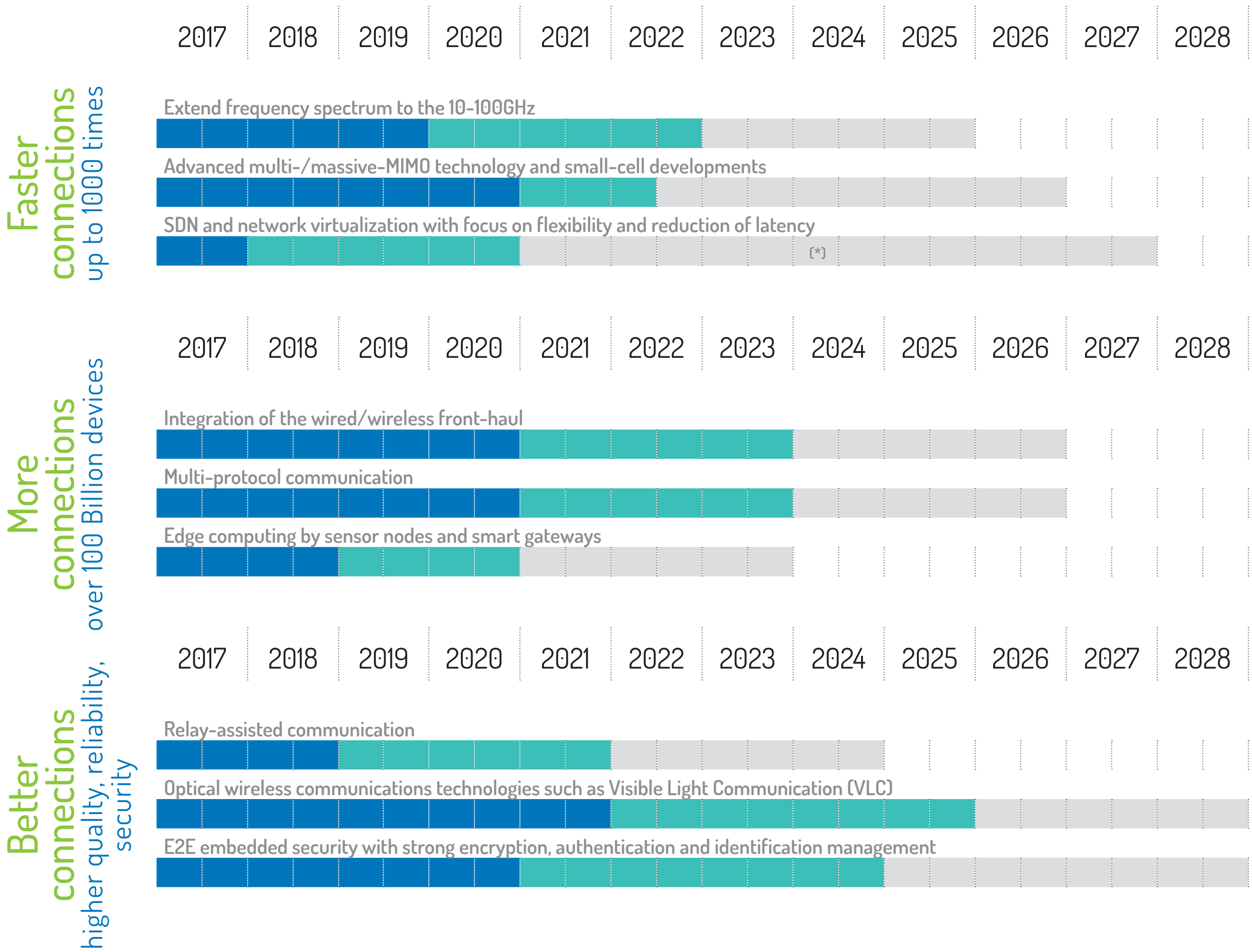
4 CONDITIONS FOR SUCCESS

Conditions for success of the realization of more, faster and better connections are manifold:

- Fast deployment in Europe of a digital network supporting the key requirements of IoT: global coverage, low latency, medium to high security, low to medium bandwidth, high reliability. Co-existence / co-operability of multiple networks will be mandatory.
- Network bandwidth/capacity growth in line with the consumer needs, implying yearly doubling. To sustain this fast growth, Software Defined Networking (SDN) and Network Function Virtualization (NFV) are mandatory, to allow operators to essentially move away from proprietary, hardware-based network equipment to software-based network functions which should allow them to manage their networks more efficiently and effectively.
- Standardization of connectivity and digital network protocols to guarantee interoperability of the different IoT devices in the market. In different domains as Smart Cities, Smart Cars, Smart Energy, an even higher level standardization will be needed to make sure all systems can communicate which each other.
- Availability of ultra-low power technologies, design techniques, platforms to allow developing IoT smart sensor/actuator nodes. But also to allow the design of less power hungry base stations and data centers.
- Availability of high frequency devices (active and passive)/processes able to operate into the 50-100 GHz, to allow the extension of the frequency spectrum for local high speed networks.

5 TIMEFRAMES

The timeframe below is our best view, but is however highly sensitive to economic factors.



TRL 2-4 Technology Readiness Level; applied research – validation in laboratory environment

TRL 4-6 validation in laboratory environment – demonstration in relevant environment

TRL 6-8 demonstration in relevant environment – prototyping in an operational environment qualified

(*) High investment in infrastructure will be needed in Europe to sustain this exploitation

6 SYNERGIES WITH OTHER THEMES

There are many synergies with other AENEAS Strategic Agenda chapters, in some cases like Automotive and Transport, Health and the Ageing Society; connectivity and digital networks are integral part of the solution. While the other chapters are key to deploy successfully the connectivity and digital networks in Europe.

- **Automotive and Transport**
  - Drive control, traffic control, secure traffic, need a standardized, reliable, secure connectivity with ultra-low latencies.
- **Energy Efficiency**
  - With the digital industry using 10% of the total energy consumption, the continuous increasing capacity and the 20 billion of devices which will be connected by 2020, a power efficient network and devices connected to it are needed.
- **Health and the Ageing Society**
  - More and more Mobile Health applications will be deployed, requiring a reliable, secure, ultra-low power connectivity.
- **Safety & Security**
  - The connection of things is boosting the need for E2E secured networks, many critical and data sensitive applications will require a watertight security level, guaranteeing our safety and privacy.
- **Design Technologies**
  - Design technologies supporting the development of ultra-low power IOT sensor and actuator nodes, low-power connectivity radio's, gateways and base stations. Also RF design techniques allowing the development of devices in the 50-100GHZ domain are needed.
- **Process Technology and Integration**
  - Technologies need to be further improved to reduce the overall power consumption, both static and dynamic consumption and increase the overall RF performance, surely in the 50-100GHz domain.
  - The IOT world will require further miniaturization through both advanced processing technologies integrating multiple memory technologies and analog/RF functions. Advanced 3D packaging techniques will be used to further integrate sensor and captor nodes, where devices will be stacked
- **Production Technologies**
  - The Smart Manufacturing or Industry 4.0, where IOT will help in the further automatization and improvement of the manufacturing flows, will rely on a standardized, reliable, secure and global network.

03

1 EXECUTIVE SUMMARY

As part of the Key Enabling Technologies, micro- and nano-electronics, including semiconductors are seen by the European Commission as essential for efficient management of electricity generation, storage, transmission and consumption through intelligent electrical grids, system applications and devices.

The European nano-electronics industry, in cooperation with the research facilities, contributes with innovative solutions, based on long term continuous research and innovation on all Technology Readiness Levels (TRLs), to achieve the targets set by the European Commission[6]. In October 2014, EU countries agreed on a new energy efficiency target of 27% energy savings or greater by 2030. On 12 December 2015, at the United Nations Climate Change Conference in Paris, the participating 195 countries agreed to reduce greenhouse gas emissions with the goal of limiting global temperature increase to well below 2 degrees Celsius, while urging efforts to limit the increase to 1.5 degrees[7]. For improved energy efficiency, it is clear that semiconductor-enabled technologies are necessary where energy is converted into electricity and for providing solutions to the most critical energy-saving issues. Those semiconductor-enabled technologies are themselves subject to drastic power reduction in order to support the ever increasing size and complexity of applications.

[6] http://ec.europa.eu/energy/sites/ener/files/documents/2014_energy_efficiency_communication.pdf

[7] http://www.c2es.org/international/negotiations/cop21-paris/summary

ENERGY EFFICIENCY

2 RELEVANCE

2.1. Competitive value

In the last several years, it has become apparent that semiconductor-based innovative technologies have enabled the savings of more electrical energy than the growth of demand 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 with reducing the costs and being more competitive. The electricity consumption in IEA (International Energy Agency) countries has flattened partly as a result of energy efficiency improvements; energy efficiency investments since 1990 saved 2 200 terawatt hours (TWh) in 2014[8].

European companies are amongst the leaders in smart energy related markets, which is to a large extent driven as well by political decisions as the move to regenerative energies and to added costs on carbon dioxide emissions. Leading market positions are achieved for electrical drives, grid technology and decentralized regenerative energy sources. With innovative research on European level this position will be strengthened and further employment secured. Competitive advantages by the use of ECS (Electronic Components and Systems) can be gained by research in the following areas for energy efficiency:

1. **reduction and recovery of losses** by significant values (application and SoA related),
2. **power density increase / decreased size of the systems** by miniaturization and integration,
3. **increased functionality, reliability and lifetime** (incl. sensors & actuators, ECS HW/SW, monitoring systems...),
4. **increased market share** by introducing (or adopting) disruptive technologies,
5. **the game change to renewable energy** sources and decentralized networks,
6. **"plug and play integration" of ECS into self-organized grids** and multi-modal systems,
7. **safety and security** issues in self-organized grids and multi-modal systems,
8. **optimization of application and exploitation** of achieved technology advances in all areas where electrical energy is consumed

2.2. Societal Benefits

The electronic components and systems for smart energy (incl. components, modules, CPS, service solutions) which support the EU and national energy targets will have huge impact on the job generation and education if based on the complete supply chain and fully developed in Europe. The key will be the capability to have the complete systems understanding and competence for small scale solutions up to balanced energy supply for regions. Mandatory are the capability for plug and play of the components enabled by a broad research contribution from SMEs, service providers including EU champions in the energy domain. Thanks to the expected wider proliferation of energy storage devices in a smart city context new distributed forms of energy storage will become available, to be exploited by smart control systems. The expected growing number of electrical cars with substantial battery capacity will greatly contribute to this, once connected and controlled in a smarter grid.

The societal benefit can be seen as the access to knowledge, modern lifestyle and energy all the time everywhere – this at minimum of wasted energy and at minimum of greenhouse gas emissions. Domains having a huge energy demand and therefore a large saving potential addressing the society are in the areas of High Performance Data centers 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 with local intermediate storage systems.

FIGURE 1 / *Smart Energy landscape – from centralized 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[9])*

High innovative technologies guarantee high value employment. With more than one million jobs in the field of renewable energies and the indirect involved technologies a significant factor for economical and societal stability is visible.

[8] http://www.iea.org/publications/freepublications/publication/MediumTermEnergyefficiencyMarketReport2015.pdf
[9] http://www.ecsel.eu/web/downloads/documents/ecsel_gb_2015_46_-_masp_2016.pdf

3.1. Sustainable power generation and energy conversion

3.1.1. Vision

The ultimate vision is and will be always the loss free energy conversion and generation. A reachable vision is to reach ~99% efficiency within 2020.

3.1.2. Scope and ambition

The topic of Energy Generation can be divided historically into two main application fields; Traditional energy generation (e.g. fossil or nuclear power plants) and the energy generation based on renewable sources (e.g. wind, solar, hydropower, geo-thermal, ...). In both cases, "raw energy" is produced in a form, which cannot be transmitted or used without conversion. A new upcoming application is the energy storage to manage overcapacities and undersupply. Examples are non-continuous energy sources like wind-mills and like solar cells. Using old-fashioned electronics for rectifying, transforming or converting (AC/DC or DC/AC) the currents, only about half of the energy could be used. New, much more dedicated and efficient components have to be used, which partially will be based on new materials. In general, everything must be done to get the capital expenses for renewable energy generation over the lifetime in the order of traditional sources to beat them.

3.1.3. 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 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 increased their power density capabilities to be used in efficient converters, supported by passive elements, new interconnect technologies and packaging techniques to achieve further miniaturization and further reduce losses.
- System EMI research to cope with higher switching frequencies and further miniaturization
- 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.
- For the upcoming IoT implementation self-powering systems for the 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.

3.1.4. Competitive situation

Request for energy is a fact in the modern society. The question is how to provide the energy in a resource efficient way and at a cost, that it is accepted by the society. Nanoelectronics is playing an important role in the generation of renewable energies. Highly efficient conversion leads to fewer investments and therefore less cost for the renewable energies. Capital cost reduction per generated power 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[10]. Overall the share of European suppliers is growing in this growing market underlining their competitiveness.

[10] IHS Technology – The World Market for Power Semiconductors – 2015 Edition

3.1.5. Expected achievements

By competitive solutions a further grow of market shares in the supply of power semiconductors and the introduction of new highly efficient technologies (e.g. wide band gap materials, disruptive innovations based on new processing approaches and architectures) is expected. On the system level it is expected that European suppliers are established in the field for 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 batteries.

3.2. Reduction of energy consumption

3.2.1. Vision

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

3.2.2. 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 build up on them and the application level in several areas.

Electronic components examples:

- One of the most challenging issues for 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 following the current trend and hence the costs of associated cooling infrastructures (with 50%-70% of the overall power dedicated to the cooling task for current generation of data centres) already exceed the costs of the HPC systems themselves. Therefore, reduction of energy consumption is becoming mandatory otherwise the consumption of exaflops systems will reach up the 100 mega-watt ranges.
- The demands for mobile electronic equipment: the scaling is tremendous since mobile electronic equipment is manufactured in the billions of devices each year and newly connected to the grid. Even low percentage improvements have a high impact energy consumption.

System configurations:

The system configuration based on innovative components themselves are addressed – energy efficiency by the use of the innovative sensors, actuators, drives, controls, simply any kind of system using energy where energy loss can be reduced by innovative or even disruptive approaches. The ambition is to reach a wide implementation of systems being adaptable and controlled to the situation by minimization of energy losses. For example, smart building management systems can ensure minimal energy usage in heating and lighting (while providing safety and security too).

Application level:

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

3.2.3. High priority R&D&I areas

- Intelligent drive control: technology, components and miniaturized (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 number

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 nanoelectronics-based integrated devices and photonics can be envisioned for such improvement.
- Energy efficient sensor networks, including hardware and software application layers.
- Optimal parallelization of traditional sequential algorithms and efficient mapping on parallel and heterogeneous architectures will not only provide necessary performance but help to reduce energy consumption.

3.2.4. Competitive situation

Having the whole value chain represented and being in world-wide leading positions, Europe has a rather good chance to build up a healthy "green industry" around tools and goods for reduced energy consumption. European companies have acknowledged strengths in power electronics and in nearly all of its applications. Market studies show leading positions of Europe in the field of power electronics and advanced LED lighting, but 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 resorting to latest micro-/nano-electronic technologies and most advanced system concepts European companies defined and set new standards and raised the bars in performance and energy efficiency. Also, the related R&D is very active in all of those domains.

3.2.5. Expected achievements

The expected achievements are directly linked to the R&D priorities. To be highlighted is that in several applications a huge price pressure, neglecting the benefits via reduced operational costs over the lifetime, asks for severe achievements in cost reduction 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.

3.3. Efficient community energy management

3.3.1. Vision

The decentralization 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 the energy management for communities and cities.

3.3.2. Scope and ambition

The scope and ambition is to reach by technologies supported highest efficient and economic energy supply and management for the communities and smart cities.

3.3.3. High priority R&D&I areas

- Smart living supported by increasingly autonomous systems in the private space
- 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,
- Smart cities, providing smart spaces in an urban environments involving many concurrent users (both humans and devices) accessing services like energy distribution, transportation, education, entertainment, health care, security etc.
- Smart E-Mobility grid for optimized charging, storage and distribution of electric power for light, medium and heavy vehicle transportation.
- Self-organising grids and multi-modal energy systems
- Improved grid visibility through advanced grid monitoring, including medium and low voltage levels.
- Smart Grid applications that exploit demand response technology in a robust and secure way, negotiating the trade-off between different levels urgency in energy need with a varying price of that energy at any given time.
- Highly resilient grid through the introduction of proactive control algorithms (that go beyond demand response), significantly improving the grid 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 realization of the

Agile Fractal Grid also including smart agriculture (e.g., greenhouse energy efficiency).

- Logistic energy savings – the development for new applications like smart agriculture will even go beyond the mere reduction of electricity usage. By introducing smart city farming, the food will be grown much closer to consumption (think of megacities: how to get the food harvested on the country city to the city with all of its traffic congestion?), resulting is substantial saving in logistics with all its corresponding energy usage.

3.3.4. Competitive situation

Advanced control and monitoring systems are already deployed at the transmission network level (high voltage), however broad inclusion of small and medium renewable energy sources into the grid and their coordination requires adoption of the control and monitoring systems at the medium voltage levels as well. Real-time monitoring of energy flows at medium voltage energy grids is needed to enable demand response management (Demand Response Management) in grids where small and medium energy sources represents significant amount of installed energy production potential.

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 dynamic pricing tariffs that are needed to increase market share of small energy producers and at the same time enables to reduce 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 impact on grid stability of the MV an LV micro-grids. Real-time monitoring at the MV enables to deploy self-healing MV grid strategies.

On the smart city level new developments like smart farming control and actuation mechanisms have to be developed to enable a cost efficient and healthy smart city and farming implementation.

4 CONDITIONS FOR SUCCESS

The conditions for success are on several sides, regulation and standards, technology availability and reliability and seamless integration & acceptance by the users.

Moreover, standard interfaces and policies for the use and implementation of renewables, grids, farming approaches and others will fasten successful implementations.

5 TIMEFRAMES

Smart Energy	Short term	Medium term	Long term
Overall – Embedded in EU strategy	EU targets for 2020 supported (20/20/20) greenhouse gas levels by 20% reduced share of renewable to 20% increased. reduce energy con-sumption by 20% Projection regarding the targets in 2020: 24/21/17	ECS for recovery of the not matched targets in 2020 and preparation for 2030 targets Supply by European manufacturing of ECS secured	EU targets for 2030 supported by ECS from European suppliers: share of renewable energy in the electricity sector would increase from 21% today to at least 45% in 2030 (1)
Energy supply landscape	1st order decentralized simple connected local systems – higher efficiency and first integration approaches including power system services (last mile – around 100 users)	2nd order decentralized – regional area balanced energy supply (villages and cities up to 100.000 users) ECS capable for efficient fast reaction oversupply and peak load management	3rd order decentralized – on country level balanced energy supply
Generation & Conversion	Highest efficient and reliable ECS for all kind of electrical energy generation – de-centralized to large power power plants, cross link to processes and materials		
	smart and micro inverter reference architecture with integrated control	new power electronic actuators for DC and AC grids	inverter on a chip or integrated modules
Reduction in con-sumption	Implementation of smart electronics and control including system integration with communication interfaces ECS for controlled power/ drive trains and illumination	smart electronic components for (MV/LV) DC power supply for buildings and vehicles (e.g. data centres, planes) Distributed DC network Design of drastically reduced-power IT systems	smart electronic components for MVDC grid integration of storage and renewable fully connected ECS for illumination and city energy use
Energy management in communities	monitoring of energy infrastructure and cross domain services (e.g. maintenance, planning) Decreased integration costs in self-organizing grids.	smart systems enabling optimized heat / cold and el. power supply ECS support for standalone grids and therefore decreasing demand for "big" power plants.	smart systems enabling optimized power to fuel and coupling of transport and el. power sector New energy market design. E.g. self-coordinated energy supply in local grids

6 SYNERGIES WITH OTHER THEMES

The synergies are with all chapters in terms of energy efficient use and enabled new approaches for instance for automotive, society or production.

The basis are the underlying technologies, mainly power semiconductors, efficient µC and all the enablers as sensors and actuators for energy efficient measures.

04

1 EXECUTIVE SUMMARY

World global healthcare expenditure is currently estimated to 6000 billion of euros and its growth will continue greater than the GDP in virtually all countries magnifying budget deficits. By 2030, world population will increase by 1.3 billion, the middle class by 3 billion, due to ageing, the world's population ages 65+ is projected to increase by 436 million people and urban population by 1.5 billion requiring increased access to healthcare facilities and service.

In order to cope with these issues, healthcare will evolve covering affordable care and well-being at home, abroad and in hospitals; heuristic care. Healthcare will be people- and patient-centric, with a key role for medical technology supporting patients throughout the phases of the care cycle (prevention, diagnosis, treatment/ therapy, and after-care).

2 RELEVANCE

2.1. Competitive value

OECD Health Data shows that Europe is the first large subcontinent to encounter the effects of an ageing society. This will lead to a large emerging home market, giving the European industry a head start on the rest of the world in answering the societal challenges that an ageing society presents. Joining forces with the ICT and healthcare industries, the nanoelectronics industry will help to achieve leadership for Europe in emerging healthcare markets, ensuring sustainable growth.

2.2. Societal Benefits

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

For patients, benefits should address a.o. shorter hospital stays; safer and more secure access to healthcare information; better personalized prevention, information about environmental factors, diagnoses and treatment; improved quality of life; and reduced risk to further complications that could result from hospital treatment.

For healthcare professionals, benefits are directed towards a.o. improving decision support; providing safer and more secure access to healthcare information; unlocking totally new clinical applications; and enabling better training programs leading to better trained professionals.

The impact on European industry is targeted to maintaining and extending leadership positions of European Industry; creating new market opportunities in the Digital world for European large industry and SME's; 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 are amongst others creation of a European ecosystem around digital healthcare; contributing to the reduction of growth of healthcare cost; raise people's healthy life years; improving quality of life and productivity of work force; and decreasing or considerably slow down increase of number of morbidity among society.

Benefits for health care payers (such as insurance companies, national authorities and citizens themselves) are targeting a reduction of cost and a leaner approach to health care provision paired with an improved quality of treatment.

To realise these benefits, significant advances in nanoelectronics, medical sensing, home monitoring, data processing and medical ICT are required.

3 GRAND CHALLENGES

The overwhelming societal challenge of keeping the cost of healthcare in an ageing society manageable can be split into three Grand Challenges:

1. Home Healthcare: Prevent institutionalization, both for the healthy, elderly, impaired, and people with chronic diseases, by providing healthcare support in an individual's typical environment (home, community, and/or workplace) and information on environmental factors affecting health (e.g. air pollution, allergens, ...);
2. Hospital Healthcare: Reduce time and costs associated with hospitalization;
3. Heuristic Healthcare: Increase the speed of pharmaceutical development and biomarker analysis.

All three challenges imply a major focus on improved productivity.

These grand challenges are shown in Figure 1, which visualizes the health continuum.

FIGURE 1 / *Health continuum encompassing Home, Hospital, and Heuristic Healthcare*

TABLE 1 / Key requirements for the Grand Challenges

	Home Healthcare	Hospital Healthcare	Heuristic Healthcare
Cost effectiveness	XX	X	X
Accuracy		XX	X
Efficiency		X	X
Ease-of-Use	XX	X	
Reliability	X	XX	X

Table 1 describes the overall characteristics and priorities for the different healthcare challenges. All forms of healthcare should be as cost–effective and accurate as possible. However, trade-offs are different in each case. For example, Home Healthcare is characterised by low cost and ease-of-use rather than high accuracy, while for Heuristic Healthcare accuracy is paramount even if it comes at a higher cost and/or requires more highly trained personnel.

3.1. Challenge 1: Home Healthcare

3.1.1. Vision

To provide devices and networks that supply high quality remote care to patients at home for the majority of chronic diseases that affect the elderly. Furthermore, to enable an active life despite ageing, by enhancing access (both physical and informational) to social groups or family networks that are supported by professional care givers.

3.1.2. Scope and ambition

Achieving highest quality of life for elderly, impaired and people with chronic diseases at the lowest cost to society, is only possible if they can fully function in society, independent of peer or medical support and without being institutionalized, but nevertheless be provided with adequate protection, security and care ('Independent Living'). Patients with chronic illness should participate in their own care for health rather than being subject to healthcare services. Electronics-based solutions will assist people who have limited mobility or impaired vision or hearing, and those with cognitive impairment – for example, people with dementia or mental health issues. Next to health and wellness for people living at home, home care and home treatment will be essential parts of modern, integrated, patient-centric healthcare systems. Information on environmental factors as air quality and allergens builds a decision basis for a healthier lifestyle. Instead of patients travelling to their general practitioner's office or an out-patient clinic for check-ups, their 'vital signs' measurements (blood pressure, heart rate, etc.) and corresponding data will be securely communicated to the relevant healthcare services on a daily basis to guarantee that they receive the necessary attention. For patient self-management and economic reasons, national governments already strongly support the relocation of care from the hospital to the home, the community or the general practitioner's office.

Home healthcare can be extended to healthy people to encourage preventive behaviours, such as lifestyle changes, via personalised healthcare portals and electronic coaching tools. Knowing about the environmental influences enables healthy people to act accordingly, to stay healthy and avoid chronical diseases and hospitalization as much as possible. Based on genetic and biomarker-based predictive profiling, healthy people will be supported in making healthy behaviour choices, customised to reduce their personal health risks.

3.1.3. High priority R&D&I areas

1. Disease prevention, promotion of healthier life-style, remote coaching and information on environmental factors.
2. Remote health monitoring and support, including easy to use interfaces (e.g. for the elderly)
3. Remote disease management, including easy to use interfaces
4. Advanced tele-rehabilitation services (e.g. with portable robotics)
5. Technological cross-application advances

3.1.4. Competitive situation

Growth rate of the home healthcare market is considerable. A trend away from static installations towards portable home monitoring devices is visible as smart wearables have become a practical platform for handling health sensor data and are now widely available to all consumers.

Europe's strong societal need to provide technological solutions for its ageing society provides Europe with a strong technological advantage that can be applied in less well developed markets too. In countries where medical services are often geographically distant, remote monitoring solutions may be a powerful solution to increasing quality of life and speeding diagnosis.

In addition to other situations (i.e. acute diseases, trauma, etc.), rehabilitation is an important aspect of treatment for chronic diseases (e.g. cardiac, respiratory disease, diabetes, cancer, arthritis, etc.). Using ICT to deliver rehabilitation services can greatly expand continuity of care to people with disabling conditions and enable them to actively participate in the management of their disease. It also promotes therapy compliance by offering personalised care, choice, and personal autonomy.

Demand for rehabilitation services, particularly in-home care services and outpatient clinics, is increasingly difficult to meet. In this scenario, in-home tele-rehabilitation (i.e. delivery of rehabilitation services via telemedicine methods and techniques) is growing as a complement or alternative to face-to-face therapy. Today's health and fitness monitoring systems are a good starting point, but do not meet quality standards of medical instrumentation and trust worthiness.

3.1.5. Expected achievements

1. Disease prevention, promotion of healthier life-style, remote coaching and information on environmental factors
   - a) Life-style profiling and activity recognition
   - b) Personal lifestyle monitoring and guidance (diet, activity)
   - c) Smart assistive services to support daily life activities
   - d) Oral health measurement for regular assessment of home oral hygiene efforts
   - e) Smart textiles with connected sensors and energy autonomous systems
   - f) Improvement of wellbeing through environmental influences e.g. lighting
   - g) Wellness environments for enhanced mental health and wellbeing
   - h) Environmental sensing for air quality monitoring, detection of allergens, ...
2. Remote health monitoring and support (e.g. for the elderly)
   - a) Personal health management
   - b) Autonomy monitoring and pre-dependency assessment
   - c) Flexible textile-based systems for on-body diagnostic and therapeutic functions
   - d) Domestic accident detection, monitoring, warning and emergency alert
   - e) Advanced tele-health, including personalized facilities to engage patients in the self-care process, and early identification of potential personal risk factors
   - f) Home monitoring systems for health related parameters by non or minimally invasive molecular diagnostics
   - g) Treatment support and control (support for quantity and time of drug taking)
3. Remote disease management
   - a) Prevention of hospitalization for chronic diseases for a large elderly population
   - b) Tele-medicine, home diagnostics monitoring, point-of-care screening

devices, ultra-small smart implanted and on-body diagnostic and therapeutic devices, broadening diagnostic scope

c) Non-invasive measurement e.g. blood parameters, bio markers and (de) hydration

d) Smart devices, e.g. e-inhalers, bandages, in vivo treatments and new responsive biomaterials

4. Advanced tele-rehabilitation services (e.g. with portable robotics)

   a) Adherence to long-term therapies

   b) Personalized therapy through smart implantable devices

   c) Peripheral medical devices to power and control ultra-small diagnostic or therapeutic implanted devices

5. Technological cross-application advances

   a) Secure/private tele-monitoring networks

   b) Wearable and in vivo electronics and smart integration to measure biometric parameters and related treatments

   c) Personalization and consumerization

   d) Localization techniques (indoor and outdoor)

3.2. Grand Challenge 2: Hospital Healthcare

3.2.1. Vision

To deliver effective diagnosis and treatment based on an individual patient's specific circumstances and medical condition. Via secure communication networks, appropriate medical specialists will be involved irrespective of whether they are local to or remote from the patient. Diagnosis and treatment will be guided by semi-autonomous workflows and decision support at several scales of magnitude (from 'whole-body' to organ, cellular and molecular levels) using multiple modalities, which together provide the best outcome in the least intrusive way.

3.2.2. Scope and ambition

Hospital effectiveness and efficiency can be increased through the use of early and improved diagnostics followed by targeted personalised therapy. Further efficiencies and improved patient outcomes are achieved through the use of minimally-invasive procedures, which combine miniaturized interventional tools (e.g. catheters) with real-time imaging techniques to perform Image-Guided Intervention Therapy (IGIT)

3.2.3. High priority R&D&I areas

1. Advanced imaging based diagnosis and treatment
2. Screening for diseases
3. Intervention / therapy
4. Smart environments, devices and materials
5. Remote diagnosis and monitoring / support

3.2.4. Competitive situation

The healthcare market, including health & wellness, represents up to 25% of the EU economy (when measured in terms of employment, expenditure and added value), making it Europe's largest industry sector. As a result of societal demand and industrial trends, continuous market growth is forecasted.

Global spending on medical imaging equipment exceeded US$23 billion in 2013 and is expected to grow to US$39 billion by 2019, driven by an ageing population and technological advancements. In 2010, X-ray constituted the largest share of the market (34%), followed by ultrasound (21%), CT scan (19.5%), MRI (18.5%), and nuclear medicine (7%). The United States has a dominant share in the global market (37%), followed by Europe (27%), and Asia (27%).

There are a few specific areas where there is higher than average growth, notably integration of medical imaging with delivery systems (e.g. robotics) and therapy devices. This trend alone has created an entire new market space for IGIT solutions.

Ultimately, this market will combine interventional imaging, delivery systems and devices, and therapy solutions. It is expected to be 10 times the size of today's interventional imaging market and to enjoy higher growth figures and gross margins (based on US market data). For diseases that are becoming more prevalent as a result of the ageing population, such as Alzheimer's, additional growth in MRI is expected in combination with specific contrast agents. Global leaders in the medical imaging industry, providing both hardware and software solutions, comprise General Electric (GE) Healthcare (based in the US), Philips Healthcare, Siemens Healthcare (both based in Europe) and Canon Medical Systems (based in Asia). Although not large global healthcare players, several other companies are leaders in specific domains related to equipment and/ or components – for example Thales for X-ray detectors in cooperation with Trixell (a joint venture of Thales-Philips-Siemens), and Ziehm for surgical mobile X-ray imaging equipment. Chinese suppliers are beginning to emerge, and although they currently focus on local markets, it is to be expected that they will expand internationally in the near future. Samsung (based in Korea) has made major investments to enter the healthcare market. There are also companies that have focused on specific applications, such as EEG, by developing innovative technologies - e.g. Nihon Kohden in Japan and g.tech in Europe. Global competition in the medical devices industry is largely dominated by US companies such as Lake Region Medical, Medtronic and Boston Scientific. Many of these companies have R&D centres in Europe. Collaborating with these companies may strengthen the European industry and address common challenges in hospital healthcare.

The medical device market is a mature one, with very little growth in most areas. However, there are still sectors that are relatively new and rapidly expanding – for example, the drug eluting stent market and the neuromodulation market. All areas of the industry that include technologically advanced devices will see growth as innovation continues to drive product development. Business in the cardiovascular and cardiology sectors will grow, as safer and more effective treatments for heart disease are developed.

Heart disorders account for a large proportion of deaths globally, so innovation in this sector will help drive growth in the entire medical device industry. Furthermore, market demand for medical devices used in the treatment of chronic disease is expected to increase considerably in the coming years.

3.2.5. Expected achievements

1 Advanced imaging based diagnosis and treatment

a) Robotic image-guided surgery

b) Improved image detectors that capture greater detail

c) Advanced imaging for several modalities

d) Smart micro-tools for advanced medical treatment (surgery, biopsy, …)

e) Image-guided biopsy and treatment procedures

f) Multi-modal heterogeneous data processing for advanced decision support

2 Screening for diseases

a) Non-invasive screening for disease

b) Early screening for diseases and improved screening imaging systems

3 Intervention / therapy

a) Digital patient for planning surgical procedures

b) Image-guided biopsy, treatment and therapy procedures

c) Robotic image-guided surgery and therapy for many diseases

d) Multi-modal, low X-ray dose, accurate visualization and guidance

e) Smart intervention devices with e.g. image guidance, pressure sensing

f) Operating room of the future: swallowed or implantable miniaturized capsules with imaging or sensors for diagnosis / surgery / therapy

g) Patient safety, pharma compatibility and treatment consistency verification

4 Smart environments, devices and materials

a) Healing environments for improved patient wellbeing

b) Energy autonomous smart systems with multi-parameter sensors

c) Smart automated drug delivery with or without smart implants

d) Adaptive prosthetics, artificial organs

5 Remote diagnosis and monitoring / support

a) Remote medical intervention and virtual team support

3.3. Grand Challenge 3: Heuristic Healthcare

3.3.1. Vision

'Lab-on-Chip' technologies allow patients to self-monitor (for example, by performing saliva or blood tests themselves) and make more accurate technologies available to medical specialists. Diagnosis will only take minutes, because samples will not have to be sent to dedicated laboratories (pathology labs). The availability of and access to biopsy analysis results will be strongly accelerated via digital pathology imaging.

3.3.2. Scope and ambition

Heuristic Healthcare focuses on the combination and parallel utilization of different analysis tools. Three application areas are foreseen:

1. Multi-parameter biosensors for preventive health monitoring and early diagnosis (see Figure 8). These will enable 'doctor in the pocket' applications for the rapid measurement of multiple parameters and/or biomarkers. The patient regains control of his/her medical data and the transition from 'simply measuring' to active personal health management is enabled (empowered patient participation). An intermediate step may be the availability of such (still expensive) instruments in the doctor's office.

2. Elimination of the educated guess (trial-and-error) methods currently used to screen chemical compounds for their therapeutic value. Based on heuristic algorithms, large numbers of compounds will be tested in parallel. Availability of (still expensive) instruments in the doctor's office will enable an intermediate learning step with expert (doctor's) support.

3. In determining drug regimens, heuristic healthcare characterises real-time response measurements to drug delivery in order to create individualised prescriptions with minimal adverse effects.

Overall, strong synergy with Home Healthcare exists. The gradual distinction between Home Healthcare and Heuristic Healthcare can be clarified by characterising the use of (bio-) sensors in Home Healthcare as a cheap and quick method of measuring a few well-described physical parameters (biomarkers) for a particular disease, whereas in Heuristic Healthcare, screening is performed by an exploratory sweep of multiple parameters. The latter is 'heuristic' in the sense that diagnosis is still being explored, based on hypotheses and assumptions involving many different biomarkers.

Characteristics common to all heuristic healthcare approaches are the fast and reliable measurement of biomarkers, and the existence of heuristic approaches to derive risk profiles and pharma (drug) effectiveness from diverse, noisy, and often incomplete data. Heuristic healthcare technology bridges high-throughput solutions (e.g. path lab blood tests) and low-throughput point-of-care solutions. It has the potential to contribute to the sustainability of healthcare by avoiding the prescription of ineffective medications, overdosing and medical waste.

3.3.3. High priority R&D&I areas

1. Screening for diseases
2. Intelligent data management
3. Personalized medicine
4. Smart environments, devices and materials

3.3.4. Competitive situation

Three distinct heuristic healthcare markets will exist. Firstly, the pharmaceutical industry (compound screening, drug development). Secondly, the home healthcare market (the 'doctor in the pocket'). Thirdly, the hospital market, where there is a real need for minimally-invasive measurement of real-time response to drug delivery via bio-sensors.

The potential for parallel measurement (e.g. multi-biomarker lab-on-chip assays) and high performance offered by nanoelectronics-based solutions is huge and will directly benefit analytical laboratories and research laboratories by providing them with tools that are an order of magnitude more efficient than current solutions. This will enable rapid progress in heuristic healthcare thanks to the more efficient screening of potential drug compounds using bio-electronic systems. As the price curve for these new technologies falls, the industry will be able to leverage synergies between high volume laboratory-based systems for advanced diagnostics/treatment, and more cost-effective home based systems. Putting doctors and their medical expert knowledge in between the technologies and the patient is a critical learning step between today's patient therapy with almost no electronic support and the final vision of a digitally steered treatment for the standard cases. The high ability of European nations in interdisciplinary system level research is a competitive advantage here.

Current predictions suggest that the total in-vitro diagnostics market will grow to €17.7 billion in 2018. Traditionally, the European molecular diagnostics industry is strong, but it is increasingly being threatened by Asian and American companies. While still leading in traditional diagnostic markets, Europe is behind in some of the new diagnostics markets. The American government, as well as American companies, have made major investments in next-generation integrated diagnostics platforms (as part of the US bioterrorism defence program) as well as investments in next-generation biomarker and assay development. To some extent, this is driven by the policy to eliminate inexcusable medical incidents (so-called 'never events') in the majority of US states, and in other cases by the country's strong Life Sciences R&D sector. The US is therefore currently leading in this field with companies like Cepheid, Life Technologies, Illumina, HandyLab, Caliper, Celera and Rosetta (MSD) paving the way forward. Europe, however, has a broad (nano-) technology base and the clinical application knowhow to become a leading player in next-generation genomic assays, especially when forces are bundled. In combination with personalised healthcare, this provides a potential European strength.

3.3.5. Expected achievements

1. Screening for diseases
   a) Non-invasive screening for disease
   b) Efficient screening of drug potential with bio-electronic devices
   c) Decision support systems based on heterogeneous multi-parametric data
   d) Point of care monitoring of health related parameters by non- or minimally invasive molecular diagnostics
2. Intelligent data management
   a) Personalized health data ensuring data security
   b) Heuristic algorithms for personalized treatment
   c) Risk profiling based on biomarkers or genetic profiles
   d) Big data analysis
      i. on image sets for treatment preparation and screening
      ii. of medical imaging and signal processing systems
      iii. of unstructured medical information
3. Personalized medicine
   a) Real-time response to drugs
   b) High performance computing systems for drug design
   c) Human organ and disease model technologies (organ-on-a-chip)
4. Smart environments, devices and materials
   a) Improved smart systems-based biosensors
   b) Microsystem technology based implants and implant support, e.g. deep brain stimulation, neuromodulation, multifunctional components, (nano-) coatings for harsh environments and long term use
   c) Development of bio-compatible sensors and devices with a long lifetime in a biological environment

4 CONDITIONS FOR SUCCESS

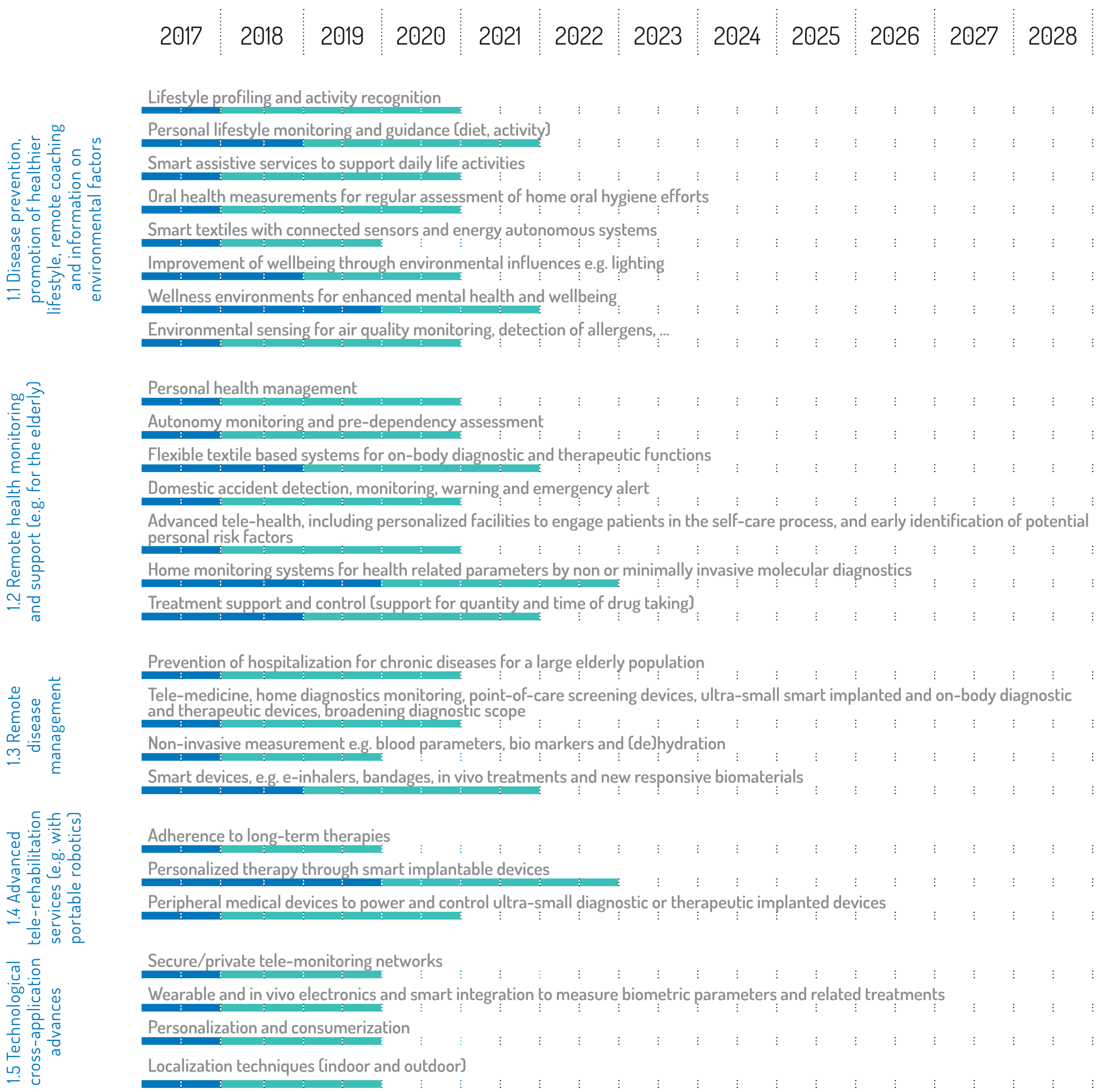
Grand challenges cannot be solved by technology alone. Before nano-electronic solutions can be applied in clinical care, a regulatory framework has to be put in place and business models have to be worked out. These will be country specific, and in general, European market fragmentation is a severe hurdle that currently hampers market penetration. Without significant convergence between European markets, industry will be exposed to the absence of economies of scales, even though the European market when taken as a whole is the second largest in the world (US 51%, EU 27% and others 22%).

Resistance to the use of new ideas in the personal health sphere or in medical staff environments can be quite large. When designed with applicability in mind (size, usability, automation, cable-free, identity secured, etc.), nano-electronics, microfluidics and actuators can be combined in ways that help to overcome this resistance.

Ethical questions, such as the desirability of patients to be informed about their genetic disposition to specific diseases, are currently under debate. Other parts of the world usually resolve ethical dilemmas faster than Europe. A worldwide marketing strategy may help to handle such differences.

Finally, a business environment in which creative SMEs can easily research and develop novel healthcare solutions in emerging healthcare fields will enhance Europe's innovative potential.

5 TIMEFRAMES



TRL 2-4 research

TRL 4-6 development

TRL 6-8 pilot test

2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028

Hospital Healthcare

2.1 Advanced imaging based diagnosis and treatment

- Robotic image-guided surgery
- Improved image detectors that capture greater detail
- Advanced imaging for serveral modalities
- Smart micro-tools for advanced medical treatment (surgery, biopsy,...)
- Image-guided biopsy and treatment procedures
- Multi-modal heterogeneous data processing for advanced decision support

2.2 Screening for diseases

- Non-invasive screening for disease
- Early screening for diseases and improved screening imaging systems

2.3 Intervention / therapy

- Digital patient for planning surgical procedures
- Image-guided biopsy, treatment and therapy procedures
- Robotic image-guided surgery and therapy for many diseases
- Multi-modal, low X-ray dose, accurate visualization and guidance
- Smart intervention devices with e.g. image guidance, pressure sensing
- Operating room of the future: swallowed or implantable miniaturized capsules with imaging or sensors for diagnosis/surgery/ therapy
- Patient safety, pharma compatibility and treatment consistency verification

2.4 Smart environments, devices and materials

- Healing environments for improved patient wellbeing
- Energy autonomous smart systems with multi-parameter sensors
- Smart automated drug delivery with or without smart implants
- Adaptive prosthetics, artificial organs

2.5 Remote diagnosis and monitoring / support

- Remote medical intervention and virtual team support

2017 | 2018 | 2019 | 2020 | 2021 | 2022 | 2023 | 2024 | 2025 | 2026 | 2027 | 2028

Heuristic Healthcare

3.1 Screening for diseases

- Non-invasive screening for disease
- Efficient screening of drug potential with bio-electronics devices
- Decision support systems based on heterogeneous multi-parametric data
- Point of care monitoring of health related parameters by non- or minimally invasive molecular diagnostics

3.2 Intelligent data management

- Personalized health data ensuring data security
- Heuristic algorithms for personalized treatment
- Risk profiling based on biomarkers or genetic profiles
- Big data analysis
- ...on image sets for treatment preparation and screening
- ...of medical imaging and signal processing systems
- ...of unstructured medical information

3.3 Personalized medicine

- Real-time response to drugs
- High performance computing systems for drug design
- Human organ and disease model technologies (organ-on-a-chip)

3.4 Smart environments, devices and materials

- Improved smart systems-based biosensors
- Microsystem technology based implants and implant support
- Development of bio-compatible sensors and devices with a long lifetime in a biological environment

6 SYNERGIES WITH OTHER THEMES

There are various synergies to be exploited between Health and the Ageing Society and other AENEAS chapters:

- Automotive and Transport: Health and wellness technologies can be deployed in automotive settings to improve safety (e.g. sensor networks that monitor a driver's vital signs and act accordingly). In addition, medical imaging systems could benefit from new electronic power sources developed for electric and hybrid vehicles.
- Connectivity and Digital Networks: Availability of inexpensive wireless communication links is essential for the realization of home patient monitoring and tele-rehabilitation, as well as for improvements in advanced imaging systems for health screening. Furthermore, exchange of high-resolution life science images and data will require high speed digital networks.
- Energy Efficiency: Low-power techniques are essential to healthcare monitoring systems using portable or on-body devices. New materials, devices and equipment for solar energy conversion can support the development of new radiation conversion detectors and efficient power converters for imaging systems.
- Safety and Security: Large amounts of patient and non-patient data has to be collected, transmitted and stored securely. Privacy needs to be guaranteed at all times. Drug delivery and surgical interventions become automated, intrinsic safety has to be guaranteed.
- Design Technologies and Integration: Efficient integration of heterogeneous technologies, the achievement of ultra-low power consumption, and high levels of reliability will be required in the complex heterogeneous systems needed in healthcare applications.
- Process Technology: Optimal solutions spearheading More-than-Moore technologies (e.g. microfluidics and gas sensors) will need to be fabricated into low-cost cartridges and platforms to monitor the human body and the environment.

05

1 EXECUTIVE SUMMARY

In a global worldwide environment Europe has to face multiple threats while its citizens and enterprises are demanding more protection in their private sphere as well as in the public space.

Considering this complex environment and a more and more connected world, the leadership of European technologies in the area of Safety and security is the corner stone of each new development. As a consequence, existing and new applications, supporting infrastructures and necessary technologies needs to be designed and developed with safety and security as key requirements.

This agenda chapter is describing safety and security aspects that affect our society through the grand challenges we are facing.

Safety is necessary to face risks and hazards that can produces damages accidents (e.g.: prevention in transport & automotive...), disasters of different types (e.g.: nuclear, climate, crisis...)

Reliability has also to be associated to safety since many activities rely on the availability and liability of electronics systems and have to face failures or threats like cyber-attack (e.g.: Health monitoring, critical infrastructure such as Smart grid or IP network including numerous connected sensors....).

Security and privacy including data protection has also to be considered (e.g.: Electronic transaction for payment , identity and data protection ....).

SAFETY & SECURITY

2 RELEVANCE

Safety and Security are key items of the development of the "digital world" of the EC objectives in terms of Industrial competitiveness and socio economic security.

This will allow protection of key infrastructure and critical application easing our life but also protecting individuals of numerous threats.

2.1. Competitive value

Since safety 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 (500Million of inhabitants) but also a re-enforcement of European companies position and market share in this domain.

On another hand European actors involved in the domain will have to transform innovations into market products and services through standardization, testing and certification. This will permit according to the level of maturity of the different sectors to increase the penetration of safety & security solutions within the applications and supporting infrastructures.

In this context 3 main grand challenges exists for Europe:

- Safety & Cyber security of critical European applications
- Security for privacy and personal data protection
- Building blocks for trusted and safe computing

2.2. Societal Benefits

Considering the demand of Security and privacy protection by citizens as the need of data protection stored but also their exchange will conduct to increase the deployment of product and solution with security & privacy by design. System safety by design will reduce risks and prevent failures, accidents and damages.

Safety and security market development will need highly skilled staff. This will have a direct impact on employment but also on education system with a need to train users on safety and security usage but also to provide numerous professionals able to design and develop necessary products and solutions.

3 GRAND CHALLENGES

3.1. Safety & Cyber security of critical European applications

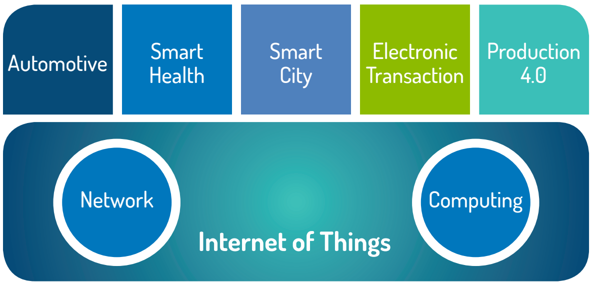
3.1.1. Vision

Our world is getting more and more connected. Devices and systems are connected through various networks and more & more data are shared and distributed over many nodes as Cyber physical systems, with the emergence of IoT serving numerous vertical domains/application providing services for Business, Public services and Private area.

Considering this situation and the numerous threats that could affect our daily life at different level and the numerous risks associated, it is clear that the huge need of safety & security is clearly the most important challenge our society will have to face and answer by appropriate technology development where Europe has a strong leadership.

3.1.2. Scope and ambition

As stated above IoT will be everywhere and is identified as the key emerging technology serving European critical applications relying on a network of interlinked sensors, node and computers (see figure below)



In this context, the identified applications will drive the evolution of the IoT ecosystem in order to guarantee: the integrity of data exchanged, that those data are delivered to the right entity or person and only received by the authorized person. Even if safety and security mechanisms are common to all applications security requirements and levels will be totally different according to each domain of application.

Automotive & Transport

Transportation systems are more and more complex involving numerous control systems operated by various service providers on different networks with on one side a huge need of safety and security to preserve people but also numerous threats related the complexity of the domain.

So this domain will be very difficult to secure due to the diversity of devices and transport operators. Anyway individual vehicles or other means of transport which will be in always-connected mode will face new risks and threats related to risk management, infrastructure monitoring, user data privacy, massive cyber-attack, incident management, emergency services management and many others that will raise with the development of multimodal transport and connected cars

Zoom on connected cars

Cars are transforming from a simple mode of transport to a personalized mobile information hubs Modern vehicles are gradually turning into 'smartphones-on-wheels', which continuously generate, process, exchange and store large amounts of data. Their wireless interfaces connect the in-vehicle systems of these 'Connected Cars' to external networks such as the internet by enabling new features and services. This connectivity also makes the car vulnerable to hackers, seeking and exploiting weaknesses in its computer systems or networks.

This will get even higher priority as functionality and computing power in cars will further rise in the future to fulfil the vision of fully automated driving. Once the driver no longer makes decision but delegates them instead to a central ADAS system with access to all functions of the car, the protection against any unwanted manipulation becomes vital, not only for the car (and the driver) itself, but to all surrounding traffic.

In conclusion the connected Car must be secured, to ensure the correct functioning of all in-vehicle systems, as well as user privacy. This implies a paradigm shift in the design of in-vehicle electronics. Traditionally, there has been a strong focus on safety (e.g.: the brakes should function correctly under all circumstances). Safety will remain equally important in the future, but the increasing amount of electronics and software in vehicles will additionally require security, to protect the vehicle against hackers.

Smart Health

Health intelligent systems are rapidly evolving on environments that include a huge amount of connected devices, sometimes with different security requirements, communication protocols and supported standards. The safety and security challenges are not limited to hospital environments, in which the number of wireless connected devices is continuously growing, but also include implantable and wearable devices in which safety and security have direct impact on human lives. Additionally, there is a new generation of wearable devices and apps (e.g. sport watch) that integrate sensors that could be used by intelligent health applications. The challenge is to guarantee the safety and security of these apps and wearable systems.

Smart City

In the coming years more and more people will live in towns. in this context, Urban authorities are facing numerous challenges such as urbanisation, population growth, climate change, along with the rise of the smart city concept for which demonstrators & pilot projects are showing the growing interest of city authorities and governments. The main question is how to ensure the safety and security of a city based on reliable infrastructure of the flows of people goods & energy as well as the information and communication flows. So to ensure a safe secure and resilient smart city a holistic approach has to be set up in order to develop the necessary technologies and solutions as: Video surveillance devices & alarm monitoring through sensors for the traffic management; Energy grid to manage and protect energy flows. Cyber security & physical security for critical communication networks in order to protect data and ensure the connectivity.

Electronic transactions

Electronic transactions are in a period of change with the deployment of NFC technologies the enhancement of the mobile and the emergence of new form factors for wearable devices. The need for safe and secure transactions will remain high and more complex considering the variety of services available while new standards and regulations will appear in Europe.

Smart card will continue to keep a central position in the landscape but with enhanced security features based on dynamic cards with frequent change of details. Generalization of various mobile solution will be also an alternative to smartcards with the development of prepaid solutions, P2P, virtual payment and instantaneous payment. All these new transactions will require the introduction of dynamic security but also re-enforced trusted infrastructure and new authentication mechanism while privacy will continue to be a key requirement of end users.

Production 4.0

By connecting components, products tools and machines with background systems in a large network a huge amount of new security requirements will appear. In addition, the network includes the interaction as well as the interoperability of a large number of systems, from central servers, cloud services, PCs, robots all the way to mobile actors and sensors.

Security in this context means mainly information security with respect to the availability, integrity and confidentiality of information in smart production facilities and systems. For security, the goal is to ward off risks that could affect a system and/or its functioning. This includes, in particular, intentional and non-intentional attacks. Information security must be assured for all functionalities, for operational functions as well as for monitoring and protective functions (e.g. safety).

Safety ("functional safety") for systems means ensuring, by taking suitable measures, that the function of a machine or a facility does not pose a risk for people or the environment. Safety is part of the protective functions for operational safety.

Network infrastructure

Networks security is a growing pre-occupation since it is the privileged infrastructure place for cyber-attacks with the increasing number of wired and above all wireless networks from Lora /Sigfox /Bluetooth to 5G networks. In other words, according to the importance of the network and the criticism of the assets to protect, safety and security will have to be adapted to various threats but also new usage brought by IoT and supported applications.

From today situation with encryption of communication, fraud protection by Identification and mutual authentication , use of secret keys, new networks and their components will have to be designed in order to support the always connected mode and in some cases the support of critical services ensuring public safety of key infrastructure. The emergence of new networks as 5G will raise the need at design time to compare SW Virtualization vs HW solution which remain more secure in some cases. Privacy protection will be also at the heart of evolution as new trust model necessary to match with new services and usage.

Computing Platforms

IoT and CPS require HW/SW platforms that combines high energy efficiency and computing capability with additional features such as environmental resilience and the capability to perform distributed/cooperative computations. In order to increase the computing capability, these systems are evolving to heterogeneous platforms with many-core and NUMA architectures that generate new safety and security challenges.

3.1.3. High priority R&D&I areas

In order to address the multiple needs related to each domain, you'll find below a list of R&D&I areas which are necessary to address in order to generalise appropriate safety and security features according to the different domains

- Safety, Security & privacy by design
  Security engineering
  Security validation & certification
  Safety validation &certification
- Identity and access management
  Identity management
  User Authentication
  Multi form factor authentication
  Peer authentication and context based security
  Usability of authentication
- Data Protection
  Reliability and liability of the data
  Secured Deployment Security update in the field
  Secured transmission
  Secured distribution
  E2E security (connected systems such as IoT and I4.0)
  Interoperability and heterogeneity
- Safe & Secure execution platform
  Secure coding
  Secure operating systems
  Intrinsically secure Ic's
- Infrastructures
  Connected cars safety
  Secured access to systems and infrastructure
  Infrastructure protection against failure
  Infrastructure surveillance and monitoring
  Industrial asset management
  Detection of abnormal behavior
  Safe and secure behavior in case of failure

3.1.4. Competitive situation

Looking at the landscape of European critical application and supporting infrastructure, Europe has a strong leadership in the safety and security domain. On another hand and in the various vertical domains as automotive, smart energy and industry 4.0 Europe has also strong positions. Nevertheless, in this world where IoT is everywhere, it appears that we face a very fragmented market with various stakeholders where knowledge and safety & security approach is not so much developed even if everybody is claiming it is in the key aspect to address.

In a world where all sectors will be impacted by ICT technologies and will have to rely on it, Europe has to face strong competitors from overseas with key techno players and service providers that in some case do not match European view on very important items as privacy for example.

So development and implementation of safety and security is key to strengthen European position on its domestic market but also on other continents.

3.1.5. Expected achievements

Based on the situation described above the expected achievements foreseen are listed below. It is based on a mutualisation and reuse of the solutions to reduce development costs and enhance good practices sharing for development and implementation of required safety and security features for European Application supported by the appropriate infrastructure:

- Generalisation of safety and security by design through a framework which address (requirements / developments /certification/verification…)
- Identity and authentication mechanisms matching various domain requirements but also matching citizens' needs.
- Secure aware data processing and storage including end user improved personal data control
- Infrastructure resilient to various attacks or failures and adaptable to new threats
- More secured networks with introduction of new protocols and tools allowing better detection of intrusions.

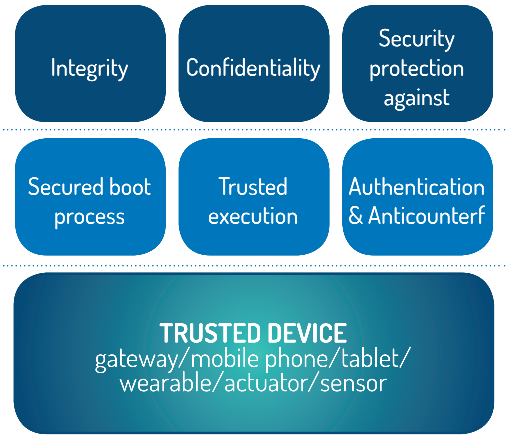
3.2. Security for privacy and personal data protection (Trusted HW Mobile & fixed device security)

3.2.1. Vision

In a rapidly changing environment the need for Privacy and data protection is key and has to be based on a trusted environment. The different applications and functions available on various fix or mobile device conduct to a significant amount of data stored on devices and transferred to and from them. Many data are sensitive and hackers try to capture them for different purposes, often related to malevolence. So the challenge here is provide adequate components able to face multiple threats in order to provide safe and secure devices.

3.2.2. Scope and ambition

Considering the need for trusted environment, the emergence of a "reference platform" based on a framework including all necessary items to guarantee the integrity and the confidentiality of the data while ensuring the level of protection in adequacy with the threat level (see fig below).



Secure Boot Process

Integrity of the device starts with the integrity of the software/firmware it runs. Secure boot is the process of validating the integrity (and sometimes authenticity) of this software/firmware during the start-up phase of a device. As such a secure boot process is a mandatory component of all trusted devices that operate in real life conditions. A secure boot process needs to have a "trust anchor" present in the hardware of the device. Most devices, also modern ones, are missing such a "trust anchor" needed for secure boot.

Trusted execution

Integrity of the device continues with the integrity of the software/firmware it runs. Devices can be used in hostile conditions where they are exposed to an ever growing legion of skilled adversaries. These adversaries are able to change the execution path of software/firmware using externally applied events (glitching, etc.). These manipulations can lead to violation of the security policy implemented by the device (e.g. disclosure of secret keys). Using multi core technology these kind of attacks can be prevented.

Authentication & Anticounterfacting

Counterfeit products are a major problem for user experience. Besides that, fake products are a significant threat to system manufacturers and original equipment manufacturers (OEM) with regard to their investments. It becomes more and more important for them to safeguard the value of their brands and the investment into their product technology. Authentication and Anti-Counterfeiting help deliver a premium user experience by checking that only authorized accessories such as earphones, flip covers and add on cameras are used, for example, with specific smartphones. This helps avoiding damage to user devices as a result of non-original, sub-standard accessories or parts.

Trusted devices identity

In an increasingly connected world, trusted device identities are becoming a number one priority for many organizations. As the attack surface widens across both existing and emerging applications, the number and severity of potential threats are rising. The consequences of security breaches range from identity theft and fraud to operational downtime and business closure.

Trusted devices identities are definitely required as an authentication solution for industrial automation systems, smart homes, consumer and medical devices as a critical success factor.

3.2.3. High priority R&D&I areas

- TPM/TEE
- Secure storage for keys and personal data
- Secured Microcontrollers & Secure OS
- Protection against HW Trojans
- Embedded secure element
- Strong Identification & Authentication
- Authentication & anti-cloning
- Key generation & Key management
- Trusted devices based on block chain

3.2.4. Competitive situation

Security providers are going towards the protection of embedded systems, basing their solutions on secured hardware and software. Solutions range from complex TPM (Trusted Platform Module) for embedded applications that require TCG (Trusted Computing Group) compliance, TEE (Trusted execution environment based on Global Platform standard or simpler modules offering only trusted one-way identity authentication and anti-cloning.

Based on existing implementation the point is not to promote a solution over another one but rather to consider, given the emerging IoT world and its diversity, that different levels of security may be required and provide the most appropriate solution for each specific case.

Looking at the market of secure microcontrollers units and security providers Europe has a key position, but regarding GC1, overseas big companies are also in good position to provide such solutions.

3.2.5. Expected achievements

Increase trust in the cyber world

- Scalable and efficient solutions to enhance trust and confidence on billions of smart devices and computing systems interconnected through various networks.
    - Secured devices and associated management
    - Trusted boot, trusted execution, authentication, anti-counterfeiting mechanisms
- Enforcement of existing standards

Maintain and develop Europe leader ship in embedded safe and secure electronic solutions.

3.3. Building blocks for trusted and safe computing

3.3.1. Vision

Looking at the GC1 and GC2 , need for Europe to develop and improve the building blocks, technologies and associated tools in order to enable trusted and safe operations of the devices and infrastructure serving digital European society.

3.3.2. Scope and ambition

In order to achieve Safety and security objectives depicted in GC1 and GC2 and which will be shared by numerous applications in the IoT world, there is a need for the development of new enhancement of technologies and associated tools

In fact,: Design of new chip and alternative techniques to validate and integrate security (e.g.: security & privacy by design), new tools including security methodology and certification new chip packaging, new chip architecture but also research on domains as cryptography, definition of new secured protocols ...

New architecture integrating security to enable “security by design”

The “secure by design” architecture will include methodologies, tools and building blocks that allows easy re-use and integration of secure components and modular system certification. The architecture also requires specification techniques to define system/component requirements and verification methodologies to validate the system security and safety.

New Design tools including security methodology

There is a need of design methodologies and tools to manage the increasing complexity of networked embedded systems for safety critical and secure applications. These methodologies have to model not only devices and components but also the continuously evolving and diverse environment.

Concerning security, there is an important lack of methodologies and tools that allow

integrating this essential aspect in the design flow. New security metrics, safety & security co-analysis and co-design methodologies and tools are required. Additionally, the impact of security requirements in the verification and validation process has to be improved.

Most of the current security certification standards include a list of features that a secure system has to include but there is not a clear security metric or design methodology definition. Additionally, the relation between safety and security standard has not been developed. The challenge is to define security certification standards that include methodologies and metrics that facilitate the design process.

Safety/security engineering

The model-driven software development (MDSD) vision has booked significant advances in the past decades. MDSD is said to be very promising in tackling the “wicked” problems of software engineering including development of safety-critical software. However, MDSD technologies are fragmented as these are typically limited to a single phase in the software development lifecycle. It is far from trivial to practically combine the various approaches into an integrated model-driven software development process, thereby building upon the appropriate safety/security languages and tools for architecture design, certification, cryptography, and secured packaging.

The ambition is to design & develop model-driven and predictive engineering methods & tools that enable on-demand composition of software, while predicting guaranteed safety/security features of the integrated system. This approach must integrate “security by design” principles and address the key limitations in the state-of-the-art of safety/security engineering, including:

- Lack of (semi-)automated safety & security analysis & verification (lack of reuse): Lack of an integrated, model-driven software engineering processes (lack of traceability support)
- Lack of variability modeling across the hardware/ software boundary
- Poor documentation, selection, instantiation and validation of architectural safety/security concerns
- Poor representation and enforcement of domain-specific constraints

Cryptography

As computing power increases (according to Moore's Law), the complexity of cryptographic algorithms and keys must increase. An even bigger challenge is caused by the possible availability of quantum computers in the near future. For symmetric encryption algorithms, increased key sizes are expected to be sufficient against quantum computers. For asymmetric encryption, currently used algorithms are not secure. For data that needs protection for a longer time, this limits the choice of key schemes. In other applications, this means developers need to be aware that future upgrades of algorithms must be possible to keep systems secure in the future.

Protocols

Advanced security controllers, based on efficient and well-known open protocols, greatly enhance the overall system security. In limited resources embedded assets, classic and well-established RSA keys are being replaced in PKI infrastructures by Elliptic Curve Cryptography (ECC), that potentially provides lower memory usage and power consumption by the usage of shorter keys. Like in the case of the substitution of discrete logarithms (RSA) by ECC, further development in cryptography techniques can lead towards the development of efficient advances without compromising the security of the overall infrastructure.

Secured packaging

Securing the communication link is a key factor to assure the integrity of any Internet of Things system. Nevertheless, there are many ways in which an IoT node can be attacked, this includes tampering techniques that can only be avoided by the usage of anti-tampering secured packaging. Secured packaging, in combination with software and protocol techniques, can countermeasure physical attacks, that can potentially lead to serious problems in both the industrial and consumer fields.

New chip architecture

Most of current security chips are based on proprietary or generic 8/16/32 bit processor and a fairly closed and controlled overall circuit architecture contributing to prevent, with a very high level of resistance various type of intrusion and leakage. The security and safety higher awareness is now creating or accelerating the need for broader architectures rather based on existing general purpose processor platforms (and introducing additional features as needed). The overall requirements for safety, security and privacy call for different intermediate resistance levels that may be achieved with different types of circuit architecture. The wide range of potential objects for the IoT, from the smallest (basic sensor + communication) to the most complex one would lead to different architectural solution.

The ambition is to study and design different circuit solutions including some form of more secure / trusted processing / storage area that may be achieved through various approaches, that may be selected/combined to achieve the required safety/security level target

In complement to the above, the arrival, on the software side, of hypervisor or secure kernel abstracting and controlling the physical resources at circuit level, may induce specific changes in circuit architecture.

3.3.3. High priority R&D&I areas

New architecture

- Secure Hardware building blocks
- Secure Software libraries and components
- Integration of secure software and hardware elements
- Methodologies for "secure by design" architectures

New design tools

- New security metrics
- Safety&security co-design and co-analysis
- Simulation techniques for safety and security analysis
- Verification and validation of security requirements
- Specification of secure systems and building blocks

Safety/ security engineering

- Embedded software architecture modeling
- Software variability modeling
- Software product line engineering
- Model-driven software engineering processes
- Reuse of architectural safety/security patterns
- Secured development process (Automated code management, tests, security testing, vulnerabilities analysis, secure firmware & software updates)
- Harmonized and interoperable security evaluation & certification
- Security analysis and evaluation
- Security & privacy by design
- Safety and security patterns
- Formal Methods for side fault analysis and fault attacks
- Fault injections on Secure Element
- White-Box Crypto: algorithms & attacks
- Fully homomorphic Encryption: algorithms & attacks
- Block chain, Post Quantum Cryptography, Quantum cryptography, Fingerprinting
- Simulation environments for security evaluations of components and Systems
- Artificial Intelligence for security fault prevention (adaptive security)
- H/W-secured Smart Contracts

Cryptography

- Full homomorphic Encryption: algorithms & attacks
- Quantum cryptography & Post Quantum Cryptography

Protocols

- Techniques to improve the efficiency in terms of cost, size and energy consumption of hardware and software solutions implementing currently well-known cryptography protocols and security infrastructures.
- Mathematical analysis to design new scalable and efficient protocols, suitable for the new requirements of billions of connected smart devices.

Packaging

- Improve the understanding of potential attack mechanisms and develop effective countermeasures to withstand these new attacks must be a key R&D&I point to allow further deployment of the fourth industrial revolution, specially in safety-critical systems.

Chip architecture

- A generic processor coupled with a secured processor integrated as secure enclave in a single chip architecture or as a two chips solutions (SiP)
- A generic processor plus additional memory protection unit(s) to insure a more protected processing and storage area within the circuit
- A dedicated processor architecture integrating a trusted/secure set of operations (such as an ARM TrustZone, but potentially applied to lower end CPU)
- Any further combination that could lead to appropriate safety/security levels
- Multi-processor redundant architecture with integrity cross checking should be considered
- All dedicated hardware resource access control

3.3.4. Competitive situation

Looking at the European landscape R&D&I priorities vs the need for a global security approach as shown by GC1 , applications and infrastructure will drive the development of necessary technology bricks and associated tools.

In fact, this will have to be conducted in the direction of product development (chips, design tools, engineering tools...) but also in research domain as cryptography for example. This will permit to preserve and develop European position in a globalized market.

3.3.5. Expected achievements

New architecture integrating security to enable "security by design"

- Design methodology that integrates security requirements, metrics and verification techniques.
- Integration techniques for modular validation and certification of secure applications.
- Standardization & reuse of architectural security patterns & tactics

Safety/ security engineering

- Tools & configuration languages (DSLs) for exploration, instantiation & verification of architectural security patterns
- Design-time & run-time variability: quality prediction, handling changing attack surface
- An integrated tool chain, enabling end-to-end traceability of design decisions
- An integrated software product line engineering approach (and tool chain) for variability management
- Modeling and tool support for automated composition of (safety, security, functionality) models
- and tool support for automated trade-off analysis between alternative architecture solutions

Protocols

- Currently used authentication protocols are mainly based on PKI infrastructures, which are widely-spread, widely-known and typically used as the standard authentication mechanism in Internet protocols. Nevertheless, Internet of things opens a new set of requirements, billions of simple connected devices make PKI inherently inefficient and open the horizon towards the development of new authentication paradigms, like zero-knowledge cryptography.
- Also, open and widely-tested authenticated encryption techniques, must become the only option when symmetric cryptography is needed to provide e-confidentiality, integrity and authenticity assurances on the data. The right usage of existing security primitives must be promoted to avoid the dangerous misuse that is frequently found in current systems.

Packaging

- Further development of novel techniques to increase the reliability and anti-tampering capabilities of current packages, like Physically Unclonable Functions (PUF), and promote the importance of using certified and secured packaging solutions for safe European applications.

Chip architecture

- New architectures adapted to wider range of objects and security levels
- Tools/methods for modeling security level vs potential architectures
- Hardware model to support development / integration of resource abstraction layer

4 CONDITIONS FOR SUCCESS

When examining the opportunities to succeed, there are several weaknesses to consider: a global fragmented market with different levels of maturity, different strategies of member states, lack of coordination at EU level in key R&I domains (between security companies), lack of skilled engineers and a limited awareness of citizens and in many companies. On the other hand, there are many strengths that can be exploited in facing the challenges: a market of 500 million consumers, many SME's and large companies specialised in safety and security, an academic leadership in some key areas for research and training plus the regulatory environment based on European policy focused on trust, privacy and directives with the goal to ensure a common level of cyber security in Europe.

The following directions may help Europe to overcome the threats and to improve its position:

- Focus on European market and local assets (like privacy protection)
- Focus on export products and know-how in emerging markets
- Develop and improve safety & security aspects in those industries where Europe has a leading position (energy, automotive and transports, telecommunication, ...)
- Speed up adoption and application of regulations at European Level

5 TIMEFRAMES

	2017-2019	2020-2022	2023-2026
GC1 Safety & Cyber security of critical European applications			
Safety/ Security & privacy by design	Basic requirements	Schemes per domain	Generic Framework
Identity and authentication mechanism	Improved identity and authentication resilience Implementation of existing standards	Multi form factor authentication Authentication scalability Partial identities according to needs	Multiple authentication HW/SW using privacy interoperable
Secure aware data processing and storage	Modelisation of data confidentriality & integrity Computation of encrypted data	Efficient techniques for secure data storage and preservation of data integrity Physical design of data encrypted according to computation requirements and protection level	Automated and continuous monitoring of data confidentiality and integrity
Infrastructure resilience and adaptable to new threats	Monitoring of threrats through dedicated tools . Analysis of new threats and requiremsnt vs applications	Integration of different prevention and defence mechanism/systems	Autonomous and holistic prevention & defence system against all kinds of threats
Secured networks & new protocols	Cryptography to secure existing protocols improve existing tools		
	New risks an threat identified	Security solutions for cyber risks Detection of attacks improved	Deployment of worldwide solution
GC2 Security for privacy and personal data protection			
Secured devices and associated management Trusted boot ,trusted execution , authentication , anti-counterfeiting mechanisms	secure component based on New standards: HSE/TPM/eSE	Product availability	Standard Secure anchors
Trusted devices based on block chain	Theorical study of feasability	Application to different domain of GC1	
GC3 Building blocks for trusted and safe computing			
New architecture integrating security to enable "security by design": New design tools Safety/ security engineering :	Requirements and specification for safety security and trust Security guideline, focused on tool support security validation Security KPI definition Definition of verification models	Methodology and tools available , secure programming languagesecurity level KPI .Generic system development methodology including certification	
Protocols	Specification of new protocols including crypto elements enforcing security	Protocols implemented	
Packaging	Definition of vulnerability level & proposed solutions	Test & Verification of deployed product to assess solutions and prepare to certification	
Chip architecture	new generation of Secure micro controllers compliant to to safety & security requirements	Generic processor coupled with secure processor Generic processor + Protected zone	Multiprocessor adaptable platform compliant to generic safety and security levels required

6 SYNERGIES WITH OTHER THEMES

AENEAS AGENDA (2016)	GC1	GC2	GC3
Introduction	X	X	X
Automotive and Transport	X	X	X
Connectivity and Digital Networks	X	X	X
Energy Efficiency	X	X	X
Health and the Ageing Society	X	X	X
Safety and Security	X	X	X
Design Technologies	X		X
Process Technology and Integration			X
Equipment, Materials and Manufacturing			

06

1 EXECUTIVE SUMMARY

Design Technology is the essential link between the ever-increasing technology push (More Moore (MM) and More-than-Moore (MtM)) and the new products and services required to fulfil societal needs for mobility, security, health, communication, education, digital life style, and safety.

It enables the conversion of ideas and requirements into specifications and then the realization of new electronic components and systems (ECS) being the essential innovation enabler for superior products of the European system houses. Design Technology includes methodologies involving hardware and software components, design flows, tools, libraries, IPs, manufacturing and process characterization. Design technology is facing the three challenges of

- managing increasing complexity,
- managing diversity of systems and devices and
- managing multiple constraints.

It blends HW, SW, a variety of non-logic functions, like analogue mixed-signal (AMS), radio frequency (RF), sensors-actuators (e.g. MEMS - Micro-Electro-Mechanical Systems), and power. In addition, a set of application-driven requirements, such as reliability, security, ultra-low power, and safety must be considered. Finally, the escala¬ting design costs, the ever-increasing size of development teams, and time-to-market delays are clear indicators of the need for advanced Design Technologies to cope with the visible bottlenecks in the design process. More and more application know-how is necessary to design components that best fit the application requirements. Thus, the focus of design technology is getting broader and the paradigm in product development has to shift from technology-driven to application-driven design, as shown in Figure 1 and Table 1.

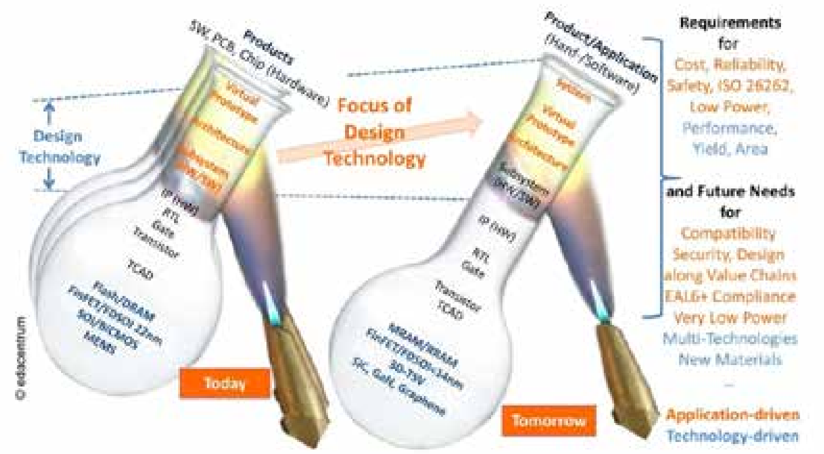


FIGURE 1 / *The innovation chain requires a shift in design paradigm*

	Present Requirements	Additional Future Needs
Application/ Product-driven	Price/Cost, Reliability, Safety, ISO26262 Compliance, Low Power Consumption	Application SW & OS Compatibility, Security, Design Along Value Chains, EAL6+ Compliance, Very Low Power Consumption
Technology-driven	Performance, Yield, Si Area	Multi-Technology Support New Materials: SiC. GaN, Graphene

TABLE 1/ *The innovation chain requires a consideration of new requirements*

DESIGN
TECHNOLOGIES

2 RELEVANCE

2.1. Competitive value

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.

A seamless open and extendable design eco system across the whole value chain is therefore needed for incorporating the fast evolving MM and MtM technologies in the new electronic products, satisfying the new application specific requirements.

Currently, the shortcomings of design technology are very much positioned in the system-level area of design. The competencies required to address them are strongly available in Europe's world-class universities and research institutes, electronic design automation (EDA) vendors and world-class system houses.

Tackling the three Grand Challenges, will enable the European Industry as a whole to benefit from the progress made in innovative electronic components and systems.

2.2. Societal Benefits

A study by the Commission stated that "Over the period 1995-2004, ICT drove half of all productivity gains in the EU, mainly through efficiency gains in the ICT sector and investment in ICT"[11]. Design technology, as a critical enabling component of 'Information and Communication Technology' (ICT) and thus of the 'Internet of Things' (IoT) and all smart applications, has a strong social impact by enabling critical applications in areas of real social relevance such as health, energy, mobility, communications, security, and transport. For example, the reduction in casualties in car transportation has been made possible by the widespread adoption of safety features (for example, ABS, airbag, and driver assistance systems), based on semiconductor design. All the above sectors are critically dependant on dedicated design solutions that typically integrate many different multi-functional blocks, including sensor technology and require high performance, high reliability, data security and ultra-low power consumption. Meeting these multiple requirements requires a tight integration between architectural design and technology, and properly applied design methods and tools. Only the continued progress in this area will allow the continued production of high quality products in Europe.

Market opportunities are huge. The design technology bottlenecks have to be removed to enable the design of all the electronic systems and components necessary to meet the societal needs of a growing population. As we already see today, new ECS with new features are the innovation engine for products and services to enhance the social, the private, and the working life of tomorrow.

[11] http://www.eurosfaire.prd.fr/7pc/doc/1274193700_europe_digital_competitivenes_report.pdf (Commission Staff Working Document: Europe's Competitiveness Report, Brussels 17.5 2010 Sec (210) 627)

3 GRAND CHALLENGES

3.1. Vision

A seamless, open and extendable design ecosystem with design technologies based on standards which starts at system level and contains flexible 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.

3.2. Scope and ambition

'Design Technologies' aim at developing solutions to design complex systems. Those consist of several billion-transistor components and their associated large software stacks of several million lines of code. These systems are the combination of several hundred types of IP blocks and subsystems coming from different sources. The main drivers for higher integration are new features, cost, form-factor, energy saving aspects and high performance interaction of subsystems with a high reliability/robustness. Besides the pure digital systems, Design Technologies apply also to heterogeneous devices com¬prising power, AMS and communication subsystems (RF or optical), and sensors and actuators (e.g. MEMS) based on mixed disciplines (mechanical, bio, optical, chemical).

Due to progressive integration these SoCs will merge different application domains, for example automotive, communication and medical (e.g. 'The-Car-That-Cares'), automation and internet (in Industry 4.0 and IoT) or medical and security/internet (in telemedicine). The resulting challenges for design technology have been condensed and are described below as three 'Grand Challenges":

1. Managing Complexity
2. Managing Diversity
3. Managing Multiple Constraints

which are not disjunct but strongly interdependent as e.g. diversity and also constraints (for safety and security) are heavily increasing complexity.

In principle all challenges have to be met holistically, because one weakness at one specific point is sufficient to endanger the whole design/product. Therefore, a complete flexible, open design ecosystem extendable for specific design domains and constraints is needed to enable future super complex electronic components in a consistent way.

Designing these highly integrated and complex products requires improved methods for On-chip integration, Verification, Embedded Software and Technology downscaling.

1 On-chip integration

System-Level Design: One major achievement in electronic system level (ESL) has been the progressive deployment of virtual prototyping. The architectural models developed were an enabler for early development and validation of embedded software, as well as functional verification activities for the chosen hardware (HW) architecture. The next step is to improve the models for early performance estimation (bandwidth, latencies, etc.), and to include non-functional property evaluation. These features will enable identification and implementation of the optimum across the different Key Performance Indicators (KPIs). For heterogeneous systems, improved methods for integration are needed, like new approaches for 'Overall Validation'. For shorter Turn-Around-Times the link to requirement engineering, including the deriving of related use cases and test benches must be addressed.

Architectural Design: The architectural design copes with system specifications, performs architectural exploration and evaluation, finds an optimum of the system, and is the starting point for automated implementation and verification at system level. This includes the selection of 'best-fit' technologies for chips, packages and boards. Even heterogeneous systems must be designed as a single system.

The large number of IPs and subsystems (HW and SW) requires a powerful archi¬tectural level design flow to attain the required product performances. Furthermore, architectural design needs also to handle non-functional requirements, like performance, thermal aspects, robustness, resilience, safety and security aspects. For a proper and fast product definition, the selection and evaluation of existing IPs and subsystems from open IP infrastructures must be ensured. Based on architectural decisions, it is necessary to derive well-defined constraints and design properties for implementation/validation.

Holistic Design Environment: The implementation of complex systems requires an efficient transfer of design data and proper understanding between actors working at different design abstraction levels. It demands for an overall handling of the specification during the implementation process and a stringent monitoring. Data exchange must include a management change and methods for handling different abstraction levels with associated design properties (top down vs. bottom up) i.e. power and timing.

An efficient methodology for handling of 'System-of-systems' requires easy adaption of IPs/subsystems in a new SoC environment and common methods for validation, based on product requirements. They include an overall regression environment from architecture to product ramp up and production test including the capability of certification.

2 Verification

Europe's strengths comprise the design skills and application know how to combine top functionality with quality is basis for success especially for safety and security relevant products and services. Especially here, verification is key for quality and to enable pro¬duct competitiveness in terms of cost/price, functionality and performance. Because even minor design errors can lead to redesign loops causing extreme cost increases and time delays, verification methodologies have to guarantee a very high level of error/fault-free design at all integration levels: chip, package, board and firmware/software.

For a while, functional verification was the main focus in verification, driven by the famous "first silicon success". A massive adoption of Universal Verification Methodology (UVM) in recent years has been a major step towards complexity challenge mainly by enabling the involvement of the designer community to the functional verification and also by enabling horizontal reuse through standardization.

However, now a major disruption is in front of us regarding verification to handle the new dimensions coming along with multiple - often implicit contradictory – constraints addressed in Grand Challenge 3.

A combination of energy efficiency, robustness, fault tolerance, safety and security is what we can expect from any smart digital system which leads to another level of complexity that needs to be handled upfront as it will impact all dimensions. Proto¬typing has demonstrated its potential to extend hardware maturity by an early stress of the design under hardware dependent software, by enabling an efficient observability and controllability of system aspects (e.g.: clock and power management, error behavior). SystemC / TLM has been recognized as a very good solution to support models implementation and deployment. Well driven in digital domain, verification needs major breakthrough in analog and mixed signals domains. Function testing requires standardization, direct and indirect metrics in order to cope with KPIs from IPs to System levels. Inspired by digital word, EDA tools are a must for increasing test coverage (e.g. chain test) and use the power of advanced statistics methodology. For the new verification challenges, it is now the time to revisit, extend, and reinvent the major breakthroughs we have seen during the past decade around functional verification (randomization, coverage driven verification, formal app's), in order to support (contradictory) application driven constraints like safety and security of the emerging smart products.

Additional to that, new approaches are needed: E.g. Security can't be normalized by definition: It's not about what should work but about how it can be misused to extract valuable information. By itself, this is an urging and promising domain that still requests an intensive research activity and is lacking methodology, flows and tools to support design developments (e.g.: security properties descriptions, negative testing, fault injection, penetration measurement). Also the upcoming new architectures showing up in context with multi/many cores, neuromorphic computing, and NOC/GALS or new technologies like FD SOI, graphene, integrated power devices will require new adequate specific verification methods.

3 Embedded Software

Software has become a major differentiation factor for innovative products. The embed¬ded software development flows must now adapt to the substantial usage of agile design methods, along with the emergence of new needs related to the system performance optimization: time, energy, temperature, etc. The integration of hardware and software components, as well as their validation at the system level is a key ingredient to deliver efficient, robust and reliable products. Consequently, new development methods are required to support:

- Early HW-SW co-design: efficient partitioning between HW and SW, optimizing system performance considering the availability of hardware resources.
- Energy-aware software development: anticipation and validation of software developments related to dynamic energy management (ultra-low power, temperature regulation, etc.).
- Hardening of embedded software for improved reliability safety and security.
- Efficient composition of robust software modules coming from different sources, to implement an application targeting a specific system architecture.

4 Technology down-scaling

Following CMOS scaling to deep submicron regions, the intrinsic device dependability of transistors cannot be guaranteed any longer. Due to increasing electric fields and local power densities, the vulnerability of extremely small feature sizes, and the very large number of elements involved, failures will occur more often and earlier in an IC's lifecycle. At the same time, critical applications in fields such as automotive, aerospace, security, or health require very high levels of dependability. The all-embracing term dependability summarises three different aspects: yield (percentage of functionally correct devices at production time); reliability, describing functional correctness over lifetime; and robustness, corresponding to 'persistence against disturbances'. Yield, reliability and robustness are becoming closely related and can no longer be guaranteed by improved production processes or design methods only.

The introduction of new process technologies (FinFET, FDSOI) are bringing additional physical effects. Additionally, the long term basic research topic beyond CMOS (e.g. quantum, spin electronic, graphene) requires an appropriate attention.

The merging of technologies ends up in a Nano-Micro-Macro Integration (NMMI) design space challenge (nanometer [nm] to meter [m] dimensions) which needs to be fully covered by appropriate design technologies. This in¬cludes coupling/interference problems arising from NMMI solutions and from System in Package integration. Furthermore, the utilization of upcoming 3D interconnect technologies, e.g. through silicon via (TSV), will require new design technology solutions. The same is true for voltage (e.g. in systems for Smart Grids): millivolt signals from sensors are processed by processors working at volt level, then controlling power devices operating at several hundred/thousand volts in battery/trans¬mission systems. Different expertise, methods, tools, environ¬ments, etc., have to be used cooperatively to come to optimal system solutions.

3.3. Competitive Situation

Europe has very strong system houses producing complex high-tech designs for products in the areas of aeronautics, automotive, healthcare, and communications. For keeping their world-leading positions, a continuously push for improved electronic systems is essential while keeping high quality in parallel. This means that system complexity is continuously increasing and probability of design errors is growing.

Large EDA companies currently provide mainly tools and methodologies for specific design domains (digital macros, analogue & RF macros, SW, package, PCB). The different domains are only roughly linked and the main focus is on digital methods. Higher design levels are not well covered, even though some initiatives for the support of higher levels of abstraction do exist. Big companies normally combine the partial solutions with (not standardized) in-house solutions. A comprehensive extendable open design ecosystem has still to be created, especially for supporting heterogeneous appli¬cations. Yield, heat, and mechanical stress need to be addressed in more holistic way.

With shrinking node size, circuit design and process variability, parametric degradations and other constraints (e.g. EMC, power, timing and temperature) become strongly interrelated. Tools and flows for complete system design should address physical interactions between the components and ensure high reliability.

To cope with the intrinsic complexity of systems, the key to success is to address issues in three critical dimensions: executable representation of the system functionality, evaluation of the system performance and design productivity using an effective design environment. Europe will maintain its competitive advantage only if it actively addresses the design technology challenges described below.

3.4. Grand Challenge 1 'Managing complexity'

3.4.1. Description:

This challenge aims at defining and developing new methodologies, tools, standardized formats and description language(s). This will allow moving the design focus to the system abstraction level in order to keep pace with the design productivity requirement for highly complex next-generation systems. It should be noted that three major trends in electronic design will change today's design practice dramatically:

a) The introduction of multi-core/many-core based architectures to reduce power dissipation is causing software content to increase exponentially, and ask for new solutions for their interconnection (NoC).

b) Low-power designs are mandatory for many current and future products to handle performance-power-thermal requirements.

c) Although many (linear) analogue functions can be handled digitally, some important analogue functionality remains and this slows down the design process.

3.4.2. High Priority Research Areas:

The success of the Grand Challenge 'Managing complexity' will depend on giving special attention to the following high-priority research areas, which are substantiated in the table in chapter 6.5:

- System Design (VP- bridge the Architecture and IP-Implementation)
- Architecture (compose the system)
- Overall design environment (Design verification for HW and SW developments)

3.4.3. Expected achievements / innovation foreseen:

The main objectives that need to be targeted are the establishment of standard languages and associated tools and methods to develop system models that can be shared across the system design value chain. The expected achievements will be solutions for the critical issues shown in the corresponding table in Section 5.

3.5. Grand Challenge 2 'Managing Diversity'

3.5.1. Description

This challenge aims at developing design technologies enabling the design of complex system-on-chip (SoC) and system-in-package (SiP) solutions including heterogeneous devices and functions.

The challenge is derived from the diversity of today's nano- and microelectronics due to the need for integration (SoC, SiP) of an increasing amount of heterogeneous systems and devices to be tackled in mixed disciplines like electrical, mechanical, optical.

3.5.2. High Priority Research Areas:

The success of the grand challenge 'Managing Diversity' requires special attention to be given to five main high-priority research areas, substantiated in the table in chapter 6.5:

- Multi-objective Optimization of products, systems and components
- Modelling and simulating in heterogeneous systems
- Eco-System for processes, methods and tools for the cost efficient design, along the whole value chain
- Integrating analogue and digital designs and design methods
- Connection of Digital and Physical World

3.5.3. Expected achievements / innovation foreseen:

The main achievement that the projects should target is the establishment of standard languages, plus associated tools and methods, to build integrated design flows and plat¬forms targeting heterogeneous SoC and SiP. Platforms enable the delivery of reusable IP for microsystems and other heterogeneous systems. The expected achievements will be solutions for the critical issues shown in the corresponding table in Section 5.

3.6. Grand Challenge 3 'Managing Multiple Constraints'

3.6.1. Vision

Beyond its pure functionality, different types of properties characterize IC designs. Such extra-functional properties often 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 for a given design. As a long term vision we aim at an integrated toolset for managing all relevant constraints.

3.6.2. Description

This challenge targets the development of design technologies considering various constraints (e.g. power, temperature, time, yield, robustness, reliability, safety) as well as constraints coming from different applications.

Appropriate models must cover physical effects at various levels of abstraction and over a very long period of time. New design technologies must treat power, time, temperature, testability, yield, reliability and robustness holistically, starting from the application level, through the system and architectural level down to technology level, ensuring good coverage of parameter spreads, parasitic spreads, and aging effects. This approach should be complemented with yield optimisation using tools that are capable of cross-checking the data coming from process, test and design. The specification and mission profile describing the application affect the whole top down design-for-reliability and robustness process. Bottom-up procedures are required to propagate basic technology related information, starting with characterization at transistor level upwards various levels to the top system/ architectural level.

3.6.3. High Priority Research Areas

The success of the grand challenge 'Managing Multiple Constraints' will require an inte¬gration of methods, tools and flows for analysing and optimizing multiple constrains in a single holistic approach: Furthermore, special attention has to be given to several high-priority research areas (which are substantiated in the table in chapter 6.5), including:

- Ultra-low power design
- Efficient methodologies for reliability and robustness in highly complex systems including modelling, test and analysis, considering variability and degradation
- Monitoring and diagnosis methods and tools
- Building secure extendable or evolvable systems
- Tackling of new technology nodes.

3.6.4. Expected achievements / innovation foreseen

Increase system properties (e.g. power consumption), reliability and robustness using methodologies, design flows tools and that simultaneously optimize designs with respect to timing, temperature, yield, process variability and lifetime-related parametric degradation. Develop methods and tools to facilitate online monitoring and diagnostics. A non-exhaustive list of the main expected achievements is shown in the corresponding table in Section 5.

4 CONDITIONS FOR SUCCESS

The conditions for success in Design Technologies are manifold, but can be summarized as follows:

- Wide European participation to achieve critical mass & standardized solutions with active involvement of all actors in the supply chain and close cooperation between industry and research institutes
- Project continuity in order to match the evolution of design methodologies to technology developments and increased application demands

5 TIMEFRAMES

All three Grand Challenges need to be met in parallel, since all the elements are required to design reliable new applications. The roadmap for the recommended activities can be derived from the tables below. Regarding the tables, it has to be mentioned, that the task boundaries and their TRL levels often do have a transition time of some years.

2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027 2028
Multi-objective Optimization of products, systems and components
Fully integrated development process for all parts of a product at different abstraction levels for multi-dimensional optimisation
Cross-Domain Methods (incl. Standards for...)
Manage various constraints in different domains along the whole design flow
Consistent and complete co-design of IC, SiP, PCB, application system, incl. mechatronics and their interfaces.
Cross domain optimization
Cross engineering domains across supply chain.
3D-Design re-use: to manage systems
3D-Design re-use for systems implemented along the supply chain and Incorporating the notion of time in the code.
Modellin & Simulating in Heterogeneous Systems
Appropriate models covering several operational conditions: focus on system level simulation with integrated special devices
Appropriate models covering several operational conditions: including aspects like variation and aging
Ecosystem for processes, methods and tools for the cost efficient design along the whole value chain
Create Ecosystems for the design of safety critical complex and/or distributed systems (ECS)
Design Ecosystem based on standards: common methodology for functional and non-functional properties for system integration and validation; open for all partners
Design Ecosystems based on standards extended to heterogeneous components and reliability, yield and robustness.
Integrating analog and digital designs and design methods
Metric method for testability and diagnosis efficiency in particular for AMS verification, validation and test
Harmonisation of methods and tools for analog and digital to come to a fast common environment
Easy re-use of analog IP in system context; efficiently integrated analog and digital design flows
Connection of Digital and Physical World
Integration of environment modelling and simulation into the HW and SW design flow.
Integrated multi-physical - logical simulation: Simulation of (digital) functional and physical effects, extending classical simulations to multi-physics simulations
Connection of virtual prototyping and physical world (including complex environment models) in complex validation environments
TRL 2-4 research
TRL 4-6 development
TRL 6-8 pilot test


2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
Ultra-low power HW/SW design Flows
Design methods for low-power , performance sensitive autarkic systems
For autarkic systems incl. energy scavenging
For autarkic systems with energy scavenging or extremely long battery power lifetime (covering power supply models)
Efficient modelling, testing and analysis for dependable complex systems, considering physical effects
Critical physical effects (ESD, latch-up, EMC, thermal/ mechanical stress)
Critical physical effect at SoC and system levels along the value chain
Design and development of error robust circuits and systems
Design for: test, yield, reliability variability, and litho friendly of IP/subsystems up to full SoC.
Multi-level analysis, modelling, and formalisms for dependability.
Automated metrics/ tools for testability and diagnosis in particular for measuring yield loss and test escape.
Models for secure and dependable subsystems, covering all operational conditions (modes, thermal, ...).
Consistent methodologies and new approaches for security and dependability for each component: hardware, HW-related SW in all operational conditions.
Avoidance, recognition and handling errors at physical, device, block, SW, system level
Models with variability, dependability information including degradation effects.
Combined HW/SW sign-off for dependability and variability at block and system levels
Dependability, variability, and yield fully integrated into a seamless design Eco-Systems
Monitoring and Diagnosis methods and tools
Monitoring and diagnosis for subcomponents
Online monitoring mechanisms implemented at system level
Monitoring, prediction and online diagnosis for full-product lifetime;
Building secure extendable or evolvable Systems
Basic structures and elements for extendable systems
Update and evolution strategies maintaining security, including self-learning and adaptation.
Online adaptive highly available, secure and safe systems incl. life cycle management for innovative products
Tackling of new technology nodes
Introduction and support of new technology nodes (FinFET, FDSOI)
Beyond CMOS research (e.g. quantum, spin electronic, graphene)
TRL 2-4
research
TRL 4-6
development
TRL 6-8
pilot test

6 SYNERGIES WITH OTHER THEMES

Possible synergy areas with other priorities are (not exhaustive):

- Design for Safety and Reliability (increasingly for mixed criticality systems) with application projects in 'Automotive and Transport' and 'Health and Ageing Society'.
- Design for complexity includes tools for reducing power dissipation, which is essential for 'Communications' and 'Health and Ageing Society', as well as for environmental considerations.
- Design for diversity includes sensor integration, 3D and SiP design, essential for 'Communications', 'Automotive and Transport' and 'Health and Ageing Society'. The smarter system integration of power devices, sensors and logic will be fundamental for 'Energy Efficiency' and 'Smart Grid'.
- Failure analysis and reliability procedures related to high temperature, high current/voltage operation will also be an issue for sub-programmes in 'Automotive and Transport' and 'Energy Efficiency'.
- Technology computer aided design (TCAD) and modeling of device reliability and variability in synergy with 'Semiconductor Processes and Integration'.
- Design for diversity implies strong cooperation with 'Equipment, Materials and Manufacturing' and 'Semiconductor Processes and Integration', especially on package modelling.
- Testing development, especially for 3D and heterogeneous components requires synergy with test equipment development.

07

1 EXECUTIVE SUMMARY

This chapter describes the challenges and roadmaps for Europe's ambition in Semiconductor process integration. Given the strategic nature of semiconductors for Europe, from tools and materials over components, circuit and system manufacturing to the enabled applications it is of essence to stay at the forefront.

The challenges are threefold:

1. Semiconductor process technology and integration for advanced and distributed compute infrastructure and system performance scaling.
2. Semiconductor process technology and integration of devices and components at chip-level and SoC for the complex heterogeneous functionality
3. Process technology and integration for advanced smart System-in-Package applications

Cross-connect with basically all application fields exist and strong ties with design and materials and equipment are evident and referred to in this chapter.

PROCESS TECHNOLOGY AND INTEGRATION

2 RELEVANCE

2.1. Competitive value

Semiconductor technology is indispensable for meeting the challenges of the European society. The availability of in-Europe manufacturing is essential to supply Europe's electronic systems manufacturers with critical components . The large difference between the worldwide market share of Europe electronic system and that of EU manufactured components is an important potential risk for large part of the Automotive, Aeronautics, Energy, Space and Health industry in Europe. The European manufacturing position must be reinforced through leadership in processing know-how for all advanced technologies: advanced and beyond CMOS (More Moore, MM), heterogeneous integration (More than Moore, MtM) and System in Package (SiP). Pilot lines in MM, MtM and SiP and supporting test beds are needed to accelerate the uptake of KETs and enable manufacturing. The well-concerted combination of activities will increase the attractiveness for private investment and talent with the goal to keep and create skilled jobs in Europe and meeting the specific dynamic needs of European industry.

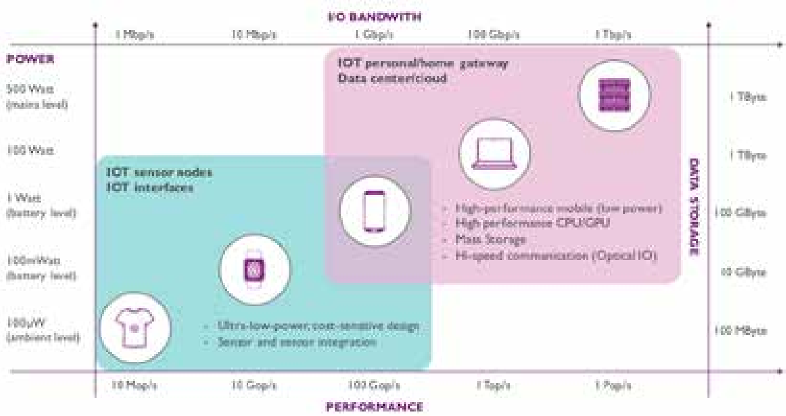
2.2. Societal Benefits

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 economy. The overall value chain of equipment, materials, system integration, applications and services is still well represented in Europe. By launching new process and equipment technologies based on innovative materials, designs and concepts into pilot-lines, collaborative projects will facilitate a strongly growing market share, increase employment and investments for innovative equipment, materials and for manufacturing of semiconductor devices and systems through European leadership positions in MM, MtM and SiP. Ensuring the continuation of competitive manufacturing in Europe supported by a high level of excellence in manufacturing science and efficiency will enforce strong global industrial positions (IoT, Industry 4.0, security, automotive, space, aircraft manufacturing, power generation and medical/healthcare) and significantly contribute to safeguard our strategic independence in critical domains and secure tens of thousands of jobs directly or indirectly linked to the semiconductor manufacturing.

3 GRAND CHALLENGES

3.1. Vision

Semiconductor processing and integration serve the needs of many applications. Advanced and distributed compute platforms are essential to support the growing need for abundant data processing, 5G and Internet of Things. New semiconductor technologies need to live up to the high demands of Power-Performance-Area-Cost while at the same time deliver the technology flavor essentially suited for the application: from the server farm and high performance computing, over the mobile systems market where low latency user interactivity at low power is key to the ultra-low power needs at low cost of the swarm of devices at the IoT. It is time to 'reboot' our compute infrastructure encompassing all technology and systems design features and it will be essential to have technology and component specialization to address the diverse application needs.



There is a continuous expectation that successful process innovation will address this specialization the levels of the equipment, unit processes, process integration and packaging with a strong technology-design-system-application interaction. Semiconductor process and integration tackles also the challenges of heterogeneous integration of the required functionalities – the senses of our systems. This heterogeneous integration is very diverse and listens carefully to the demands of the application. This is equally true for the system on chip and system in package integration where innovation has been very strong over the past decade. This segment of the industry will innovate dynamically its processes and integration routes to translate the various application driven specifications reliably, in the appropriate form-factor and at the right cost for a very wide set of application domains.

3.2. Scope and ambition

In the scope of this chapter we identify three Challenges that need specific attention and targeted collaborative actions at European level:

1. Semiconductor process technology and integration for advanced and distributed compute infrastructure and system performance scaling
2. Semiconductor process technology and integration of devices and components at chip-level and SoC for the complex heterogeneous functionality
3. Process technology and integration for advanced smart System-in-Package applications

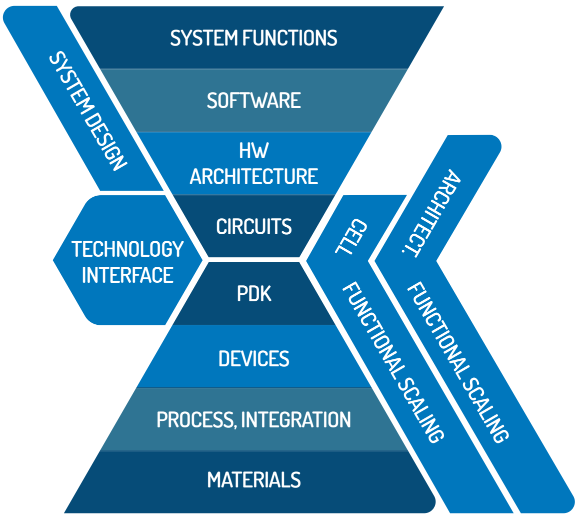
These process technology and integration developments will be executed in close synergy with design efforts, and as such offering opportunities for building unique European IP to establish leadership in applications for global markets. This responds to the growing need of co-design efforts for security, energy efficiency, data management, distributed computing etc.

There is an urgent need to tackle the needs of these three grand challenges in a concerted fashion to sustain Europe's presence in semiconductor enabled applications. Technology research and pilots connect technology and application communities and can lead to European demonstrators and new IP-related business opportunities. Testbeds will roll out the demonstration, create awareness, stimulate entrepreneurship and enable new industry and job opportunities.

The ambition is to build on the strength of the European industry, to enable new industry growth and to promote the involvement of all actors in the value chain of process technology, including partners in materials and equipment, partners in integration and component manufacturing, partners in assembly and packaging, and partners in design and architecture of application-specific systems, all active in the global market.

3.3. Competitive situation

When considering the competitive situation of the European semiconductor process and integration technology, it needs to be seen in the overall perspective of the value chain. Whilst the manufacturing of electronic components, circuits and systems is under pressure, some European companies are able to keep a strong position in specific domains and there are opportunities for growth. The suppliers of process integration equipment and novel materials are evidently key partners in this path to growth, since Europe has a very strong tradition in this field as described in Chapter 8 of this agenda. The further development of technologies for future generation computing, communication, and heterogeneous functionality will allow the European industrial players to grow their presence in the opportunity areas like automotive, healthcare, internet of things. It further links to other strengths in Europe on the system implementation and the software and service innovation. Furthermore, through a traditionally strong and advanced educational system, the R&D position in Europe throughout the whole stack of competences is remarkable.



3.4. Challenge 1: Semiconductor process technology and integration for advanced and distributed compute infrastructure and system performance scaling.

3.4.1. High priority R&D&I areas

Semiconductor process technology and integration actions will focus on introduction of materials, devices and new concepts, in close collaboration with the equipment and materials community, to allow for the diversity of compute infrastructure needed, 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 the transistor level: (i) extensions of the scaled Si technology roadmaps (including FD SOI, FinFET and stacked, Gate-All-Around nanowires, 3D versions), (ii) the exploration and implementation of devices beyond Si (TunnelFET, III-V, SiGe, Ge, 2D, CNT, ferroelectric, spin-based) and (iii) novel device, circuit and systems concepts for optimum Power-Performance-Area-Cost specifications, high energy efficiency and novel paradigms like Neuromorphic and Quantum computing.

New memory concepts will be targeted to support the correct memory hierarchy in the various applications. As an example we mention the opportunity to push new transistor and memory concepts (RRAM, PCRAM, STT-RAM) to the demonstration level in the IoT infrastructure (from server, over edge to nodes). A much closer collaboration between the device team and system architects is indispensable in the future. More opportunities are brought by new markets: storage class memory is planned to bridge the gap between DRAM and NAND, Internet of Things applications crystallize the needs for low power embedded devices, cloud and fog computing always need more mass-storage space. The standard memory hierarchy is challenged.

Simultaneously, advanced interconnect, SoC integration and packaging challenges will need to be addressed (cfr also challenges 2 and 3), where innovative solutions to reduce the cost are required. The system performance scaling not only depends on the transistors and memory cells characteristics and their local interconnects but also on the input-output (I/O) interfaces between the computing and memory units or between computing units, usually packaged separately on a board. With staggering demands of the ever-growing graphics applications, all computing systems encounter similar bottlenecks locally within package, within systems or system-to-system. 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.

A strong effort in semiconductor process technology and integration linked with design enablement for circuit and system exploration and demonstration is required in this ecosystem. European effort in Semiconductor process technology and integration and design enablement will allow the industries' designers to make sense of the different technology options and helps technology developers make sense of designer requirements. There is a clear need for collaboration on (open) platforms for IoT, to build partnerships and grow towards standardization to avoid sub-optimal solutions. Therefor all actors need to be on board. It has never been more important for Europe to build leadership going forward in this coming generation of advanced and distributed compute infrastructure and diversified system performance.

For safety or mission critical applications, e.g. Avionics and Space, reliability needs to be addressed and becomes a more and more challenging task. There is an urgent need to develop explicit security and privacy requirements in electronics, with a focus also on finding simple, low cost, energy efficient implementations for security. Effective security will require new technologies incorporated as standard building blocks in all devices and networks. In particular, mobile computing on smartphones and embedded devices present special challenges, given that security provisions must be automated and largely invisible to end users.

3.5. Challenge 2: Semiconductor process technology and integration of devices and components at chip-level and SoC for the complex heterogeneous functionality

3.5.1. High priority R&D&I areas

The smart systems in our applications – from health to smart environments – will rely on advanced components with a very diverse functionality provided by sensors, imagers, power handling components, energy harvesting and storage devices, actuators etc. The process technology and integration challenges are specific. Also the packaging requirements, the power budget restrictions, the manufacturing conditions need to be taken into account specifically in defining the roadmaps of future generations of these components.

Semiconductor process and integration technologies for the realization of industry roadmaps in heterogeneous functionality will require the introduction of novel functional (nano-)materials and advanced device concepts. A non-exhaustive materials list includes wide bandgap materials, III-V and 2D materials, ferroelectric, thermoelectric and magnetic thin films. At the functionality level we seek introduction of innovative RF technologies, integrated logic and embedded NVM, photonics, 3D integration technologies, MEMS and sensor systems. The driver for their integration is always a clear demand from the application domain. To maintain Europe's position, special attention will be given to emerging technologies as they come along as well as to new developments in the equipment and materials industry, in which Europe has a leading position. Early generation of models and their initial validation for benchmarking and IP generation. More specifically the following challenges are identified (non-exhaustive).

Digital functionality is specifically treated in Challenge 1, but it is evident that heterogeneous integration will require specific solutions for related challenges: (i) embedded NV memories for smart functional devices, (ii) energy efficient computing and communication, including focus on developing new technologies, architectures, and protocols. Development of ULP technology platform and design.

Analog functionality will be introduced in systems through e.g. (i) integrated application-defined sensors technologies. With the recent success of on the fields of mmWave sensors and MEMS devices enabled by high volume semiconductor manufacturing capabilities in automotive and consumer applications (acceleration, radar, microphones, starting environmental sensors) the progress will be on further integration, miniaturization and packaging, surface conditioning, structuring and innovation in selectivity. (ii) New RF and mm-wave integrated device options, incl radar (building on e.g. SiGe/BiCMOS, FDX, CMOS); (iii) and the many photonics-enabled device and system options. This is a domain where process technology exploration for functional integration of novel materials (e.g. Graphene, TMDs, Ferroelectric, Magnetic, e.a.) for various application domains is essential. Specific process technology platforms may be requested such as in the case of biomedical devices for minimally invasive healthcare, or mission critical devices in automotive and avionics and space.

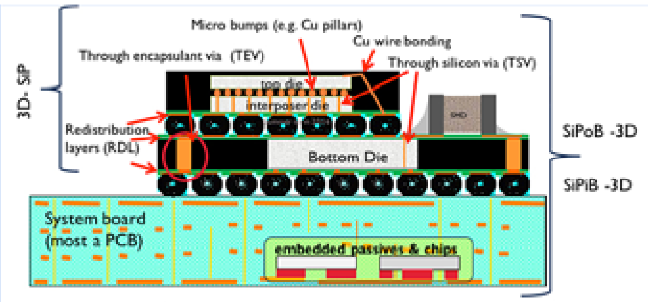
Power devices, energy and power management and energy efficient components and systems are in high demand: (i) power electronics with a myriad of options such as higher power density and frequency, wide-gap materials, new CMOS/IGBT processes, integrated logic, uni- & bipolar; higher voltage classes, lateral to vertical architectures; (i) continuous research on performance, efficiency, power density and reliability aspects – either through further thinning of wafers, topologies and material compositions; (iii) Energy harvesting, as well as microbatteries and supercapacitors, and wireless energy.

Manufacturing specific elements for the heterogeneous integration requires specific focus: (i) cope with high volumes and high quality (for e.g. power semiconductors, sensors and MEMS devices) and (ii) enable flexible line management for high mix, and distributed manufacturing lines. It will also require adapting factory integration and control systems to adopt industrial internet principles to manufacturing environment in Europe, a clear area for synergy with the manufacturing challenge in this agenda.

3.6. Challenge 3: Process technology and integration for advanced smart System-in-Package applications

3.6.1. High priority R&D&I areas

Integration of the above functionalities in (sub-)systems in package requires fundamental insight in the application needs and in the appropriate system architecture. Process technology for the realization of this integration is a third area of focus and is essential for Europe's prominent role in supplying the solutions for the various application domains.



SiPoB = System in Package on Board | SiPiB = System in Package in Board | SoC = System on Chip | SiP = System in Package

For the application fields of AENEAS, advanced system-in-package (SiP) integration capabilities are crucial for Europe. Compared to chip technology, assembly and packaging are becoming of higher value. Today already a portion of the assembly and packaging cost is higher than the chip cost. To tackle this trend, we must focus on SiP process technologies that take into account all the three domains chip, package and system/subsystem-board and find the optimum trade-offs between function and cost. We must set up a European toolbox of process technologies for cost-effective and outstanding system-in-package integration to be sustainable competitive worldwide in respect to system integration.

In addition, miniaturization and increasing functional density for SiP integration lead to increasing importance to consider chip-package interaction. For future devices chip-package interaction as well as the interface to the system/ board need to be taken into account. Special examples are More than Moore devices like MEMS devices which need a careful designed package for optimum performance.

At the macro-scale level, a system can be seen as consisting of a collection of large functional blocks ('tiles', IP blocks). These functional blocks have quite different performance requirements (analog, high voltage, embedded non-volatile memory, advanced CMOS, fast SRAM,...) and technology roadmaps. Therefore, it is of increasing interest to split the system in heterogeneous parts, each to be realized by optimum technologies at lower cost per function, and recombining the system using a high-density 3D interconnect processes. It is clear that 3D integration in electronic systems can be realized at different levels of the interconnect hierarchy, each with 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. We must provide the technology base for 3D stacking as well as horizontal interconnecting of dies, the latter might be needed because of heat dissipation.
- encapsulation technologies, handling carriers as well as panels which on the one hand protect the dies, but on the other hand allow optimum electrical performance. Chip embedding technologies like chip embedding in mold material (e.g. fan-out WLP or eWLB technologies) and chip embedding in laminate material, for both 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 door-opener 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[12]e.
- 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. All the research and development needs a strong link especially to materials research and compatibility. In the last 10 years nearly all assembly and packaging materials changed and in the next 10 years it is expected they change again. Also a close link to the design chapter is crucial. Chip-Package-Board co-design will be of outstanding importance for introducing innovative products efficiently with short time to market.
- 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.

It is very likely that at some point, the capabilities of some 3D integration technologies will overlap, allowing "coarser" technologies to be used for deeper 3D integration applications. One example would be die-to-wafer stacking at very fine pitch for semi-global 3D-SOC applications. System requirements and semiconductor device technology (Challenge 1 and 2) will however also evolve at the same time, creating a momentum for further interconnect pitch scaling for each 3D integration technology platform. The timelines of the 3 Challenges are hence strongly connected.

[12] See the 3D landscape in the chapter 7 appendix

4 EXPECTED ACHIEVEMENTS

The most important achievement for these Challenges is to stay on par with the state-of-the-art of the global technical developments through positioning of European actors as main players in bringing process and integration options to maturity and manufacturing with insights in the actual strengths and weaknesses of the technology with respect to the target applications. This will be done in synergy with the materials and equipment community, a European strength. This should be the outcome of a balanced combination of advanced research projects complemented with Pilot Lines for the validation of new technologies and equipment, including packaging and assembly. Technology research and pilots connect both technology and application communities and can lead to European demonstrators and new IP-related business opportunities. System-technology co-development projects bring early benchmarks of innovative solutions and specific IP to fully exploit technology developments.

Well-focused projects in the TRL 2 to 4 are needed as technology push enabling new applications. Extended projects will aim at Pilot lines with emphasis on TRL 4 to 8 delivering industry-compatible flexible and differentiating platforms for strategic demonstrations and for pushing manufacturing uptake. This will be done in close concertation with the equipment and materials community since heterogeneous functionality requires integration of advanced multifunctional nanomaterials which depends upon the development of new process tools for specific post-processing. New flagship projects focused on employment of advanced multifunctional nanomaterials for new product development can be expected.

Similarly, to allow future generations of SiP hardware in Europe we need world-leading research on TRL3-5 to prepare the proper system integration technologies on the one hand, and pilot line activities of TRL4-7 that allow SiP hardware demonstration. By research and development on proper process e.g. parallel processing similar to front-end technologies, wafer level processing, as well as with increasing automation and logistic European companies can set up an infrastructure to keep SiP manufacturing also in Europe.

Testbeds and demonstration of incorporation of advanced technologies in flagship applications like IoT and its advanced, distributed compute and communication infrastructure, Industry 4.0, Automotive, Consumer, Health and (in the longer term) in new paradigms like Neuromorphic and Quantum Computing.

To ensure that the education builds talent for investments in the future, attention should also be given to university education in close collaboration with the industry in the above fields, for example by means of joined (Academia and Industry) courses, traineeships, and other support actions (including EC grants).

All research and development in this section needs to provide the fundaments enabling EU companies to set up their dedicated process technology toolbox environment tackling their specific applications and to prepare sustainable for their next generation products. This must ensure to keep Europe in a competitive position and keeping high quality jobs in Europe.

5 CONDITIONS FOR SUCCESS

Essential to success is to have major players of the European ecosystem take leadership in defining the larger projects and setting up the pilot lines and demonstration testbeds. This will allow the follow through of the innovations from the lower to the higher levels of Technology Readiness.

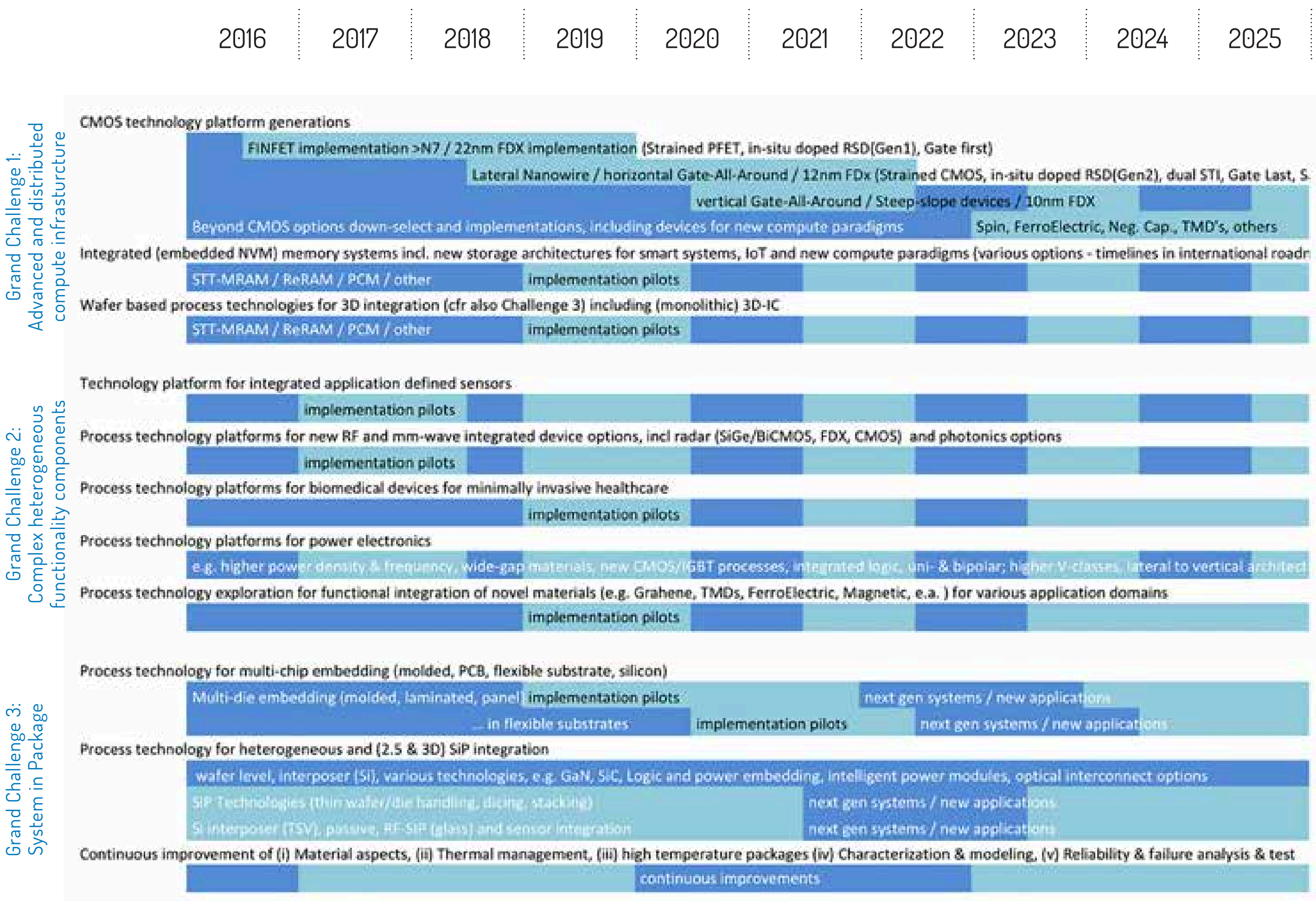
Applications, systems and technology need to be co-developed. A strong synergy between the various roadmaps and technology landscapes is essential to success.

6 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[13] and the recently announced IEEE IRDS[14] in which European academia, RTO's and industry participate. The European R&D priorities are to be planned in synchronization with the global timeframes and developments, which are under continuous adaptation. The timelines below are high-level derivatives from these global evolutions.

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. Areas where the roadmaps are less clear (e.g. new compute paradigms) are not introduced here since timelines are too speculative now. For Challenge 2 and Challenge 3 the timeline of implementation of new technologies largely depend on the systems needs and roadmaps and will result from the interaction within application driven projects and testbed initiatives.

These timelines are supported by landscape views for the different semiconductor processes technologies and integration strategies. For clarity, a selected set of these landscapes is available in the chapter 7 appendix.



[13] NEREID is a Cooperation and Support action (Horizon 2020) to develop a roadmap for the European Nanoelecronics industry, starting from the needs of applications and leveraging the strengths of the European eco-system. In addition, it will aim to an early benchmark/identification of promising novel nanoelectronic technologies, and identify bottlenecks all along the innovation value chain.

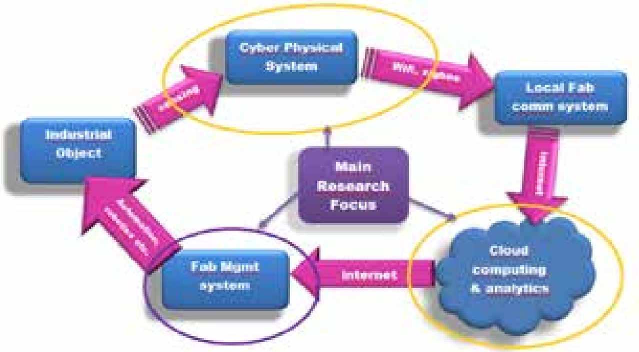
[14] International Roadmap for Devices and Systems (IRDS, announced May 2016), a new IEEE Standards Association Industry Connections program sponsored by the IEEE Rebooting Computing (IEEE RC) Initiative in consultation with the IEEE Computer Society. It intends building a comprehensive, end-to-end view of the computing ecosystem, including devices, components, systems, architecture and software.

7 SYNERGIES WITH OTHER THEMES

Synergies with Equipment and Materials: 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. Semiconductor manufacturing and technology is strongly linked with the other Essential Technologies. Furthermore, it is key to Europe's strong global positions in all application domains (e.g. security, automotive, aircraft manufacturing, power generation and medical/healthcare industries).

Synergies with manufacturing: The goal is to enable cost competitive semiconductor manufacturing in Europe develop new solutions, cost competency and business models that enable a high degree of manufacturing flexibility required by diversified products, while achieving sustainability targets (resource-efficiency and "green" manufacturing) without loss of productivity, cycle time, quality or yield performance at reduced production costs as well as innovative solutions to control the variability and reproducibility of leading-edge processes. A Productivity Aware Design approach and Control System Architectures will be key.

Synergies with the systems and application community: System-Technology co-optimisation is key to all leading edge innovations. Specific actions include: Specification of technology and product roadmaps for the planning of future products, Advanced access to new technologies for prototyping, Cooperation on development of dedicated technologies, advanced access to testbeds 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, compute 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, we need to consider the integration of the whole system. Thus, we should not restrict our scope to semiconductor devices; instead, we need to combine research in all key domains of which the Industry 4.0 is composed and the importance of a consolidated effort cannot be overemphasized.



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 enforced. The number of technology options, each with its own challenges, explodes. Early and quantitative assessment of the gains, issues, and risks is key to maximize the value of this technology for a given application. Likewise, technology development faces the same challenges to deliver a technology that suits the purposes of designers. Specific focus 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 device in package integration with the modelling of thermal, mechanical and EMI effects. Use 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 optimized properties.

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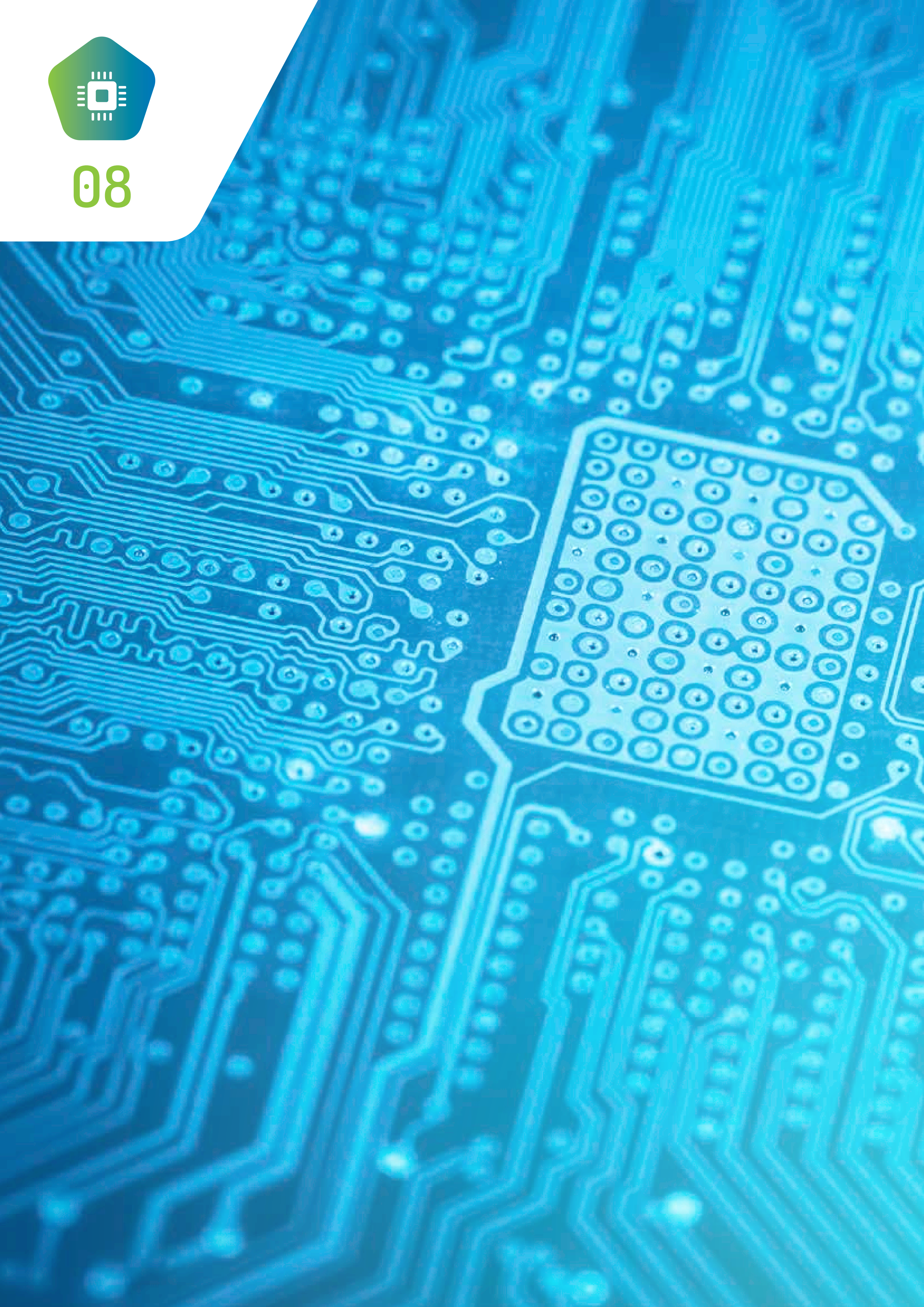


1 EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

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 which 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 semiconductor equipment and semiconductor materials sectors employ in Europe more than 100 thousand individuals, the majority of them in high education level jobs.

Thanks to international collaborative research projects involving semiconductor manufacturers, solution providers and academics, Europe has acquired a high level of excellence in manufacturing science. Maintaining this level of excellence is of paramount importance for keeping competitive semiconductor manufacturing in Europe.

European research centers, such as IMEC (Interuniversity Microelectronics Centre), CEA-LETI (Laboratoire d'électronique des technologies de l'information), Fraunhofer institutes and TNO (Toegepast Natuurwetenschappelijk Onderzoek), offer world-leading process and equipment development capabilities and involvement in transnational development projects.

Europe's semiconductor manufacturing industry mainly serves electronics and system markets in which Europe already holds strong global industrial positions, for example, the automotive, aircraft manufacturing, power generation and medical/healthcare industries. Therefore, its semiconductor technology strengths are also in these domains, i.e. chip development and manufacturing in automotive, power, healthcare, security and safety.

2 RELEVANCE

2.1. Competitive value

The value of the Equipment & Materials (E&M) industry for Europe is twofold. Firstly, E&M products address large multi-billion Euro, self-sustaining markets. Based on their technical excellence, European E&M companies have achieved world-leading positions in several global market domains, and therefore constitute a powerful engine for European economic growth by themselves. Their world market share is about 20 percent. Secondly, the products and technologies developed by European E&M companies exhibit high leverage potential for Europe's core industries. Hence, the research and development activities of Europe's E&M companies strengthen its capability to maintain and develop a profitable and sustainable semiconductor manufacturing base of key strategic relevance, both in economic and societal terms.

Accordingly, close interaction between the E&M industry, European chip manufacturers and research institutes is required to develop E&M that serve the semiconductor industry - for example, providing low cost and energy efficient manufacturing and tailored E&M solutions. Figure 2 illustrates the international status of Europe's E&M industry. Its sales have reached 20B€, which is about 40 percent of the whole European semiconductor industry.

2.2. Societal Benefits

The European E&M industry enables the semiconductor industry to provide new products for sustainable growth, specifically in the domains mobility, energy efficiency, health care, security and increasingly for smart systems and smart societal solutions. With its highly-educated workforce, it can provide solutions and innovations that are keys for success in several other technology-based European industries. Combining the ability to leverage a large home market with success, Europe's E&M industry, being mainly based on innovation and knowhow generation, significantly contributes to Europe's economy. Due to global networking it has excellent potential for future revenue and employment growth.

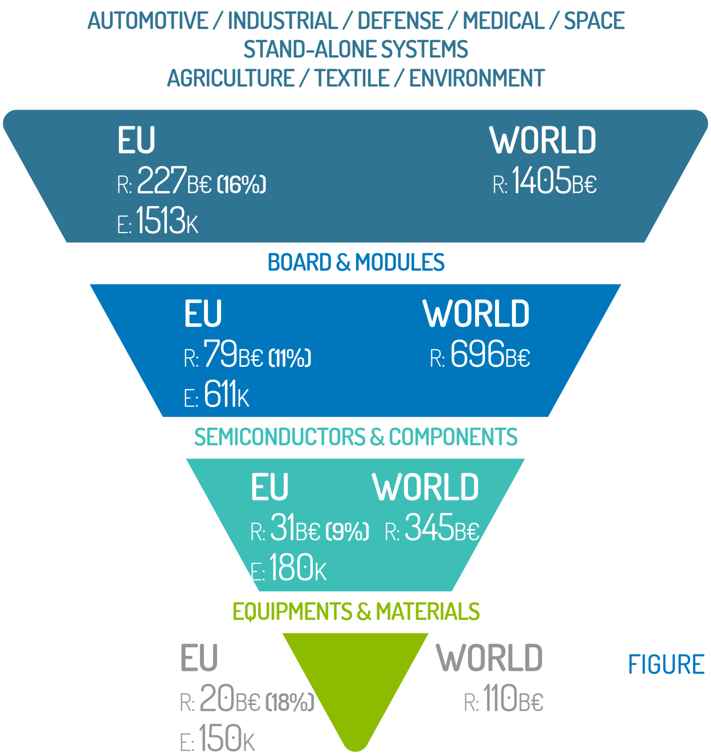


FIGURE 2 / *Digital value chain: Europe's strength and weaknesses (K. Rouhana: Status and Next Steps for Europe's Electronics Strategy, SEMI Industry Strategy Symposium (ISS Europe), Nice, March 8, 2016*

3 GRAND CHALLENGES

3.1. Grand Challenge 1: More Moore Equipment and Materials for sub 10nm technologies

3.1.1. Vision

Develop European know-how for advanced Equipment, Materials & Processes for sub-10nm semiconductor devices & systems manufacturing.

3.1.2. Description

This Grand 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 to supply the world market with technology leading and competitive products.

The overarching goal of the equipment and material development is to lead the world in miniaturization techniques by providing appropriate products two years ahead of the shrink roadmap of world's leading semiconductor device and components manufacturers. Internationally agreed roadmaps such as the ITRS (International Technology Roadmap for Semiconductors) and its successors will also be taken into consideration.

Accordingly, research and development is needed to facilitate innovations for, among others:

1. Advanced lithography equipment for sub-10nm wafer processing using VUV and EUV, and corresponding sub-systems and infrastructure, and mask manufacturing equipment for sub-10nm mask patterning, defect inspection and repair, metrology and cleaning.
2. Advanced holistic lithography using VUV, EUV and NGL techniques such as e-beam and mask-less lithography, DSA and Nano-Imprint.
3. 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 big data support with predictive methodologies.
4. Thin film processes including thin film deposition, such as (PE)ALD and PIII for doping and material modification, and corresponding equipment and materials.
5. Equipment and materials for wet processing, wet and dry etching, thermal treatment, and wafer preparation.
6. Si-substrates, Silicon on Insulator substrates, SiC, III-V materials, advanced substrates with multifunctional layer stacking, including insulators, high resistivity bulk substrates, mobility boosters, corresponding materials, manufacturing equipment and facilities. More details are available in the chapter 8 appendix.

3.1.3. Competitive Situation

In E&M for advanced CMOS, Europe has a world leading position in several areas, foremost in lithography, metrology, and material deposition techniques, as well as in silicon and advanced substrates. Europe's E&M manufacturers generate most of their revenues in these areas. Intention is to defend and expand the market position by continuously investing in research and development on new advanced products. This will create new commercial opportunities and will contribute in securing and generating highly skilled jobs.

3.1.4. Expected Achievements/ Innovation Foreseen

Ambition of the European E&M industry for advanced semiconductor technologies is to lead the world in scaling by supplying new equipment and new materials approximately two years ahead of the volume production introduction schedules of advanced semiconductor manufacturers. For instance, in the next timeframe European lithography systems suppliers will have to provide solutions for sub-10nm patterning for high-volume high-yield manufacturing (see attached roadmap). The corresponding mask technologies and the respective infrastructure have to be made available. Comparable challenges to wafer metrology and deposition equipment have to be met too, to secure future competitiveness in these domains.

3.2. Grand Challenge 2: More-than-Moore Equipment and Materials

3.2.1. Vision

Strengthen European competitiveness by developing advanced More-than-Moore (MtM) Equipment, Material and Manufacturing solutions for front-end-of-line (FEOL) and back-end-of-line (BEOL) wafer processing, and device assembly and packaging (A & P).

3.2.2. Description

More-than-Moore (MtM) technologies will create new technological and business opportunities and demand new skills and know-how 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 sensors including MEMS (Micro-Electro-Mechanical Systems), Advanced Imagers, power electronics devices, automotive electronics, 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 generalize the concept of distributed manufacturing. This will require the development of new concepts for Information and Control Systems (see Grand 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 new equipment will be required for future A&P, creating new R&D challenges and new business opportunities. Over the last decade, nearly all assembly and packaging materials have been replaced by more advanced materials - a process that is ongoing. This will have a strong impact on future processes and equipment.

More-than-Moore will pose significant challenges and therefore requires R&D activities in a multitude of fields. Equipment and material research must tackle the general technology trends in respect to miniaturization and integration of more functionality into smaller volume. Application dependent reliability and heat dissipation are of high importance. Examples for necessary research on new equipment and materials will be on:

1. 3D integration technologies (e.g. chip-to-wafer stacking),
2. Chip embedding technologies (e.g. fan-out WLP),
3. Vertical (e.g. TSV or micro flipchip bumping) and horizontal interconnects (e.g. RDL, thin film technology),
4. New processes (e.g. reliable die attach, thinning, handling) for reliable as well as heterogeneous system integration technologies
5. New materials and equipment enabling novel sensor concepts (e.g. for chemical, bio or light sensing)
6. Failure analysis, and in-line and off-line metrology

An overview of technical details is available in the chapter 8 appendix.

3.2.3. Competitive Situation:

Europe's equipment and materials manufacturing companies supplying the MtM market have strong market positions in selected sectors, for example in engineered substrates, chip testing, bonding or backend patterning.

A & P materials are currently dominated by Japanese and US companies.

There is a consolidation in the industry and there are possibly other major changes, such as a movement towards multiple-ownership fabs or towards foundry models. The rapid obsolescence of first-generation (2000-2006) digital 300mm fabs will force these fabs to find other opportunities for business in specialized digital niche markets and within the MtM space. 300mm fabs will try to catch more market share. The 300mm conversion for MtM lines will therefore be a key challenge over the coming years.

Note that the trend towards MtM increases opportunities for SME's to enter the market with new products e.g. on metrology and services.

3.2.4. Expected Achievements/ Innovation Foreseen:

More-than-Moore processes and E&M can be partially sourced from previous-generation CMOS infrastructures. However, new technology generations will also require capabilities which are not yet available in advanced CMOS fabs.

Today's MM equipment is designed for high-volume continuous production. The performance of future MtM production tools must be enhanced for smaller lot production providing high flexibility and productivity at low Cost-of-Ownership (CoO). This requires major modifications to existing equipment or their re-design.

European E&M companies must target the provision of equipment and materials for manufacturing of devices such as sensors, MEMS, power electronics, RF, and bio-tech devices according to market needs.

Furthermore, the 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 equipment.

In order to create an industry-wide basis for technology development, it is very important to continue with the roadmap definition process for MtM, including corresponding actions and standardization processes.

3.3. Grand Challenge 3: Manufacturing

3.3.1. Vision

Develop new fab manufacturing and appropriate E&M 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.

3.3.2. Description

The Grand 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 new wafer fab management solutions that support flexible and competitive semiconductor manufacturing in Europe, as well as supplying the world market.

For that, aspects of Industry4.0 need to be incorporated, with 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 loss of productivity, cycle time, quality or yield performance, and for reduced production costs. A key will be to invest in people's skills and competency to adapt work-flows to new, data-driven manufacturing principles.

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 interconnected. Moreover, blurring of the frontiers between these domains will require considerable consolidation of knowledge capitalization and exchange of knowledge. Factory Integration and Control Systems will have to become modular, allowing information to flow between factories in order to facilitate rapid diagnostics and decision making, also through BYOD (Bring Your Own Device) concepts. The focus of high-mix/low-volume manufacturing will be on flexible line management for high mix, and possibly distributed manufacturing lines. New manufacturing techniques combining chip and packaging technologies (e.g. chip embedding) will also require new manufacturing logistics and technologies (e.g. panel molding etc.).

FIGURE 3 / 300mm wafer fab (Copyright ©Artechnique)

To achieve this, new fab management and equipment solutions will be required in several fields. An overview is available in the chapter 8 appendix.

3.3.3. Competitive Situation

While challenges in the manufacturing domain are similar for More Moore and More-than-Moore fabrication, their initial positions and constraints are different: MM equipment and solutions are delivered at a much higher grade of automation compared to depreciated equipment and grown solutions of MtM fabs. Thus, MM fabs' automation can be much easier brought to the next level of automation. Beyond that, standardized solutions, interfaces and respective software solutions, often provided by worldwide active "large" companies, are more easily available for MM fabs.

For MtM fabs, the situation is more diverse: Often, only partial (and sometimes "island") solutions are available, many of them comprising "home-made" elements and commercial parts, introducing the need for specific interfaces. Currently, no provider for a comprehensive MtM fab solution is on the market. This gives opportunities for SMEs to penetrate the market, which is actually ongoing to some extent.

Success in introducing the next level of manufacturing science solutions is of paramount importance especially for European MtM fabs to stay competitive on the world-wide market.

Further opportunities will emerge from the drive towards "Industry 4.0" in other industrial branches: cross-fertilization is expected between solutions for semiconductor manufacturing and other manufacturers of high-value products, especially in the area of data-driven manufacturing optimization (including big-data, machine learning, prediction capabilities etc.).

3.3.4. Expected Achievements/ Innovation Foreseen

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, defectivity, functionality) will be needed.

New developments in equipment, materials and manufacturing should support flexible and competitive semiconductor manufacturing in Europe, as well as competitiveness in the world market. Therefore, future innovations need to enable solutions for productivity improvement (even at low production volumes), resource saving, energy-efficiency improvement, as well as world-class performance in terms of quality, yield and cycle time in the full manufacturing spectrum of semiconductor fabs. In particular, any potential for cost reduction should be leveraged in order to compensate for some of Europe's cost disadvantages (e.g. its higher labor and environmental costs). Of great importance will be to develop generic solutions for current and future fabs that allow high-productivity production of variable size, and energy-efficient, sustainable, resource-saving volume production.

For example, a successful outcome would be the creation of high-performance computing systems for process control that are useful for multiple European companies. Accordingly, focus topics should include, among others, 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.

4 CONDITIONS FOR SUCCESS

Due to its profound competences in mechanical engineering, tailor-made machinery, optical equipment, and chemical processing tools, and its world-leading market position in several areas, Europe has an excellent opportunity to remain a leader in several sectors of the worldwide E&M industry, and to gain further market share. However, timing is of the essence, and high technology risks have to be taken and upfront investments have to be made.

European excellence in lithography, metrology and deposition processing tools already support the semiconductor industry worldwide and contributes to job sustainability and job creation in many adjacent industries within Europe. In moving forward, one of the key conditions for success will be the establishment of collaborative initiatives between actors in the European E&M and semiconductor manufacturing industries, specifically in relation to lithography, metrology, deposition and wafer substrate processing. This will lead to better understanding of future technical needs and corresponding solution options, resulting in optimally tuned solutions of world-class standards. The ability of Europe's semiconductor and E&M industries to leverage synergies in domains such as photovoltaics, LEDs and photonics will also be important.

A key element of the technological leadership and business success of Europe's E&M industry is R&D collaboration at test-bed and pilot lines. Test beds in this domain will give SME's the opportunity to evaluate and optimize their products under operational conditions prior to market introduction. Pilot lines will allow advanced process integration to take place in an environment where interoperability standards can be implemented and proven and will also foster the development of future processing equipment.

5 TIMEFRAMES

5.1. Grand Challenge 1: More Moore Equipment and Materials for sub-10nm technologies

The sub-10nm patterning solutions to be developed in the Grand Challenge “More Moore Equipment and Materials for sub-10nm technologies” will need to be available two years ahead of the point in time at which advanced semiconductor manufacturers will start the high-volume IC manufacturing at the corresponding node.

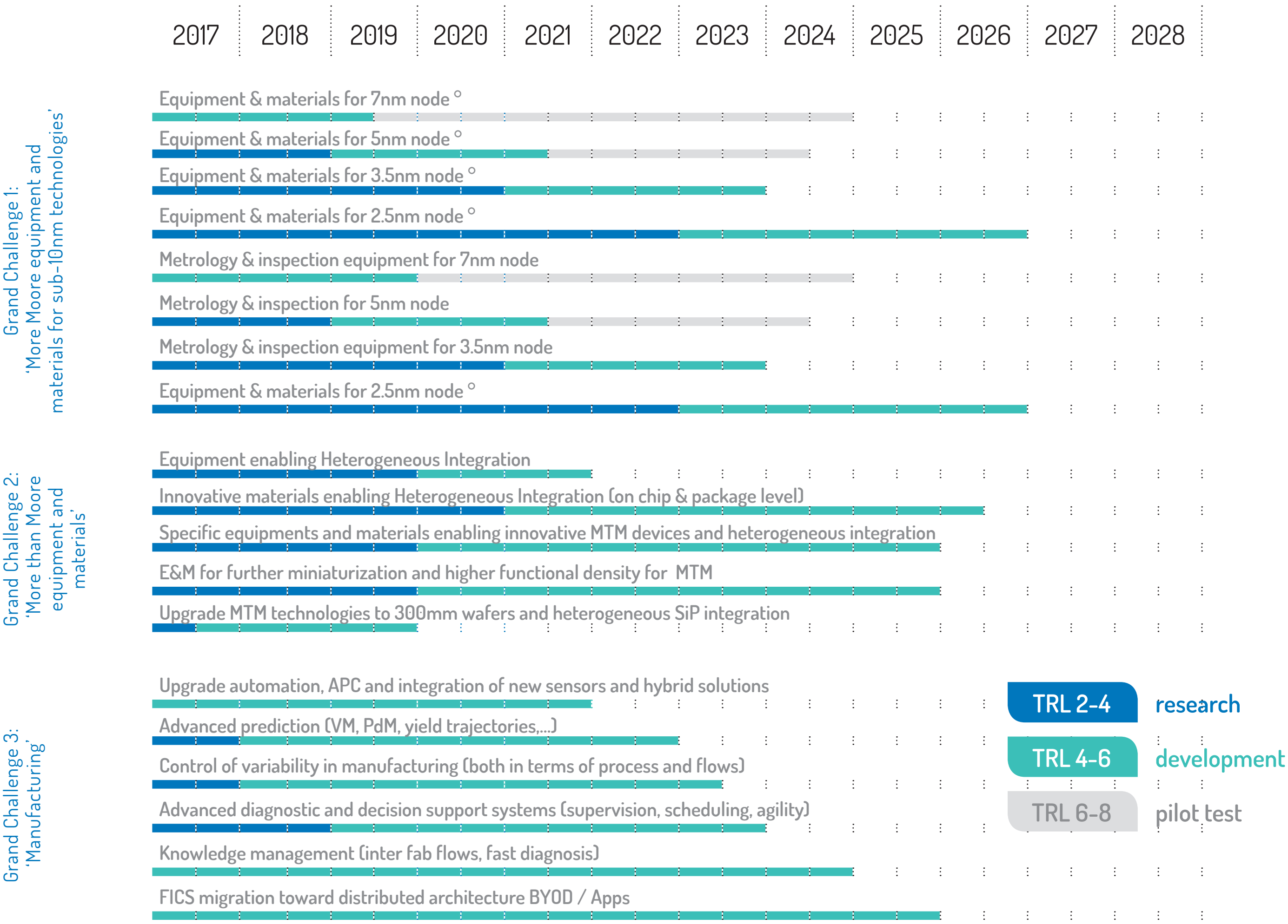
5.2. Grand Challenge 2: More-than-Moore Equipment and Materials

The timing of new E&M solutions for the Grand Challenge ‘More-than-Moore’ should be derived from the schedules of the major European semiconductor manufacturers. Of course, also the updated More-than-Moore roadmap for devices and technologies need to be taken into consideration.

The MtM roadmap outlines roadmaps for key future semiconductor domains, such as automotive, health care, safety and security, power, MEMS, image sensors, biochips, lighting etc. Fast implementation and adaptation of these new device technologies will pave the way for the More-than-Moore technologies of tomorrow.

5.3. Grand Challenge 3: Manufacturing

New E&M solutions for the Grand Challenge “Manufacturing” should be developed according to the market needs defined in the More Moore and MtM roadmap and enhancing state-of-the-art manufacturing practices. Improving manufacturing efficiency, and enhancing yield and reliability are on-going tasks that need to be performed in accordance with the needs of the ‘More Moore’ and ‘More-than-Moore’ domains.



° Mask technology always 1.5 years ahead wafer technology
VM - Virtual Metrology, PdM - Predictive Maintenance, BYOD - “Bring Your Own Device”, FICS - Factory Information and Control System; Logic nodes definition

6 SYNERGIES WITH OTHER THEMES

All these Grand Challenges clearly exhibit synergies with the domains 'Semiconductor Process and Integration' and "Smart Production". Furthermore, synergies exist with the 'Design Technology' domain, in particular between More-than-Moore and package modelling, but also in the areas of design-for-test, and design-for-test tools. Furthermore, there is synergistic potential with domains such as photovoltaics, LEDs and photonics, which should be increasingly leveraged.

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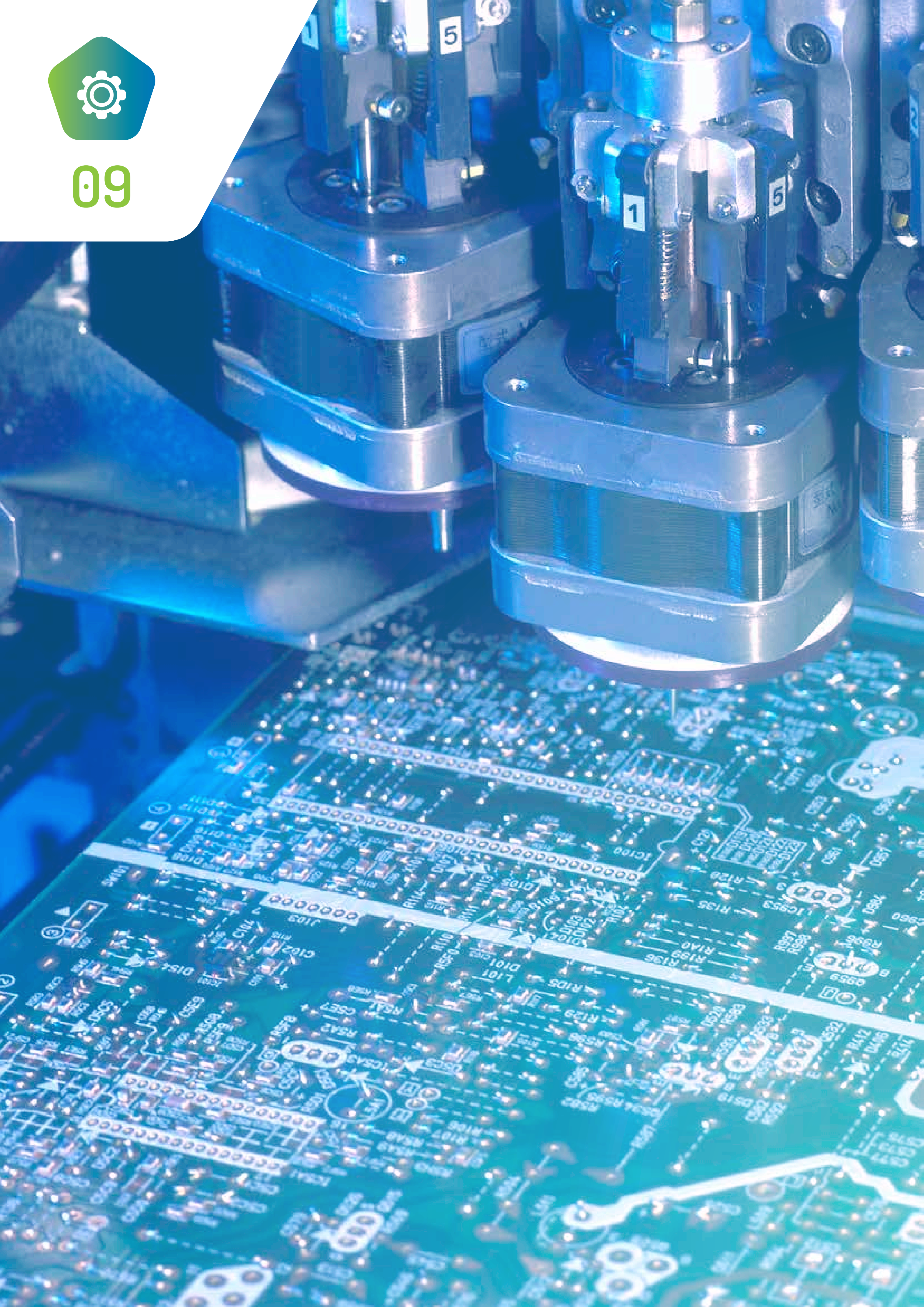

1 EXECUTIVE SUMMARY

EXECUTIVE SUMMARY

The development of new production technologies for digital automated production is essential for strengthening European leadership in production technologies and precondition for the re-industrialization of Europe. The Aeneas focus on 'Production Technologies' is the automation and digitization of European industrial production by means of advanced electronic components and systems (ECS). The approach covers horizontal integration of technologies for digital production planning and control within the factory or company as well as the integration of all supply chain partners along whole supply chain or covering complex supply chain networks.

A revolution in European industrial manufacturing requires extensive R&D in the area of production technologies. Chapter 9 identifies three Grand Challenges which have to be addressed by the European R&D community until 2030. These Grand Challenges in production technologies are:

Grand Challenge 1	Digitising the production
Grand Challenge 2	Connecting the digital production value chains
Grand Challenge 3	Development of cross-cutting technologies

PRODUCTION
TECHNOLOGIES

2 RELEVANCE

2.1. Competitive value

The digitization of European industry will have an impact on all areas of industrial production, lead to significant increase in efficiency and enable and create new production processes and scenarios. Digital product design, digital supply chain management and digital manufacturing will allow highly time- and resource efficient production. Additionally, production planning and control will refer to the whole production process and product life cycle. Covering the whole product life cycle including the product application phase enables manufacturing more individual products and further development of products according to market needs e.g. through providing continuous functionality updates and preventive maintenance. As a result, products can be maintained state-of-the art for a longer timeframe. Increased lifetime and addition of functions enables resource-friendly, sustainable use of products and may influence user behavior on a long term perspective. Within the factory automated production control enables more flexibility and tailoring of diverse individual product versions. Data collection and exchange will allow collaboration manufacturing of all supply chain partners within a supply chain network.

According to recent market studies Europe's industrial countries can achieve additional revenues in the range of 1.25 trillion € until 2025. PWC predicts investments of 40 billion € per year until 2020 and with increasing digitalization of the supply chain an increase of production efficiency of 18% as well as an additional revenue of 30 billion € per year. Industry and industrial manufacture are the backbone of Europe's economic strength with European companies as leaders in many world markets. If Europe wants to maintain its leadership and competitiveness towards USA and Asia is must not only take part in the digital transformation but lead it.

Relevant aspects strengthening the European industry's competitive position in this context are:

- increased productivity and improved OEE (Overall Equipment Effectiveness)
- improved production stability enabling and improving consistent quality and delivery reliability
- optimal effective usage of resources along the whole supply chain
- automated coverage of the entire product lifecycle management
- possibility to response to customers' individual desires and requirements
- cost effective digital production and effective digital supply chain management
- enhanced cost-effectiveness of manufacturing low volumes (lot size one)
- Creation of new services, work and business models

2.2. Societal Benefits

Industrial production is the backbone of European economy and society. Effective production is a requirement for economic growth, material prosperity and social security. To be effective and sustainable, production must adapt to environmental and social changes and challenges. Modern production must e.g. fulfil recently developed environmental standards and regulations, serve the customer's desire for more individualized products while being competitive with delivery times of traditional mass production. The adaption of new challenges and the change of production means and methods is a continuous process, which can only be realized with the support of research and development in the field of production and process technologies. Nanotechnologies are key enabler for innovative production technologies, which serve the requirements of future societies.

The development of production technologies for digitizing European industry will have diverse societal impacts:

- Digitalization of industry will foster the re-industrialization of Europe
- Digital production will enable new work models and structures
- Automated production will free employees of exhausting, dangerous work and routine tasks of traditional production
- Digital production will create a need for qualified high potentials and skilled employees and lead to creation of new job opportunities
- Development of innovative production technologies will create new business opportunities for European small, large and medium enterprises
- Automated, time and resource efficient production is precondition for environmental friendly and CO2 reduced industrial production in Europe
- Production will become an agile part of society meeting its requirements for customer integration, flexibility and diversity

In this process, the sector of Nanoelectronics can act as a role model for other industries.

2.3. Competitive situation

Manufacturing represents approximately 21 % of the EU's GDP and 20 % of its employment, providing more than 30 million jobs in 230 000 enterprises, mostly SMEs[15]. Moreover, each job in industry is considered to be linked to two more in related services. European manufacturing is also a dominant element in international trade, leading the world in areas such as automotive, machinery and agricultural engineering. Today, however, it faces intense and growing competitive pressure on several fronts. US, Korea and Japan pose the greatest threat on high-tech sectors, while manufacturing in more mature sectors is increasingly migrating to low-wage countries such as China, India and South-East Asia.

After the general downturn in 2008, European manufacturing has reached pre-crisis values in 2014, but the European share in world manufacturing value has been constantly decreasing, from about 30% in 2004 to just above 20% in 2013, and, what is more critical, also the share of manufacturing value added has been decreasing[16], related to a decreasing position in high-tech sectors.

Restoring growth and achieving sustainability require a strategic shift in Europe towards the creation of high added value, based on a greener and sustainable economy. Since 2010, the Commission focused on promoting an integrated industrial policy for the globalisation era, by prioritizing competitiveness and sustainability[17], which led to the Fab-of-the-Future Public-Private Partnership.

The strengths of European industry are in the long-lasting industrial culture, with large networks linking all the supply chain, the availability of a European Nanoelectronic industry with a strong specialization towards industrial technologies, leading-edge research capabilities leading to high levels of knowledge generation and a reputation for scientific excellence and the propulsive force of SMEs, which typically exhibit greater flexibility, agility, innovative spirit and entrepreneurship

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http://ec.europa.eu/research/industrial_technologies/innovation-in-manufacturing_en.html, 10.06.2016.
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3 GRAND CHALLENGES

A revolution in European industrial manufacturing includes three main challenges which have to be solved in a common approach:

- Grand challenge 1: Digitizing the production
- Grand challenge 2: Connecting the digital production value chains
- Grand challenge 3: Development of cross-cutting technologies

Nanoelectronics will enable the vertical integration of digitized and highly automated control and communication processes and systems within the factory. Technologies like smart sensors and actuators, labelling technologies, autonomous robots and automated control will enable digital production with minimum human interference (1). HW-based Big-data handling, real time communication and automated decision making will allow process virtualization and interconnection of different digital production value chains (2). With the increase of automated processes and the decrease of human interference and decision-making all systems must be fully fail-operational to component level. Safe and secure component and system architectures for fail-operational behavior, deep machine learning, fast secure data processing units for encryption and decryption in real time and secure authentication, identification modules for automated access and rights management are only few of the required cross-cutting Nanoelectronics based technologies which need to be developed (3).

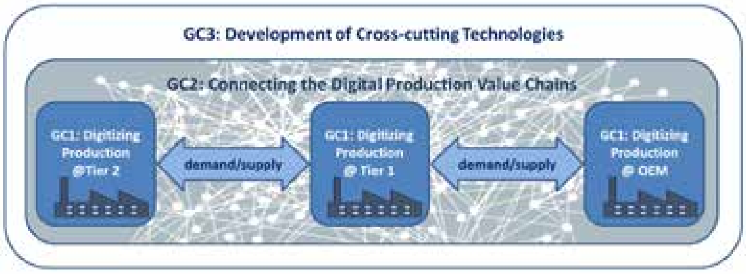


FIGURE 1 / Interrelation of Grand Challenges (GCx) in Production Technologies

3.1. Challenge 1: Digitizing the production

3.1.1. Vision

By means of Nanoelectronics it will become possible to realise “end to end solutions for automated processes in manufacturing”.

Through this production processes become predictable, more precise and faster, the manufacturing stability and therefore a consistent quality can be improved and the utilisation of the manufacturing equipment increases.

3.1.2. Scope and ambition

The grand challenge1 ‘Digitizing the production’ aims to support the vertical integration of digitized and highly automated control and communication processes and systems within the factory.

That ultimately means the consistent integration of Industry4.0 and IoT technologies at any industrial domain in Europe.

To achieve this, it is not sufficient simply to stick to the implementation of existing Nanoelectronics components. Innovative and smart ECS are urgently needed. That will give research and development in Europe a push.

In order to meet the functional and non-functional demands of the digital production innovative ECS are desired to enable high performant and automated sensing, communication, security handling, knowledge management, automated decision-making, efficient control and actuation and much more.

Especially the introduction of autonomous processes in critical production environments will significantly increase the demand for fail-operational electronics at component, module and system level.

The ambition is to produce more efficient, reliable and in higher quality than anyone else in the world.

3.1.3. High Priority R&D&I areas

Sensor related

- Smart sensors with IoT-interfaces, high precision sensors, combined sensors easily to integrate and to configure

- Semiconductor-based energy harvesting for smart sensor nodes
- Wireless real-time sensor networks in challenging environments
- Smart MEMS (Microelectromechanical systems)

Actuator related

- Labelling technologies like RFID
- Autonomous robotics
- Additive Manufacturing

Software related

- Simulation and virtualization of control processes, logistics, flows
- Improvement of enterprise efficiency and flexibility, OEE
- Enhanced production planning, security and increased utilisation of production capacities

System related

- Production technology development using innovative ECS and related migration concepts
- Integration of legacy equipment, processes and tools
- Plug&produce agent based equipment for production
- Innovative Actuators; energy efficient robust power semiconductors and technologies
- High performance embedded multi- and many-cores with application specific accelerators
- Embedded systems on chip and 3D-integration – chip stacking
- Collaborative production
- Enabling of collaborative automation environments comprising both human and technology

3.1.4. Expected Achievements/ Innovation Foreseen

Comprehensive ECS-based (electronic component and systems) solutions for production technologies will foster the transition of European industry to an efficient digital industry which will to enhance the global competitiveness.

There is the unique opportunity that disruptive automation and production technologies from Europe will create a huge potential for new electronic systems and products and for setting industrial standards.

It is expected to make an important step forward in automation the production, improving line flexibility and controllability / traceability and enhancing the availability.

Standardized processes and interfaces will foster the introduction of new partners, services and business models and especially a high SME-involvement.

Not only traditional industries will benefit from these innovations the building of new cross-domain ecosystems is expected. This will enable new generation of innovative products made in Europe.

Crucial for the success will be robustness to industrial production environments, interoperability, validation and standardisation, and last but not least security capabilities of ECS.

Examples of innovative production technologies based on ECS are: secure real-time networking, cyber-physical production systems, human-machine interaction, autonomous manufacturing equipment, advanced sensor systems, high-integration manufacturing technologies, integrated additive and subtractive manufacturing processes, high-speed closed-loop control and traceability technologies.

Production technologies, which will directly benefit from new ECS are example: technologies to realise collaborative automation, cloud services, virtual world, big data handling, autonomous processes, adaptive and predictive control, computing (multicore), connectivity in real-time, complex event processing, real-time data analysis, and forecasting of complex scenarios.

3.2. Grand challenge2: Connecting the digital production value chains

3.2.1. Vision

Well-designed and coordinated supply chain networks can operate highly efficient like a "Virtual Company" for the benefit of all production partners.

Nanoelectronics offer the decisive advantage for the implementation of high performant networking supporting automated processes.

This will be a precondition for a fair, transparent, resource-saving and therefore sustainable management. Such ecosystems will generate a significant competitive advantage for the European industry.

3.2.2. Scope and ambition

The ambition of Grand challenge 2 'Connecting the digital production value chains' is to research and provide ECS, which support the efficient secure communication in Supply Chain Networks (SCN) using attractive concepts like automated decision making, automated order and contract handling, order driven manufacturing and predictive production planning.

ECS and IoT-Components urgently required for this horizontal integration of European Value Chain networks addressing aspects like:

- "virtual company"-efficient highly automated supply chain management along the entire supply chain in order to:

- improved coordination of process steps between supply chain partners,
- improved logistics,
- better production planning and prediction,
- automated order handling, automated decision making and contract handling
- Automated Supply chain management
- Product lifecycle management
- Handling of legacy equipment, processes and tools
- instant access to a digital and virtual dynamic factory
- automation system for distributed manufacturing
- Additive and subtractive manufacturing technologies integrated in real production chains

3.2.3. High Priority R&D&I areas

Hardware

- Hardware-based security
- HW-based big-data handling
- HW-based real-time communication between supply chain partners
- HW-supported automated decision making: order driven manufacturing and automated contract handling

Software

- Process virtualization: Production Planning and prediction
- Cloud-computing
- Enhanced production planning, security and increased utilisation of production capacities

Legacy

- Handling of legacy equipment, processes and tools

3.2.4. Expected Achievements/ Innovation Foreseen

Digital Twins

One specific topic of SCM (supply chain management) in I4.0 is the creation of a digital twin. This concept is crucial for the benefits of supply chain members and users. Today digital twins are implemented in cell phones to map production and life time cycles. In future each complex technical product (cars, machinery, equipment ...) will have its digital twin to track production and usage data. This will greatly facilitate the service, maintenance and upgrading of products.

Electronic components and systems (ECS)

The communication along the value chain will be performed by ECS that monitor and record each movement, process step and external influence on the product. Europe can use its strength in MEMS and electronics industry to provide the necessary ECS. This will provide a growth market for the respective European industries. In the past these ECS have been pushed in several waves and established Europe as a leading supplier. The first wave was automotive applications, the second mobile applications. It is assumed that the IoT/I4.0 will give rise to the third wave in the near future.

Infrastructure of CPS (cyber-physical systems)

Large amount of information needs to be handled in real time driven by ubiquitous sensors and other sources of data. This will lead to the creation of an infrastructure of CPS. The required hardware and know how needed for data aggregation and processing will have benefits for establishing a reliable cross European ecosystem.

Cloud services

For tracking of the manufacturing flow described above a storage media such as cloud services is mandatory. In addition, the whole life cycle of the product will be part of the data set. Thus, the consumer will be involved to a much larger degree in order to get information from the market. This may give rise to concerns about the "transparent consumer" in particular with an information leakage to entities located overseas. These concerns can be mitigated by a pure, secure and reliable European network of cloud services.

3.3. Grand challenge3: Development of Cross-cutting technologies

3.3.1. Vision

Through the application of Nanoelectronics, the necessary conditions will be created to implement and operate complex automated production ecosystems in a reliable, robust, safe and secure manner.

3.3.2. Scope and ambition

The scope of Grand challenge 3 'Development of Cross-cutting technologies' is to serve the first two challenges dealing with vertical integration within the factory and horizontal integration across the value chains with essential cross-cutting technologies and ECS-based solutions applicable in both. As in the first two challenges, developed technologies and methods are expected to be almost cross-domain.

The spectrum of cross-cutting technologies ranges from EMC performance of Nanoelectronics components, security capabilities to standardization and certification.

A new characteristic of production environment is the "24h on" aspect. The infrastructure and the equipment run always or are in operational readiness all the time except from maintenance or re-configuration downtimes.

Thus, safe and secure operation of autonomous systems and components without negative interaction with human operators becomes a major task.

The autonomous production systems and the applied ECS have to behave 'Fail-operational' and should have self-learning capabilities. 'Fail-operational' system behavior is not only a matter of redundancy concepts but requires test, monitoring and repair strategies from component to system level.

3.3.3. High Priority R&D&I areas

Automation

- Embedded processors and HW-accelerators supporting deep machine learning and artificial neural networks
- Simulation and virtualisation
- Autonomous decision making
- Industrial Internet of Things
- Autonomous robotics
- Automated decision making
- Rapid or virtual prototyping
- Deep machine learning

Safety & Reliability

- Safe and secure component and system architectures for fail-operational behavior
- redundancy concepts
- system health monitoring
- EMC, EMI- system design
- Extended reliability and lifetime of components
- Enhanced robustness against environmental parameters

Security

- Dynamic and adaptive security concepts
- Secure authentification, identification modules for automated access and rights management
- Fast secure data processing units for encryption and decryption in real-time

Big Data Handling

- HW supported analytics of Big Data (e.g. HW accelerators)
- HW based storage, compression and distribution of Big Data
- Cloud Computing
- Distributed local clouds

3.3.4. Expected Achievements/ Innovation Foreseen

The production environments and industrial infrastructures will be 'always on'. We will have to operate systems which run 24h a day. The different infrastructures will be interlinked and will be remote accessible. The required security services like fast data encryption and decryption in real time, rights management, identification, and authentication will be in place for industrial usage. A first spectrum of fail-operational nanoelectronics technology at component, module and system level will be available. Embedded high performance multicore processors with HW-accelerators will support deep machine learning using artificial neural network infrastructures for mixed critical applications. Certification and qualification processes have been established in the design processes of nanoelectronics at the different levels component, module and system. We expect standardisation initiatives and de-facto industrial standards for ECS out of Europe.

The technological evolution of cross-cutting aspects like reliability and predictable lifetime will strengthen the semiconductor sector in Europe in a sustainable manner and will enable autonomous production processes even in critical industrial environments.

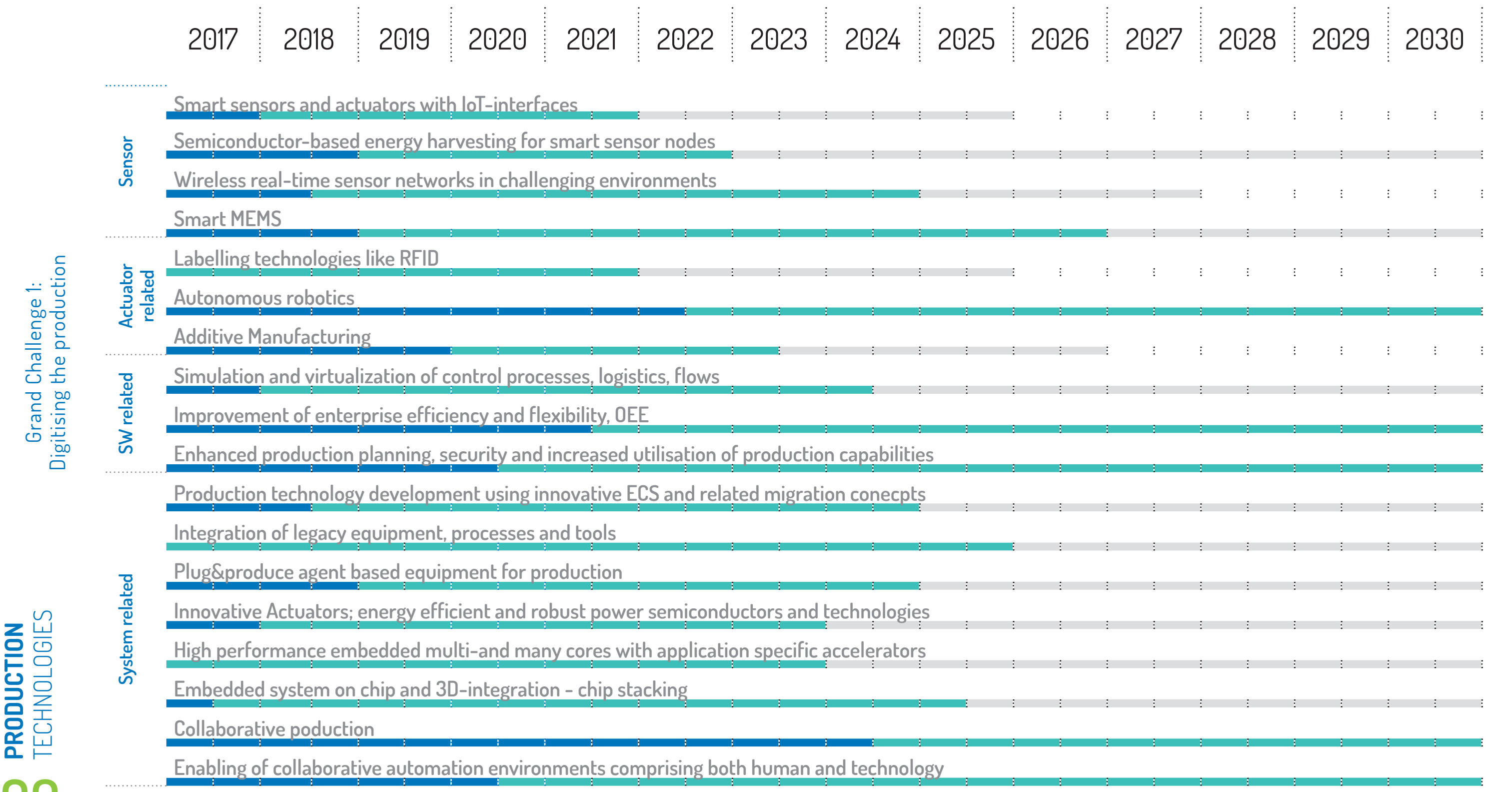
4 CONDITIONS FOR SUCCESS

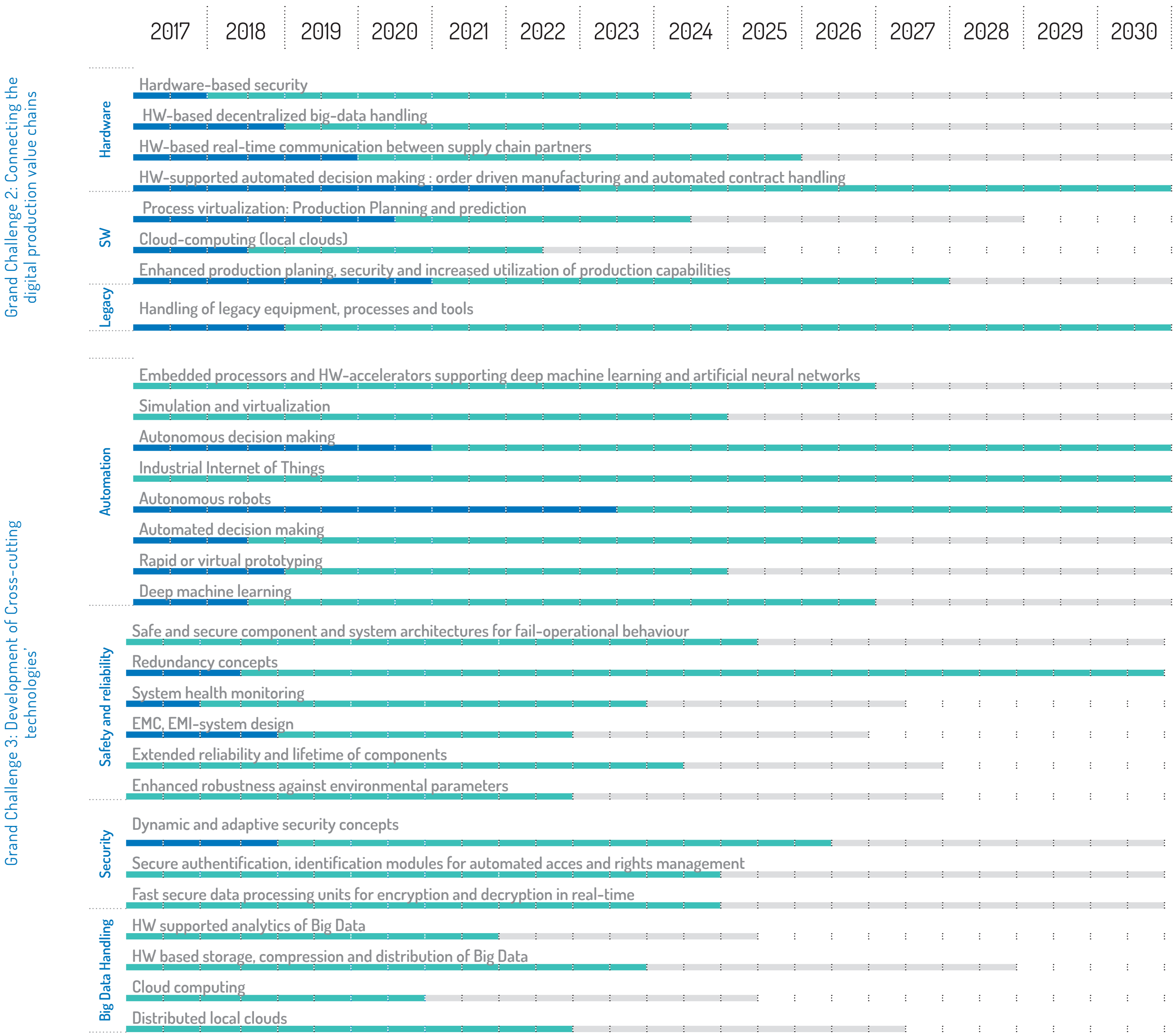
Digitizing European production is a competitive task, which requires a common approach of between academia, industry and politics. Innovations in nanoelectronics are the precondition for digital and autonomous production. The success of modernizing Europe's industries is directly dependent on successful research and development of nanoelectronics and nanoelectronics-based systems for digital production.

The conditions for success are in the creation of an environment for research and innovation on digital industry in Europe. This requires the development of networks and frameworks for research, innovation and investment, development of competence networks and exploitation of research results created by academia.

On technology level, conditions for success are not only development of new electronic components and systems, but also the integration of legacy equipment/systems and a cost-efficient transition towards digital production, development and adaption of suitable test processes, certification and qualification of production equipment and standardisation.

5 TIMEFRAMES





TRL 2-4 Technology Readiness Level; applied research - validation in laboratory environment

TRL 4-6 validation in laboratory environment - demonstration in relevant environment

TRL 6-8 demonstration in relevant environment - prototyping in an operational environment qualified

6 SYNERGIES WITH OTHER THEMES

Technologies for digital production rely on innovative ECS, which might not be specific designed for this domain only and therefore have many synergies with other themes and Aeneas agenda chapters. In terms of IoT-technologies there are synergies especially with the Connectivity & Digital Networks. Seamless connectivity and interoperability are key enabler for automated production and logistic flows along the value chain. Future automated production requires not only wired but also reliable wireless connection of sensors, actuators and controllers. Robots must move as freely as possible without being limited by wired connections. RFID and other tags and labels enable registration, tagging and information delivery for products. Safety and security are essential to avoid human damage in production and to protect the confidentially although connecting factories and suppliers with each other.

Energy Efficiency is of mayor importance in digital production to keep the costs for transformation of manufacturing and logistic processes as low as possible. Energy-harvesting product tags are an example of direct synergies with Technologies for Health and the Ageing Society. High performance embedded multi- and many-cores are also of mayor importance for in Automotive and Transport, e.g. to reduce the amount of control units and wires in cars. And last but not least Production Technologies is closely linked to Design Technologies, Process Technology and Integration e.g. in terms of simulation virtualization methodologies and will directly benefit from progress in Equipment, Materials and Manufacturing.

APPENDICES

ACRONYMS

A & P	Assembly and Packaging
ADAS	Advanced Driver Assistance System
AFM	Atomic Force Microscopy
ALD	Atomic Layer Deposition
AMS	Analogue Mixed-Signal
APC	Advanced Process Control
BEOL	Back-End of Line
BiCMOS	Bipolar Complementary Metal Oxide Semiconductor
C2X	Car to X (communication)
CMOS	Complementary Metal-Oxide Semiconductor
CNT	Carbon NanoTube
CPS	Cyber Physical System
CPU	Central Processing Unit
DRAM	Dynamic Random Access Memory
DSA	Directed Self-Assembly
DSL	Digital-system Specification Language
DSP	Digital Signal Processor
E2E	End-to-End
E&M	Equipment and Materials
ECS	Electronic Components and Systems
ECSEL	Electronic Components and Systems for European Leadership
ECU	Electronic Control Unit
EDA	Electronic Design Automation
EEG	Electroencephalography
EMC	Electromagnetic Compatibility
EMI	Electromagnetic interference
ESD	Electrostatic Discharge
ESL	Electronic System Level
EUV	Extreme Ultra-Violet
FDC	Fault Detection and Classification
FDSOI	Fully Depleted Silicon on Insulator
FEOL	Font-End of Line
FET	Field Effect Transistor
FICS	Factory Integration and Control System
FinFET	Fin-shaped Field Effect Transistor
GALS	Globally Asynchronous Locally Synchronous
GCn	Grand Challenge n
GPU	Graphics Processing Unit
HPC	High-Performance Computing
HW	Hardware
I4.0	Industry 4.0
IC	Integrated Circuit
ICT	Information and Communications Technologies
IGBT	Insulated Gate Bipolar Transistor
IGIT	Image-Guided Intervention Therapy
I/O	Input / Output
IoT	Internet of Things
IP	Internet Protocol or Intellectual Property
IPCEI	Important Project of Common European Interest
IRDS	International Roadmap for Devices and Systems
ITRS	International Technology Roadmap for Semiconductors
KET	Key Enabling Technology

KPI	Key Performance Indicator
LEIT	Leadership in Enabling and Industrial technologies
LPWA	Low Power Wide Area
M2M	Machine to Machine
MASP	Multi-Annual Strategic Plan
MDSD	Model-Driven Software Development
MEMS	Micro-Electro-Mechanical System
MIMO	Multiple Inputs – Multiple Outputs
MM	More Moore
MtM	More than Moore
MVDC	Medium Voltage Direct Current
NFC	Near Field Communication
NFV	Network Functions Virtualization
NGL	Next Generation Lithography
NMMI	Nano-Micro-Macro Integration
NoC	Network on Chip
NVM	Non Volatile Memory
OEE	Overall Equipment Efficiency
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Board
PCRAM	Phase Change Random Access Memory
PEALD	Plasma-Enhanced Atomic Layer Deposition
PENTA	Pan-European partnership in micro- and Nanoelectronics Technologies and Applications
PIII	Plasma Immersion Ion Implantation
PKI	Private Key Infrastructure
QoS	Quality of Service
R&D&I	Research and Development and Innovation
RAN	Radio Access Network
RAT	Radio Access Technology
RDL	Redistribution Layer
RF	Radio Frequency
RFID	Radio Frequency Identification
RRAM	Resistive Random Access Memory
SDN	Software-defined Networking
SiP	System-in-Package
SL VP	System-Level Virtual Prototyping
SME	Small and Medium Enterprise
SPC	Statistical Process Control
SoC	System-on-Chip
SRAM	Static Random Access Memory
STEM	Scanning Transmission Electron Microscopy
STT-RAM	Spin Torque Transfer Random Access Memory
SW	Software
TCAD	Technology Computer Aided Design
TEE	Trusted Execution Environment
TEV	Through Encapsulant Via
TLM	Transaction-Level Modeling
TMD	Transition Metal Dichalcogenide
TPM	Trusted Platform Module
TRL	Technology Readiness Level
TSV	Through Silicon Via
ULP	Ultra Low Power
UVM	Universal Verification Methodology
V2V	Vehicle to Vehicle
VLC	Visible Light Communication
VP	Virtual Prototyping
VPN	Virtual Private Network
VUV	Vacuum Ultra-Violet
WLP	Wafer-Level Packaging

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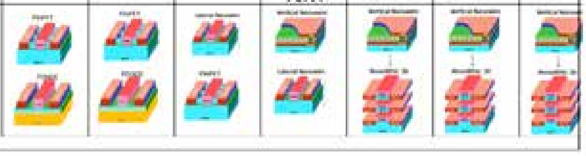
APPENDIX TO CHAPTER 7

The AENEAS Strategic Agenda provides essential roadmaps for Europe to address important societal challenges, to compete worldwide with innovative products and services, and to strengthen the competitiveness of European industry along the electronics value chain. In particular, Chapter 7 describes the challenges and timelines for Europe's ambition in Semiconductor process integration. These timelines are supported by landscape views for the different semiconductor processes technologies and integration strategies. A selected set of these landscapes is given in the present appendix for clarity, without the ambition to be exhaustive.

Advanced devices landscape

Research		2016 - 2018	2016 -	
Early production	2018-2019 N7	2020-2021 N5	>2022 N3	
	FinFET	Lateral nanowire horizontal Gate-All-Around, hGAA	Vertically integrated device & circuits vertical Gate-All-Around, vGAA	New functional scaling on top of base CMOS: Spintronics, 2D devices, (Steep-Slope switches)

YEAR OF PRODUCTION	2015	2016	2018	2020	2023	2026	2029
Logic device technology naming	P70M52	P52M36	P42M24	P32M16	P24M12	P24M12V1	P24M12
Logic industry "Node Range" Labeling (nm)	"16/14"	"11/10"	"8/7"	"6/5"	"4/3"	"3/2.5"	"2/1.5"
Device structure options	finFET FDSOI	finFET FDSOI	finFET LGAA	finFET LGAA VGAA	VGAA, M3D	VGAA, M3D	VGAA, M



Embedded memory landscape

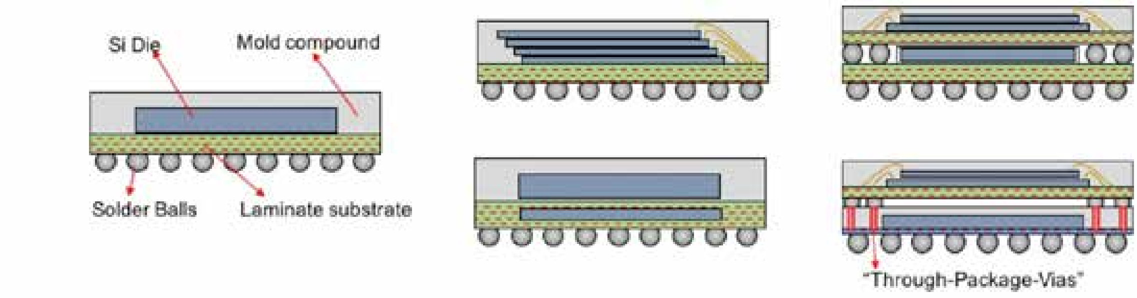
EMBEDDED Memory	2016-2017	2018-2019	2020-2021	2022-2023
SRAM node (L1 – L3)	N14	N10	N7	N5
MRAM node Application entry point	N40 / N28 eNVM, IoT	N28/N14/N10 eNVM (automotive), cache	N14/N10 Cache up to L2/L1	N10/N7 Cache up to L2/L1
RRAM node Application entry point	eNVM (non automotive)	40nm / 28nm eNVM (non automotive)	28nm Neuromorphic synapse!	28nm

Optical interconnect packaging and device landscape

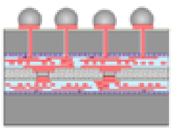
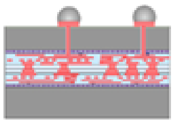
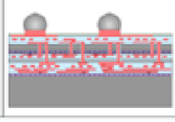
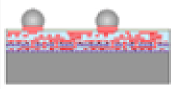
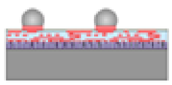
	Link Reach	>5m [Datacenter Network]	>1m [Backplane]	>5cm [Board]	>5mm [Package/Interposer]	>1mm [Chip]
	Year of introduction	2016-2018	2020	2022	2024	2026
Silicon Photonics Building Blocks	Packaging & Assembly	Pluggable Optical Module	Optical Module on Board	Optical Module on Package	Optical Interposer	Wafer-bonded Optical Layer
	Lasers Modulators Detectors	Hybrid III-V / Monolithic III-V or Ge Si, SiGe, III-V, Graphene Ge, III-V, Graphene (A)PD				

3D SoC and SiP landscape

For relatively low 3D interconnect density integration and when 3D integration is mainly driven by form-factor constraints, 3D-system-in-Package (SIP), can offer an attractive solution. Schematic view of a ball-grid array package (left). Top row: a BGA with 3D stacked Si die using wire bonding for 3D connectivity (center); and a 3D package-on-package (3D PoP) configuration of two BGA style packages (right). Bottom row: BGA package with embedded die in the laminate substrate (left) and fan-out wafer-level package (FO-WLP) with an embedded die in a reconstructed wafer by mold compound (right).



For higher integration density and performance driven 3D integration (power/speed) the table below gives an overview of this 3D interconnect landscape. The approaches are ordered along the interconnect hierarchy from global to local wiring. The key attributes of the different technology approaches are listed and for each technology a roadmap direction for interconnect scaling is given. Overview of the 3D technology landscape, as defined by the 3D insertion point in the electronic system wiring hierarchy. For each interconnect hierarchy level (columns in the table), a different 3D integration technology can be identified based on the current technological capabilities. These technologies also have their own interconnect density scaling roadmap, as indicated in the bottom row of the table.

	3D-SIC	3D-SOC			3D-IC
3D-Wiring level	Global	Semi-global	Intermediate	Local	FEOL
Partitioning	Die	**blocks** of standard cells		**Standard cells**	**Transistors**
3D Technology	Die stacking Die-to-Wafer stacks Die-to-Si-interposer	Parallel FEOL wafer processing Wafer-to-Wafer bonding		Sequential FEOL processing Active layer bonding or deposition	
2-tier stack schematic				2nd FEOL after stacking 	Multi-tier FEOL 
Characteristic	Known Good Die 3D stacks or Si-interposer stacking	BEOL between 2 FEOL layers *Overlay 2nd tier defined by W2W alignment/bonding*		BEOL between 2 FEOL layers *Overlay 2nd tier defined by litho scanner alignment*	FEOL/FEOL stack *Overlay 2nd tier defined by litho scanner alignment*
Contact Pitch *Relative density:*	40 20 10µm 5µm 1/16 ¼ 1 4	5 1 µm 4 100	2 µm 0.5 µm 50 400	200 100 nm 5000 10000	< 100 nm > 10000

APPENDIX TO CHAPTER 8

The AENEAS Strategic Agenda provides essential roadmaps for Europe to address important societal challenges, to compete worldwide with innovative products and services, and to strengthen the competitiveness of European industry along the electronics value chain. In particular, Chapter 8 describes the strategic R&D&I directions to be pursued in order to keep competitive semiconductor manufacturing in Europe, and maintain / develop world leadership of its Equipment & Materials (E&M) industry. The present appendix further details the research and development topics to be addressed to face these grand challenges.

Grand Challenge 1: "More Moore Equipment and Materials for sub-10nm technologies"

Research and development needed to facilitate innovations for GC1 is among others:

- Lithography systems, in particular EUV (Extreme Ultra Violet) technology, for high- volume manufacturing including tools, optics, and radiation sources, as well as NGL (next-generation lithography) technologies including E-Beam and maskless lithography, and advanced (often complementary) patterning strategies such as DSA (Direct Self Assembly) and NanoImprint.
- Mask manufacturing technology (specifically for Immersion, EUV and Mix&Match), including equipment for mask patterning and infrastructure, such as defect inspection and repair, metrology and cleaning, as well as holistic mask processing approaches for optimum pattern transfer that take into account image transfer, CD (Critical Dimension) metrology, overlay metrology, and defect repair and verification.
- Novel materials for new nano-structuring technologies, such as substrate materials, resists, chemical gases and pre-cursers etc. for next-generation processes, including the corresponding manufacturing infrastructure, equipment, and manufacturing technologies.
  For example:
  - Nanometer process development including thin film deposition, and (PE)ALD (Plasma Enhanced Atomic Layer Deposition) processing, many specifically enabling materials, (PE)ALD precursors etc.
  - Nanometer process developments for removing of sacrificial materials, including specific etching and cleaning gases to enable (PE) Atomic Layer Etching, dry-etching and vapor phase cleaning
  - Si-substrates, SOI (Silicon on Insulator), SiC, III-V materials, advanced substrates with multifunctional layer stacking, including insulators, high resistivity bulk substrates, mobility boosters such as strained Silicon, SiGe and sSOI (strained SOI), corresponding materials and related technologies (bonding and thermal treatment), and corresponding manufacturing equipment and facilities.
  - Graphene/Carbon Nanotubes, other 2D materials and Nanowires, and corresponding manufacturing techniques, equipment, and facilities
- Wafer preparation: equipment and processes for wafer slicing, etching, polishing, cleaning, epitaxial deposition, wafer thinning, and laser marking.
- Preassembly technologies, such as thinning and dicing, and preparing semiconductor devices for assembly and packaging (chip/package technologies merge/interact).
- General metrology developments needed for sub-10nm technologies:
  - Tighter Process Control
    - Internal Tool Monitoring – "closer to the process"
    - Tighter Process Monitoring for advanced nodes
    - In-Die metrology
  - Below 10nm technology challenges
    - Holistic & Hybrid metrology – smartly combine metrology and Fab data
    - Material & Dimensional metrology combined – on structure metrology
    - Advanced modeling
  - Advanced Metrology at Reasonable Cost of Ownership (CoO)
    - Design for cost and Throughput
    - Automation (Recipes, Reports)
  - Big Data – combine all available information sources
    - Computation - parallelism
    - Smart Algorithms and artificial intelligence

- Wafer and mask metrology including layer thickness; CD, placement and Overlay; inspection and review and big data process and analysis using virtual intelligence (VI) smart algorithms.
- Nanoprobe analytical techniques, including thermal, electrical, topography and chemical (multi-domain, nano-resolution).
- Development of standards (samples) allowing calibrating subtle, nano-level analytical and metrology techniques.
- Wafer processing related Advanced Process Control systems for Multi-Dimensional Metrology (MDM) challenges of latest transistor (e.g. gate-all-around (GAA) and Fin-FET) and connectivity (e.g. through silicon via (TSV)) architectures. In particular advanced in-line metrology, such as Thin-Film metrology by Optical and X-Ray techniques, Critical Dimension by E-Beam and Scatterometry (multi-dimensional or beyond 3D) techniques, and Overlay by Optical, Scatterometry and E-Beam techniques.
- Advanced wafer and mask process holistic metrology techniques e.g. by Optical and e-Beam imaging, defect review by e-Beam imaging and Fast AFM (Atomic Force Microscopy).
- Equipment and modules for failure detection, analysis and control (FDC), characterization and dedicated testing.
- Metrology equipment development based on the Productivity Aware Design (PAD) concept which includes CAD data (i.e. design data) integration on system level to allow an efficient data processing and flows.
- Thin film metrologies such as DRM (Differential Reflective Microscopy).
- Wafer metrology including layer thickness, CD and Overlay, inspection, and data handling.
- Wafer processing related Advanced Process Control systems, in particular advanced in-line metrology, such as Thin-Film metrology by Optical and X-Ray techniques, Critical Dimension by E-Beam and Scatterometry (3D) techniques, and Overlay by Optical, Scatterometry and E-Beam techniques.
- Advanced wafer process inspection techniques by Optical and e-Beam imaging, defect review by e-Beam imaging and Fast AFM (Atomic Force Microscopy).
- Equipment for failure analysis, characterization and dedicated testing.
- Manufacturing science, advanced data handling and yield analysis systems, defect analysis and test methods, and DFM (Design for Manufacturing) methods for yield improvement.
- Open platform technologies, including automation, handling, software, interfaces (hardware and software) and standards.
- Equipment and materials for Quantum Computing device development & manufacturing.

Grand Challenge 2: “More-than-Moore Equipment and Materials”

Research and development needed to facilitate innovations for GC2 is among others:

- Assembly and packaging (A & P) equipment, in particular for 3D packaging (wafer level and chip level), and novel approaches for die thinning and die separation (singulation), including defect/crack detection after dicing.
- Manufacturing equipment for chip embedding and related assembly and packaging (e.g. process tolerant systems for encapsulation and lamination).
- Back-end-of-line/assembly and packaging process E&M, for processes such as sintering, die-attach bonding, copper bonding, and cost-efficient TSV’s (Through Silicon Vias).
- Chip embedding technologies: methods, materials and equipment.
- E&M for the handling and processing of ultra-thin wafers (and specific MEMS wafers).
- Thin film technology: equipment and new materials (new dielectrics, electrolytes, (PE)ALD, Chemical Vapor Deposition (CVD).
- Advanced chip-to-chip, chip-to-wafer and wafer-to-wafer bonding techniques.
- Wafer and layer stacking with precision wafer to wafer alignment.
- E&M for alternative patterning approaches, such as imprint, maskless or roll-to-roll.
- Process characterization tools, in-line and in-situ metrology and defect /contamination control equipment and sensors (see also Grand Challenge 3)
- Test equipment: equipment for thin wafers, scalable and modular test equipment for low/medium volume production, high-voltage testing, highly-parallel testing, contact-less testing.
- Equipment and new methods for testing of 3D heterogeneous systems, including TSV based devices (e.g. for high contact densities).
- Equipment enabling wafer size transitions.
- 3D high aspect ratio metrology.
- Failure localization, preparation and analysis methods and tools, especially for heterogeneous integration (especially 3D) and System in Package (SiP) solutions.
- Specific methodologies and tools for Advanced Process Control (APC), optimized for high-mix environments (see also Grand Challenge 3).
- Innovative data analysis methods and software capable of handling small data samples and

addressing specific market requirements, e.g. automotive (see also Grand Challenge 3).

- 300-mm Si and SOI substrates, including low-resistivity substrates for power applications, high-resistivity substrates for power and RF applications
- Advanced substrates - e.g. for Si interposer, glass interposer, ceramics.
- Alternative semiconductors and photonic materials, such as GaN and SiC.
- New materials - for example, thin film dielectrics, biochemical coatings for sensor surfaces, thermal interface materials, III-V materials for civil applications of Radar (e.g. for automotive and healthcare applications), materials for 'beyond CMOS' (e.g. for on-chip light management), and materials for added functionality at reduced scales and associated enabling materials (e.g. precursors, gases), and thermally highly robust materials
- New materials for assembly and packaging, e.g. for reliable die attachment, tailored mold compounds, and new interconnects
- New engineered substrates and solutions for heterogeneous integration of materials to bring new functionalities to multiple MtM applications - for example, solutions to ensure the convergence of More Moore and More-than-Moore, to enable high-performance wireless communication combined with low power consumption, or to increase battery life (hybrid bulk), and for III-V material for power, photonics and lighting applications. Examples: GaN on X (Si or alternative handle substrate), Si.
- 'Green' equipment design by reducing base material usage (water, power, chemicals etc.) and using smaller processing chambers (for CVD, spatial ALD, etc.).
- Alternative metallization concepts on chip but also on board/package level especially in the MtM domain and associated deposition methods like printing instead of mask processing.
- Equipment and materials for 3D monolithic integration allowing improvement in scaling while sustaining dimension scaling advantage.
- New materials and respective production equipment for enabling and industrializing new and improved sensors based on not yet fully exploited physical effects to detect and analyze properties of radiation, materials and objects (e.g. chemical sensors, bio-sensors, light sensors, etc.)

Grand Challenge 3: „Manufacturing"

Research and development needed to facilitate innovations for GC3 is among others:

- Definition and development of the next generation of modular and flexible Factory Information and Control Systems (FICS), Work-in-Progress (WIP) and resources management, process control planning and simulators etc., to support fab automation and flexible fab management.
- Advanced prediction techniques for Predictive Maintenance and Virtual Metrology, as well as Time Constraint Tunnels management (simulation) and the necessary tools to maintain them in real time.
- Yield Modelling and new approaches to Design-for-Manufacturing, Design-for-Yield, Design-for-Test and Design-for-Metrology.
- Data analysis systems to support Advanced Process Control (APC), Yield Analysis and modelling (including "big data" crunching and business-oriented data vision). Process control and monitoring for 3D integration, in-line, with 100% vision for wafer defect inspection and control (including the use of high speed cameras, advanced data processing, and appropriate software solutions).
- Knowledge capitalization and sharing tools to enable faster diagnostics and decision making (i.e. process adjustments) for intra- and inter-facilities.
- Optical inspection, yield and process improvement for 3D and SiP (System in Package).
- Solutions to detect and control very subtle contamination sources (airborne or in vacuum). This holds true also for vacuum environments. Hence advanced in-situ and/or ex-situ sensors to monitor the process, plus metrology and inspection tools for various types of harmful contaminants, will be required.
- Software solutions for streamlining CAD (Computer Aided Design) files to manufacturing environments as a basis for classification/filtering of defects (based on additional information) will be required. An infrastructure (systems, software, protocols etc.) that enables the smooth streamlining of CAD files to the manufacturing environment therefore has to be developed.
- The integration of decision and analysis systems in a consistent and flexible framework needs to be organized (i.e. allowing the adaptation of the control plan with respect to real time equipment status and product critical area). The definition and development of these new decision systems could become a large technical and commercial field of activity for European SMEs.

More in detail, solutions to the following (non-exhaustive) list of future R&D challenges need to be developed:

- Small and variable lot size manufacturing.
- Automation robotics and related decision systems (also for existing 200-mm MtM fabs, including chip embedding and other innovative assembly and packaging fabs).
- Efficient solutions for data handling and analysis (including data security and quality).
- High-performance computing platforms for process control and metrology.
- Predictive control systems (for example, Predictive Maintenance, Virtual Metrology, Equipment Health Factor).
- Optimization of equipment load and lot logistics in MtM fabs with variable fab load and flexible manufacturing strategies.
- Quality and process robustness.
- World class yield and defectivity; 100% defectivity control techniques; metrology solutions to detect «seeing more» and control very subtle contamination levels (airborne or in vacuum), and to handle the exponential increase in defects count.
- Manufacturing robustness (tools - for example, Streamlining CAD files to manufacturing environment) and facilities reliability (see also Chapter 6).
- Production environment adaptation to the MM and MtM challenges (people, tools, process), including the optimization of clean room management, waste/resources management and energy efficient manufacturing.

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