VISION, MISSION AND STRATEGY

R&D&I in European Micro-and Nanoelectronics

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Aeneas

CATRENE
Cluster for Application and Technology Research in Europe on NanoElectronics

CHAPTER 1

AUTOMOTIVE AND TRANSPORT

1.1 Introduction

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:

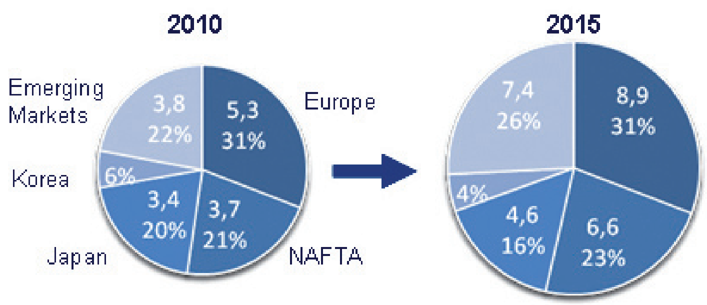
Grand Challenge 1 - Smarter Electric Vehicle
Grand Challenge 2 - Safety in Traffic
Grand Challenge 3 - Co-operative Traffic Infrastructure and Management

These three Grand Challenges aim to broaden the R&D horizon so that future research and development focuses less on the development of 'purely electric vehicles' and more on holistic sustainable mobility solutions for all the main transportation domains - Automotive, Railway, Aviation and Shipping - as well as encouraging the development of cross domain solutions.
The defined Automotive and Transport challenges not only address the most urgent Research and Development priorities in the sector, but also focus on developments that could be substantially driven by innovations in the European microelectronics and nanoelectronics industry. The previous 'one-mobility' focus will remain in place.

1.2 Relevance for Europe

1.2.1 Competitive Value

Mobility is not only a visible expression of Europe's economic and societal prosperity, it is also an important source of that prosperity.
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[1], automotive semiconductor revenues are expected to grow year on year, by 5% in 2013 and 7% (CAGR) over the five-year forecast period



Source: Strategy Analytics, June 2010

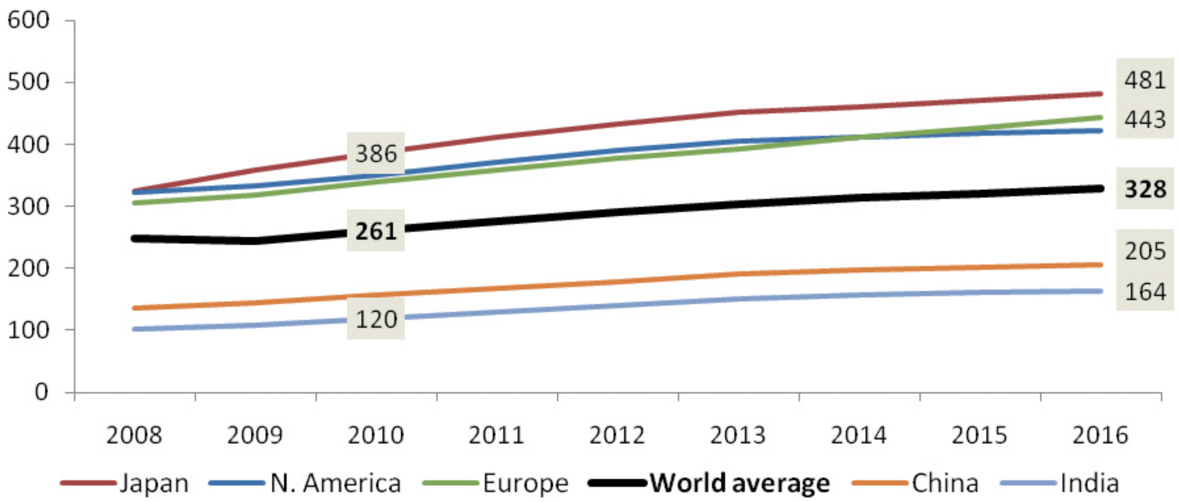
Figure: Automotive semiconductor market 2010, forecast 2015 by regions (USD billion)

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

Market research undertaken by Frost & Sullivan suggests that the number of public charging stations in Europe will grow from 10 thousand in 2010 to around 2 million by 2017. The expected public funding over the next seven years will amount to €5 billion. In the United States, the expected value of public funding, loans and guarantees for e-Mobility R&D amounts to as much as US$22 billion by 2015. The second highest funders in this context are the Chinese authorities, which collectively support local companies with the equivalent of around €3.3 billion. In Europe, France leads the pack, with an investment of €670 million plus €1.5 billion for related infrastructure developments, followed by Germany, which has committed to investing around €500 million in e-Mobility.

The value of the electronic components in a typical production car has already reached around 20% of the car's production cost, and is expected to reach around 25% in the next five years. As a proportion of the electronic component cost, microelectronics currently accounts for 44% and is expected to reach 55% in the next five years. In total, automotive components represented 20% of the European electronic components market in 2012, with a stable growth rate of approximately 3.5%.

On average, European vehicles with conventional power train systems currently contain around €250 worth of semiconductors devices. In hybrid and electric vehicles this figure will increase to around €750.



Source: Strategy Analytics, June 2010

Figure: Average Semiconductor Value (in USD) per car in selected Regions

To enable electric vehicles to transition from a niche market product to a mainstream product, three things must happen: there must be a massive reduction in cost, effective energy storage solutions must be developed (progress in battery technology), and an intelligent power distribution infrastructure needs to be put in place. Smart grids and nanoelectronics will be key areas of innovation in the field of electric mobility.

Nanoelectronics will be a key enabler 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.

Microelectronics and nanoelectronics will also enable highly effective communication and interaction between vehicles, between traffic infrastructures and vehicles, and between infrastructures/vehicles and other participants in traffic systems.
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 and *AUTOSAR* for a standardized modular software-stack in automotive applications.

1.2.2 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.
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 and safety are clear societal needs for the future intelligent road.

E-mobility based on electric vehicles will be the key element in maintaining individual mobility.
Autonomous driving is expected to gain increasing importance in improving traffic flows, safety and driving comfort.
Traffic infrastructures will be more effectively utilized, largely through the use of information technology to efficiently implement and quickly establish the necessary systems.

1.3 Grand Challenges

1.3.1 Grand Challenge 1: Smarter Electric Vehicle

Vision:

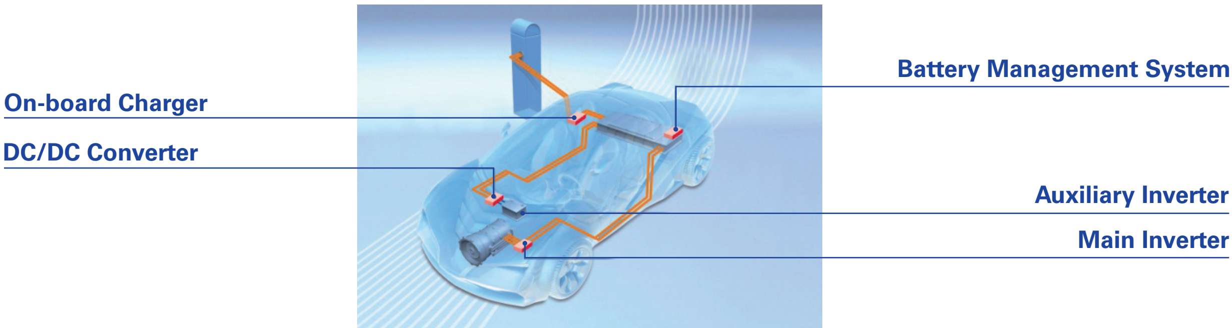
Needs-based, user-friendly, affordable electric vehicles embedded in a sustainable mobility infrastructure satisfy the need for individual mobility. Nanoelectronics will provide essential features.

Description:

The Grand Challenge 1 ‘Smarter Electric Vehicle’ should be considered as a refinement of the previous Grand Challenge ‘Intelligent Electric Vehicle’. The Smarter Electric Vehicle should be embedded in Grand Challenge 3 ‘Co-operative Traffic Infrastructure and Management systems’ and should 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.

High Priority Research Areas:

- holistically applied energy-efficient electronics - i.e. at vehicle architecture, application specific system, module and component levels, and combinations thereof
- electronics to control and connect advanced storage technologies (applied to innovative battery cells, hybrid batteries and fuel cells)
- efficient power electronics - e.g. for inductive charging technologies
- introduction of multi-core processor technology for real-time control in mixed-criticality systems
- heterogeneous system integration, inclusive of thermal management
- advanced safety and reliability research, fully operational under required security functionality (e.g. EMC, safety monitoring)
- connections to smart grids
- seamless bi-directional communication networking (on-board, and car to X) featuring enhanced security concepts, including secured transfer of data inside and outside of the vehicle to ensure safe operation (security of control, access and communication)
- smarter communication and interaction between vehicles , and between vehicles and other traffic participants, such as pedestrians and street infrastructures



The high priority research areas identified above involve fundamental research in semiconductor technology, research at device, module and system level, and research in new assembly/packaging technologies.

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 stabilise 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.

Expected Achievements/Foreseen Innovation:

Well-recognized economic and ecological reasons will drive the introduction of intelligent electric vehicles. A significant CO^2 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.

As a result, innovative application systems are expected, including:

- interacting information systems for secure connection electric vehicles to grids for remote identification, diagnostics, charging and metering
- intelligent on-board traffic management and navigation systems to achieve maximum efficiency and driving range
- innovative advanced driver-assist systems
- interaction between individual vehicles as well as between vehicles and infrastructures, to enable intelligent urban and metro area traffic management systems

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.

1.3.2 Grand Challenge 2: Safety in Traffic

Vision:

'Zero Accident Driving' – based on highly reliable electronic active safety systems, a major breakthrough will be made on the road to accident-free traffic.

Description:

The Grand Challenge 2 'Safety in Traffic' should cover all the different layers, from individual vehicle level up to complete traffic management system in terms of safety. In urban traffic especially, at least 50% of fatal accidents should be avoided.

Safety improvements inside and outside vehicles and in complex traffic infrastructures will be based on a new generation of smart sensors (e.g. radars, cameras, and their associated processing units), communication networks that offer flexible data rates and algorithms for priority and channel reservation, and highly advanced safety-aware actuators (entities that control the behaviour of the vehicle). Public demand and legislative requirements for safer cars and safety in traffic are increasing, which means that safety in vehicles will become a prerequisite for successful market penetration. As traffic management and network infrastructures improve, the same holds for security. The estimated global market for the «safety in traffic» challenge is the total vehicle market, plus complex traffic infrastructure such as like traffic management systems, vehicle-2-vehicle, vehicle-2-X, logistic systems etc.

High Priority Research Areas:

- innovative interacting safety systems
- lifetime, reliability and safety at all levels - component (e.g. sensor), module and application level in vehicles right through to complex vehicle and traffic safety management systems
- functional safety in operation, control and communication, including initiation of European standardisation for deployed technologies, safe communication protocols, certification and testing
- systems that enable interaction between vehicles and traffic infrastructures
- technologies supporting autonomous and semi-autonomous driving

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. Against the background of declining car sales caused by the global financial crisis, China is expected to produce more cars than Europe in 2013. It will be the first time this has happened. Nevertheless, when it comes to conventional combustion engine vehicles and vehicle safety, European companies, particularly tier 1 manufactures and component suppliers, are still in a world leading position. In addition to this, Europe also has a very strong aeronautics industry (Airbus) and railway industry. The success of Europe in these transportation domains is increasingly dependent on early access to the latest technologies – especially for improving energy efficiency, safety and comfort.

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.

Expected Achievements/Innovation Foreseen:

Innovative new traffic safety management concepts and systems based on a holistic view of all transportation types are expected, as well as new active safety and driver-assist systems in electric vehicles enabled by components such as sensors, actuators and multi-core processors. Expected progress in overall safety infrastructures, both internal and external to vehicles, will strongly support the European target of decreasing fatal accidents by 50%.

1.3.3 Grand Challenge 3: Co-operative Traffic Infrastructure and Management

Vision:

Efficient cross-domain and co-operative traffic management systems will ensure substantial progress towards jam-free traffic without any major diversions.

Description:

The Grand Challenge 3 'Co-operative Traffic Infrastructure and Management' should be considered as multi-modal in nature and covering trustworthy communication systems. 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. 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 analysed 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 standardisation of interfaces between components from different suppliers.

High Priority Research Areas:

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

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 BroadR 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.

Expected Achievements/Innovation Foreseen:

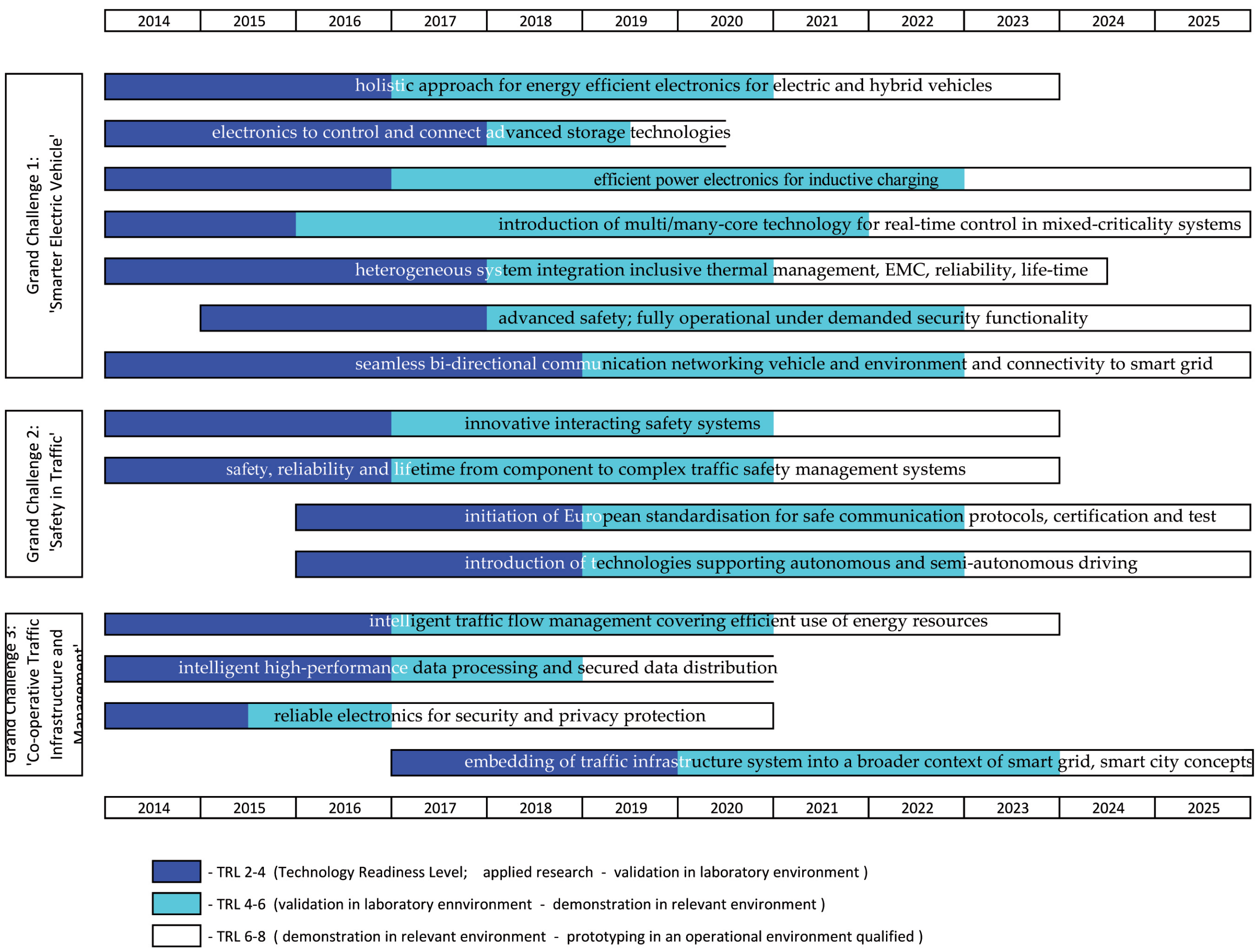
Innovative new concepts, such as co-operative traffic management systems that interact with systems in other application domains (for example the Internet or logistics) are expected. Such systems will strongly support improvements in the efficiency of traffic movements by reducing traffic jams, reducing 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 CO^2 emissions due to traffic jams and road congestions, while also saving lives.

1.4 Conditions for Success

ENIAC/CATRENE is capable of achieving these 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. A limiting factor will be the available R&D budget. The total development effort needed for drive-train, battery, integration, and energy management) over the next decade will be in the region of 2 to 5 billion Euros per year, of which around 0.5 billion will be R&D.
One important aspect is that the effort put into preparing and administering projects should be well balanced with the research work itself.

1.5 Timeframes

The general rule is that research topics should be transferred into product development within a 5-year timeframe. The intention of the following roadmap figure is to emphasise examples of high priority research areas (there is no claim for completeness).



1.6 Synergies With Other Domains

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.
Satisfying this demand leads on the one hand to the multi-domain deployment of existing applications, basic technologies, methodologies and architectures, and on the other hand to new cross-domain applications. Seamless connectivity and interoperability therefore become more and more important.
This should be supported by cross-domain use of Design Technologies, Semiconductor Process, Integration Technologies and Communications.
In contrast to other domains, Automotive & Transport applications are characterised by stringent real-time requirements and severely limited energy resources. To meet these requirements, robust technologies 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.
The challenge for nanoelectronics is to develop solutions with almost no degradation in performance and comfort.

CHAPTER 2
COMMUNICATION & DIGITAL LIFESTYLES

2.1 Introduction

Ubiquitous access to all media types - data, voice and video - has largely become a reality, enabled by the increased bandwidth of access networks, and the convergence between fixed and mobile networks, which has progressed rapidly over the last few years. Meanwhile, multimedia-enabled mobile terminals, such as smart phones and tablets, are rapidly replacing PCs and laptops. They are also complementing conventional consumer devices such as TVs and radios, which also now increasingly feature communication functions. However, the ever-improving performance of today's communication networks opens up new application scenarios that are highly bandwidth dependent, quickly eating up most of the bandwidth improvements that have been made so far. Based on today's multimedia scenario, high definition (HD) video already accounts for a significant share of communications traffic. Today's high-performance ICT infrastructures also encourage offloading and distribution of computing tasks and services onto the network. Continued service virtualization and 'cloudification' will be major trends over the coming years. All of this, together with the increased level of personal and social networking, has given rise to the need for large data centres, which like the core network of the communication grid need to handle huge data rates. These data rates are currently enabled by ultra-high bandwidth optical routing and transmission gear. Data centres also need to incorporate huge amounts of computing power to deliver the services expected by cloud users. As a result of 'always and everywhere' Internet access, intelligence and smartness have also found their way into people's everyday environment. Concepts such as machine-to-machine (M2M) communication and the 'Internet of Things' (IoT) will increasingly support people's daily lives, enabled by developments such as smart cars, smart cities and smart infrastructures. The omnipresence of communication networks is evident from the fact that their relevance appears repeatedly in the various chapters of this document. During the course of communication technology development, energy efficiency and system security will remain both as key features and technical challenges.

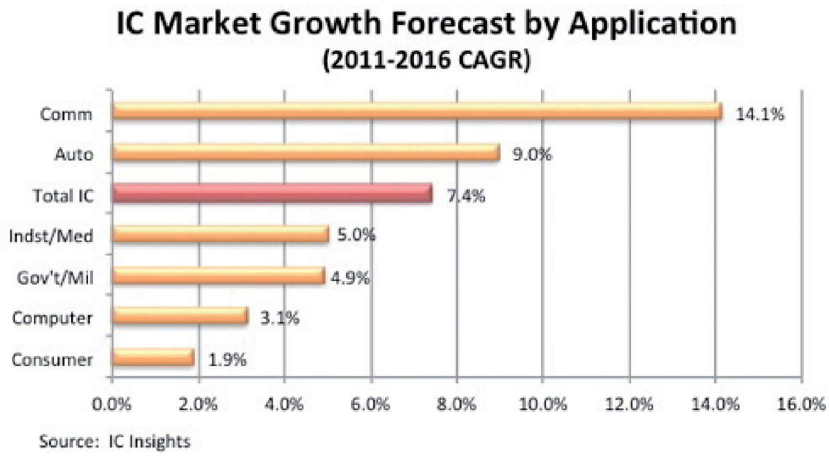
2.2 Relevance for Europe

2.2.1 Competitive Value

With a highly developed telecommunications market, Europe is both a major producer and a consumer of ICT technologies and services. For example, roughly 60% of the EU population have access to the Internet. The telecommunications market in general increased by 3.7% in 2011, while the broadband market grew 8.1%. It is expected to increase from its 2011 value of US$55.2 billion to US$69.7 billion in 2015. Home to a number of major communications equipment suppliers and semiconductor companies, as well as many universities and institutes with relevant competencies, Europe has traditionally held a major stake in communications technology and knowhow. It is now of extreme importance to maintain and cultivate this high level of European knowledge and expertise at all integration levels and along the entire value chain, bearing in mind that communications technology influences virtually every aspect of people's daily lives.

According to a recent 'IC Insight' overview, the market for communications chips will grow at 14.1% CAGR for the next four years. By 2016, it will have reached a total value of US$160 billion, almost twice as large as in 2011.

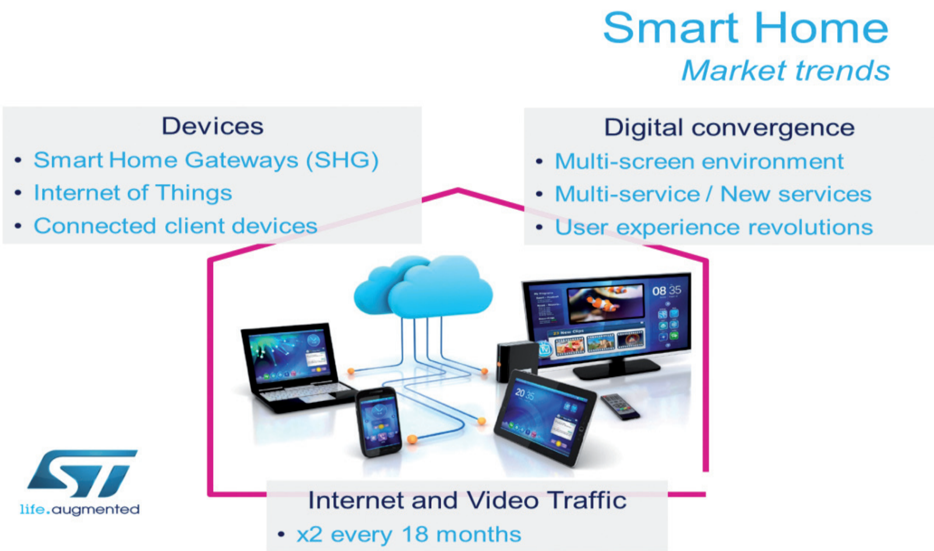
As mentioned earlier, these chips will increase the value of various products produced by European industry - for example, multimedia, automotive, energy-efficiency products, etc. This is why early access to the latest communications technologies and a multidisciplinary dialogue between ICT experts and application specialists is very important.



Communication and digital lifestyles are crucial requirements both for individual wellbeing and for improvements in personal efficiency. They are also two of the foundations of Europe's economic development and growth. As outlined above, ubiquitous 'anytime anywhere' broadband Internet access is already enabling advanced multimedia services. It will also enable everyone, and before long everything, to network with each other. Future progress in 4G and 5G wireless broadband access technologies will further accelerate this trend. The convergence of telecommunications and entertainment electronics is already unifying and merging features of television and mobile terminals - for example, Internet TV on smart phones or tablets.
All the relevant European R&D actors must reinforce their position in order to guarantee

European competitiveness and make sure that the European nanotechnology industry, and all those European industries that rely on it throughout their respective value chains, will remain a substantial source of economic value and employment. In particular, the trend towards greater energy efficiency and Europe's leading position in the required enabling technologies, could benefit European players by enabling them to enter markets for products such as data centre micro-servers and energy-efficient HPC (High Performance Computing) servers.

In the entertainment domain, Asian companies (mostly in China) with large industrial capacity and low labour costs are managing the assembly of a large part of the related



equipment at prices that are not achievable within the European Union. However, most of the component value in this equipment remains in the hands of IC suppliers, and European companies still have leading positions in the IC market. Europe's R&D community is determined to keep Europe in this leading position, through the development of innovative new technologies, products, and applications that allow European manufacturers to offer innovative features, advanced applications and expert know-how to the rest of the world.

To maintain its leading position in the global nanoelectronics industry, Europe must continue to play a key role in the definition and application of standards. Public funding for research and development has already helped Europe to lead the way in defining standards such as RF4CE, DECT-ULE, ZIGBEE-Lightlink, MPEG-2, DVB-T/S/C, H264, GSM, HSPA and 3G that are now widely adopted throughout the world. These standards and their associated patents still bring European companies important revenues through the development and licensing of ICs and IP blocks.

2.2.2 Societal Benefits

The emergence of global challenges, such as climate change, energy saving and population ageing, will require advanced nanotechnologies and innovative communication solutions/services to address them. The strong need for M2M communication and the ‘Internet of Things’, which will heavily rely on embedded actuators, sensors and controllers, **makes broadband communications and nanotechnology key technologies to master in order to address societally relevant applications such as healthcare, lifestyle, automotive, smart buildings and connected homes.**

2.3 GRAND CHALLENGES

In order to address all the technical issues associated with convergence in the most efficient way, R&D activities should be organized around the following four Grand Challenges, coupled with long-range planning and close cooperation throughout the relevant value chains. The objective is to spur the development of innovative and cost-effective technologies, enabling the efficient design and high-volume manufacture of advanced silicon system solutions for communications and digital lifestyle markets. The four Grand Challenges are: INTERNET MULTIMEDIA SERVICES, EVOLUTION TO A USER DIGITAL LIFESTYLE, SELF ORGANIZING NETWORK and SHORT RANGE CONVERGENCE.

2.3.1 Grand Challenge 1: Internet Multimedia Services

Vision:

Moving towards the convergence of applications, devices and networks, the ‘Internet Multimedia Services’ Grand Challenge aims to develop innovative silicon solutions for managing the volumes of data required for future broadband services in the most effective way. It also addresses the technical requirements of communication nodes - e.g. in the core network or in high-capacity data centres.

Description:

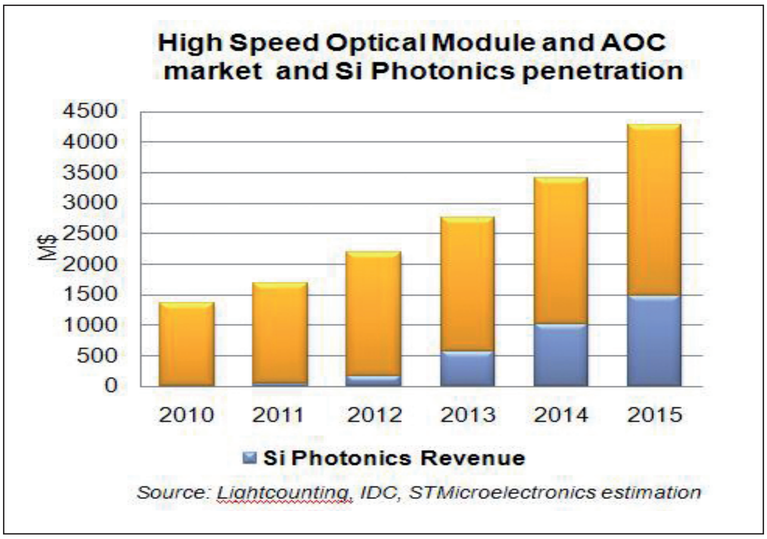
The convergence of consumer products, computers and communications will result in exponential growth in the volume of code and data in electronic systems. At the highest level, ‘convergent’ system performance is measured a) in term of latencies - in order to allow uninterrupted information streams; b) in terms of bandwidth - to speed up internet connections; c) in terms of reduced power consumption - in order to enhance portability and mobility. Reduced power consumption will have a strong impact on the performance of network equipment and on consumer-grade devices (e.g. set top boxes and tablet PCs), because of regulatory power consumption standards and the need to reduce energy costs. The continuous introduction of new multimedia formats will impact processing capabilities, because of decoding/encoding requirements (access to content always requires spatial and temporal transcoding). Ease-of-use will have a strong impact on processing and memory requirements, because making things simple for users requires greater levels of intelligence to be built into devices.

Competitive Situation:

The telecommunications market includes cellular mobile phones, cordless telephones, cellular base station equipment and switching equipment (BS&SE), pagers and two-way radios. Wireline communications includes data communications as well as voice communications, with the emphasis shifting to data communications because of the growing use of smart phones and tablet computers. The wireline communications market is dominated by companies such as Ericsson, Huawei, Alcatel-Lucent, Cisco, and Nokia Siemens.

Wireless communications will represent around 27% of the market over the period 2015 to 2020 compared to only 20% in 2005. It includes mobile handsets, wireless communications infrastructures such as base stations, and local-area communications. Wireless communications will be a major driver for the semiconductor industry over the next five to eight years. The former number-one in wireless communications was Qualcomm (US) but today other suppliers such as Samsung, Texas Instruments, Mediatek, Broadcom, Infineon, Renesas, and Micron are important market players. Optical components that support end-to-end data transport over optical fiber also represent an innovation engine for the networking industry. The advent of 'big data' and the exponential growth in data managed by enterprise data centres is also a significant driver of innovation. The global optical component market reached US$3.6 billion in 2012 and is anticipated to reach US$12.3 billion by 2019 (source: Wintergreen Research, 2013). The hardware market for data centres is currently worth around US$100 billion, with optical modules currently representing around US$1.2 billion, growing to around US$5 billion within 10 years (source: Ovum, 2013).

While silicon-based photonics is indispensable for ultra-high performance networking gear (e.g. terabit routers), it will also be used extensively in end-user equipment and local networking equipment. The total Silicon Photonics market is predicted to reach US$2 billion by 2015, with a CAGR of 78.2% from 2010 to 2015 (Source: Markets and Markets). Although currently in its infancy, Silicon Photonics is expected to be widely commercialized by 2016. It can reasonably be foreseen that it will progressively replace traditional optical solutions in high-speed optical modules and active optical cables (AOC). According to analysts, the market for Infiniband AOC (for HPC) and 10-40-100G optical modules (for parallel LAN, Telecom, Metro and Access applications) accounted for revenues of US$1.35 billion in 2010 and will grow to US$4.27 billion by 2015. Even if market penetration is only moderate, the value of the Silicon Photonics content in these two application areas alone could ramp up to US$1.5 billion by 2015, which would represent more than a third of the total market.



Key players in the sector, ranging from industrial giants to consolidated start-up companies and academic R&D laboratories, are located worldwide: in the US (e.g. Intel, IBM, HP, Oracle, Luxtera, Mellanox, Cisco, Aurrion, Skorpios Technologies, UCSB, MIT); in Asia (e.g. Fujitsu, NTT, IME); in Europe (e.g. Alcatel-Lucent, STMicroelectronics, SOITEC, Calopia, DAS Photonics, CEA-LETI, Imec/Gent University).

Expected Achievements/Innovation Foreseen:

- **System memories**

Memory system design has to support ever-more demanding requirements in terms of increased bandwidth and lower power consumption. In terms of reduced power consumption, non-volatile solid-state memory is clearly the best way forward. In order to secure its competitiveness in multimedia and data storage integration, Europe needs to secure its leadership in (non DRAM) memory design both from an architectural and technology point of view. Memory systems will have to satisfy the bandwidth needs of demanding applications, with advanced caching techniques and mixed memory technologies being forecast as the most promising solutions.

Due to the limits of device scalability (which was previously regarded as the solution to higher performance, lower cost, memory systems) it will become impossible to continue shrinking Flash memory much further over the next decade. **New memory technologies that do not rely on charge storage are needed, two of the most promising ones being magnetic and resistive memories.**

Because critical computing applications are becoming data centric rather than compute centric, high-performance, high-density, low-cost non-volatile memory (NVM) technologies with access times similar to those of DRAM offer the best memory system solution for new computing applications.

The challenge for solid-state memory technology is therefore to meet the demands of future storage servers by modifying the storage-memory hierarchy - especially in terms of reducing the reliance on hard disks.

- **Implementing new energy-efficient computing approaches**

Multimedia broadband services are already providing people with a rich mix of audio, video and graphics. In particular, video content for real-time or streaming applications is growing fast, with the advent of HDTV (High Definition Television) driving demand for ever-increasing picture quality. The challenge is to develop energy-efficient networking technologies and advanced video compression techniques in order to deliver the required quality while also minimizing bandwidth requirements. The introduction of HDMI interfaces on mobile devices also brings new challenges, since applications and services need to merge the small-screen user-interface and viewing experiences with the equivalent wide screen experiences. Support for new HD formats in such devices introduces **very complex problems relating to processing power,** because the amount of data that needs to be processed in real-time increases dramatically. This processing power demand will require the development of **solutions that integrate more and more processor cores coupled to high-bandwidth memory interfaces** (needed for video algorithms) making programming such devices more challenging than ever.

The energy problem is now ubiquitous, whatever the source of energy. It has been a critical challenge in the design of mobile devices for several years, but it is now also an enormous problem for systems connected to a mains supply. There are several different ways of addressing the energy reduction problem, the most obvious one being to continue leveraging Moore's law so that new semiconductor process technologies can deliver equal or higher performance at lower energy consumption. Unfortunately, this single-focus approach is far from optimal. To overcome the problem, the energy issue must instead be addressed at all levels within a system, from the silicon right up to the software services running on top it. It is only when hardware and software modules are co-designed for effective energy management that high performance coupled with low power consumption can be achieved.

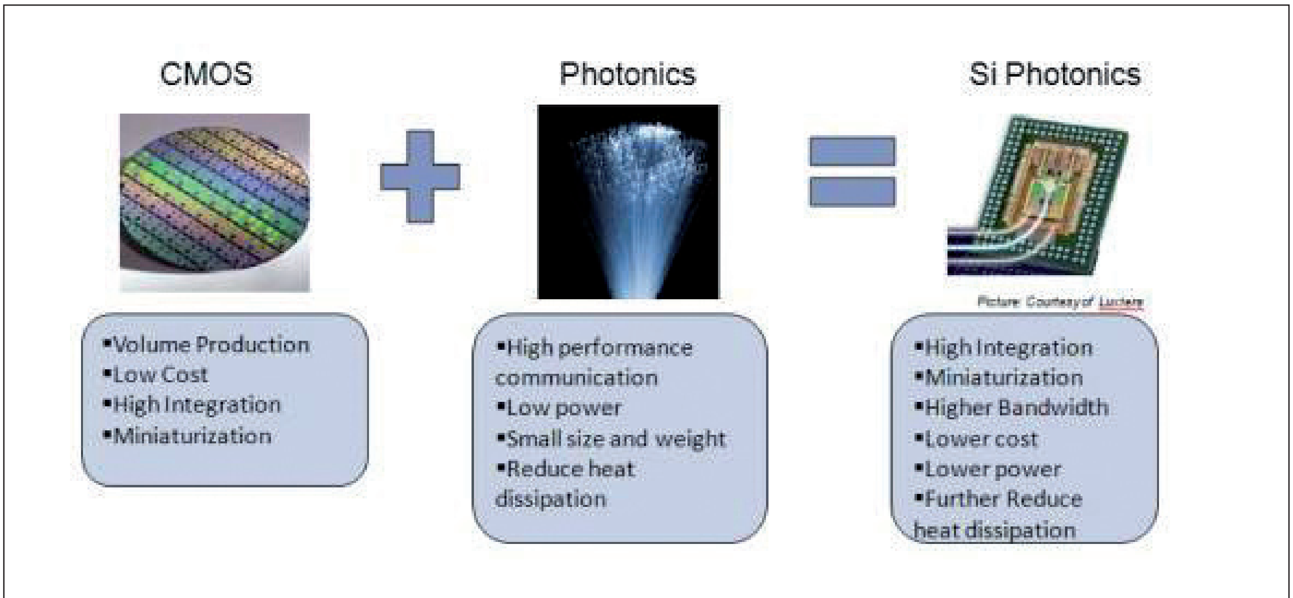
New 64-bit architectures, combined with silicon technologies such as FDSOI (Fully Depleted Silicon On Insulator) can provide very efficient solutions able to simultaneously match the required performance and energy constraints. This approach is also important for data centres and HPC systems, which face the same challenge of providing more computing power within a limited energy budget. In order to reach the performance required to support user needs, the energy efficiency of computing chips must be improved significantly. Providing innovative computing chips with better energy efficiency will open new opportunities in these important markets.

To make the situation even more complex, new silicon solutions will have to efficiently manage existing (legacy) software in order to meet aggressive time-to-market constraints. The integration of heterogeneous systems made up of many different IP blocks will also make interconnection of these blocks a critical issue, because the interfaces between them will have a strong impact on the viability and performance of individual solutions. Due to the size and complexity of today's SoC (System-on-Chip) solutions, it is already clear that such systems will only work if they comprise asynchronously connected synchronous islands. This means that **concepts such as NoC** (Network on Chip) will become very important.

- **Photonics, at the heart of high-speed broadband services**

The ultra-high performance of today's communications networks is based to a large extent on optical communication technologies that allow very high bit rates in the backbone, and increasingly also in the local networks connecting residential areas (fiber to the curb) and individual users (fiber to the home). The ever-growing demand for higher traffic in communications networks means even higher bit rates will be needed in future. As a result, WDM (Wavelength-Division Multiplexing) optical transport backbones surpassing bit rates of 100 Gbit/s per optical channel are already being deployed. Electronic circuits dealing with such high data rates will be highly sophisticated designs most probably based on the most advanced Silicon-on-Insulator (SOI) CMOS or even higher performing SiGe BICMOS technologies. Circuits intended for use in the passive optical (access) network (PON) will face lower speed requirements ranging up to several Gbit/s, but will be required to meet extremely challenging price points. Similar requirements will hold for optical backhaul systems for base stations in wireless access networks. The conflicting requirements of increased performance and reduced energy consumption are extremely demanding. As a consequence, **future high performance systems will increasingly be based on photonic system concepts, which promise significantly higher performance at reduced energy consumption.**

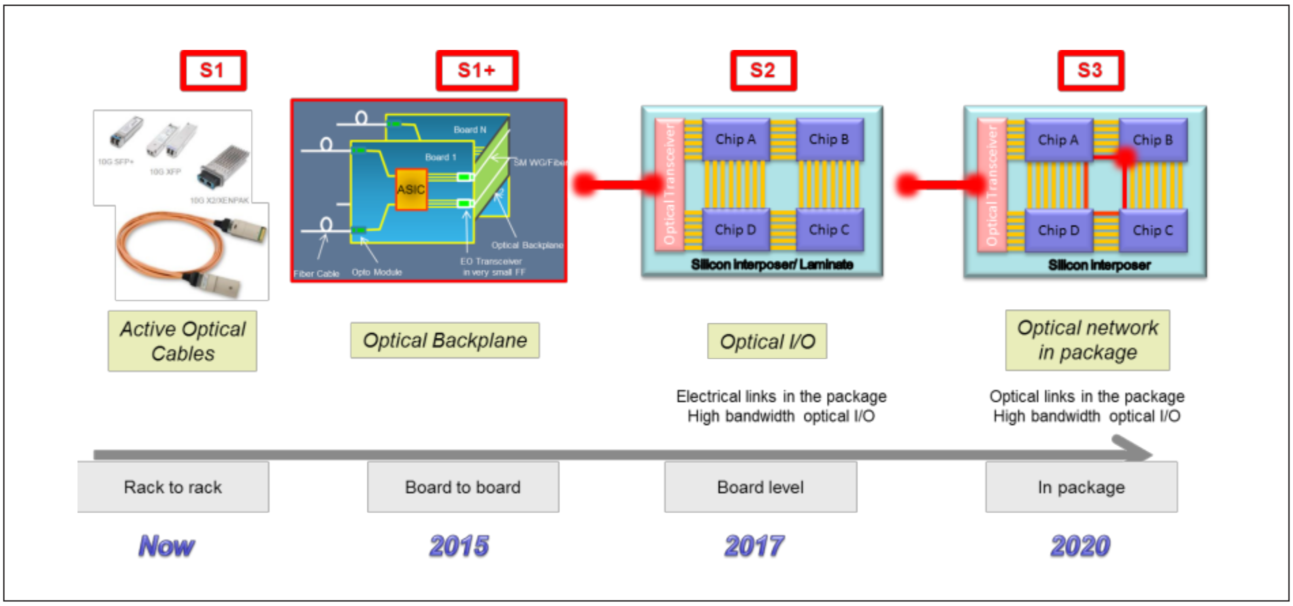
Integrated optics and CMOS circuits based on SOI wafer technology, commonly referred to as 'Silicon Photonics', are going to become the new mainstream processes, opening the door to pervasive high-speed communications at lower cost and lower power. The possibility of combining optics and advanced



CMOS/BiCMOS devices on the same substrate and in the same package offers unique opportunities to miniaturize today's high speed applications and reduce cost and power consumption by factor of 100 compared to traditional on-chip and inter-chip copper interconnects. In fact, it is now possible to envisage solutions where conventional electrical (copper) interconnects are replaced by very high speed on-chip links. Such technologies are already emerging in server markets for die-to-die connection but will soon be required in SoC and SiP solutions to meet the bandwidth requirements. The use of these very high bandwidth links will have an important impact on system architecture and system partitioning and will offer a gateway to the new high-end multimedia systems of the future.

Silicon Photonics can therefore be seen as a disruptive process technology that will remove the bottlenecks to high-speed intensive computing, data communications, telecom and high-end storage applications.

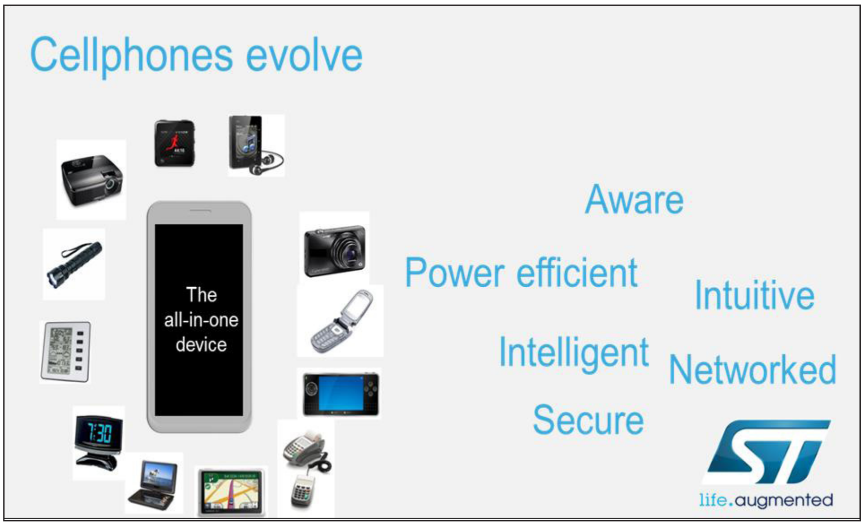
Pilot lines
It is proposed to set up a silicon photonics pilot line during the period **2015 to 2016 in an existing European industrial CMOS wafer fab** to address the roadmap for Silicon Photonics illustrated in the diagram below. Silicon photonics fabrication is based to a large extent on standard CMOS process technology, but dedicated equipment and processes (e.g. III-V bonding, III-V etching, metrology, etc.) will also be needed. Because the future generation of components required for steps 2 and 3 in the diagram below will have a strong impact on packaging, this pilot line is intended to cover **photonics/ electronic integration and packaging as well as photonic chip fabrication.**



2.3.2 Grand Challenge 2: Evolution to a Digital Lifestyle

Vision:
To offer consumers multiple multimedia services through a variety of receiving devices connected to ubiquitous networks with improved intuitiveness in interaction in order to enhance user experiences; and to enable broadcasters and content providers to produce multi-platform content and seamlessly delivery it in a plurality of new formats at reduced cost.

Description:
Consumer electronics devices are becoming more and more complex, with exponential growth in the number of features embedded in to them. The large number of interfaces they feature and the new applications and standards they have to support are adding to this complexity. **Keeping complex devices easy to use is very challenging but it has a strong societal impact.**
The aim is to help less ‘technology oriented’ European citizens to access the digital world and the knowledge that is contained in it. These ‘late adopters’ need seamless access to advanced features/services but should not have to go up a difficult learning curve to accomplish it. Consumers must be able to move content between computer screens, tablet PCs and TV sets without noticing the way the content is re-routed and



transmitted. For example, switching from a wired network to a wireless network should be transparent to the user, with efficient management of the associated bandwidth constraints. Easy access to content leads to an increase in both data exchange and data processing that must be accomplished with latencies that are in line with user expectations.

In addition to multimedia 'infotainment' applications, universal access to services with important societal impact should be provided - for example, telemedicine services. Once again, there will be a requirement to make these services accessible via any device with seamless and secure hand-over and data exchange between devices, also taking privacy issues into account. Smart appliances and home installations (e.g. lighting) will also be controllable via mobile terminals (e.g. smart phones and tablets) potentially communicating via a home gateway. Due to their portability, smart phones are strong candidates to become the centre of people's digital lifestyle and could emerge as the central hub of people's digital activities. In order to limit system complexity and power consumption in end-user devices and guarantee flexibility and de-localisation, it is highly likely that many functions will be virtualised and offloaded to the cloud. Smart phones may therefore play several roles: mobile telephone, personnel organizer, companion device for Digital TV services, smart home control device and gateway to web services.

The evolution of Digital TV is a good example of new challenges in the area of digital lifestyle. Looking at the roadmap for TV over the coming 10 years, this evolution can be positioned along two closely linked axes:

1. The new High Efficiency Video Coding (HEVC) or H.265 codec, which offers more than 50% better bandwidth efficiency than the current MPEG AVC codec, will enable deployment of new IPTV, OTT and DVB-T2 services. HEVC also paves the way for the delivery of what is often called 'beyond HDTV' or more precisely, UHDTV

2. Ultra-high Definition TV (UHDTV), the next-generation Digital TV for the coming decade, may start by the year 2016 in the form of HDTV with a higher frame rate (e.g. 100 Hz). It is likely to be quickly followed by 4K Ultra-HD around the year 2018 and by 8K Ultra-HD around 2025. Compared to HDTV, 4K Ultra-HD, also called UHD1, offers roughly twice the number of horizontal pixels (3840) and twice the

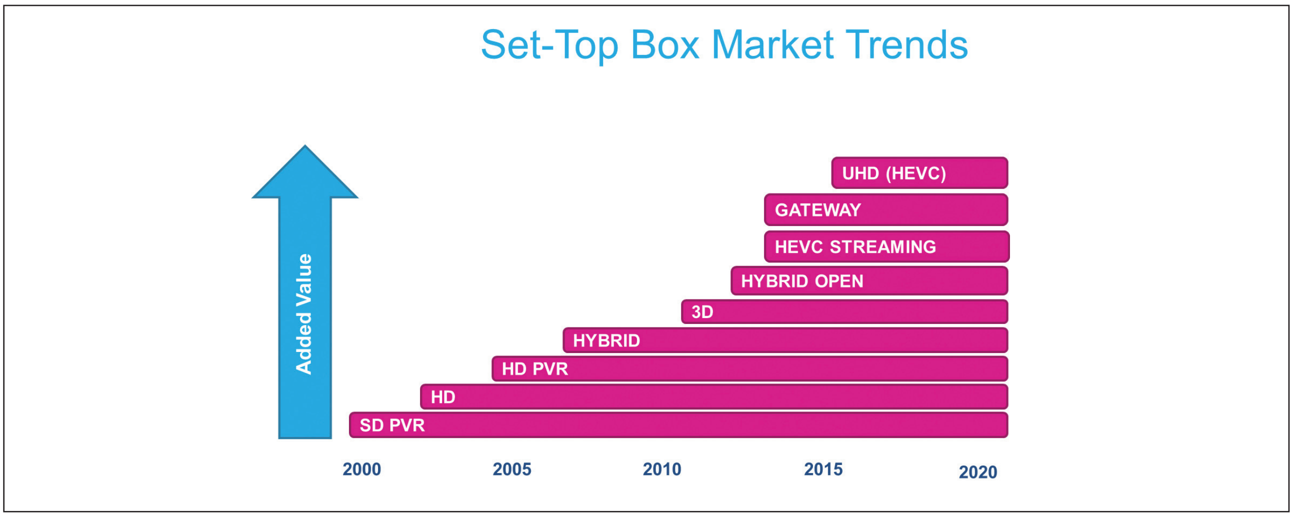
number of lines (2160), possibly also with higher frame rates as well as increased colour space and colour depth (10 bits or more). The 8K Ultra-HD standard, also called UHD2, offers four times more pixels than 4K Ultra-HD.

Thanks to increased spatial resolution, UHDTV would naturally be viewed at large picture angles (large screen sizes in relation to viewing distance).However the viewer's eyes will more frequently have to track moving objects, which means that the natural 'motion blur' of the human eye will no longer mask the 'motion blur' introduced by the end-to-end capture, delivery and display.. To maintain good or better motion portrayal, the frame rate (temporal resolution) will have to increase at least as much as the spatial resolution.
Note that each step in the TV roadmap indicated above brings new challenges along the end-to-end value chain, from camera to display, including the codec used and the delivery system. The inclusion of metadata and the deployment of 3DTV (with or without special glasses) are additional challenges that need to be addressed in the coming years. To fulfil the need for ever-more bandwidth intensive services, more effective delivery systems such as DVB-S3 or better broadband IP services will be needed. As a consequence, set-top boxes and TVs will need to be a lot 'smarter' than they are today. Driven by CMOS scaling and advanced multi-core computing architectures, highly integrated silicon devices are already providing innovative multimedia services, including home microserver data management, home personal assistance, home security, energy monitoring, and the relay of content around the home to a large number of connected devices.

The above trends in the evolution of digital TV also have consequences for broadcasters and content providers. From the same event coverage (e.g. a football match), multiple production versions may need to be generated. This could be extra content for premium viewers, or special adaptations to suit the display device. For example, even smart phones are now capable of displaying full HD resolution, but their picture angle is dramatically smaller than that for a person viewing a large 'immersive' living room TV. This calls for different production versions to be tailored to the different viewing formats, while still using the same camera feeds.
With the introduction of new video formats, such as UHDTV, 3D, super slow-motion and surround video, bandwidth requirements throughout the whole production chain will explode. Not only will different formats have to be generated for different consumer devices (multi-platform content delivery), but the rate of introduction of new formats will also increase. To keep pace with the demand for new video formats and the creation of different content streams, content production infrastructures (studios, outside broadcast vans, and remote production facilities) will have to move from proprietary infrastructures and transmission systems dedicated to one video standard to Internet Multimedia infrastructures that can handle a mix of video formats at the same time (and mix them in one program). As more content will have to be produced at the same cost, workflows will have to be optimized by extensive automation (e.g. less human intervention in video shaders and the use of autonomous cameras), and production costs for location shooting (travelling, labour costs and equipment) minimized. In the longer term, the use of Internet infrastructures may enable new services, such as user-access to individual camera feeds during live productions.

Competitive Situation:

The consumer electronics market continues to move out of the analogue world and in to the digital world, offering the possibility to connect people's homes to a wide range of multimedia services. Towards the 'digital connected home', the set-top box already plays a central role in offering multimedia services, and despite the poor economic



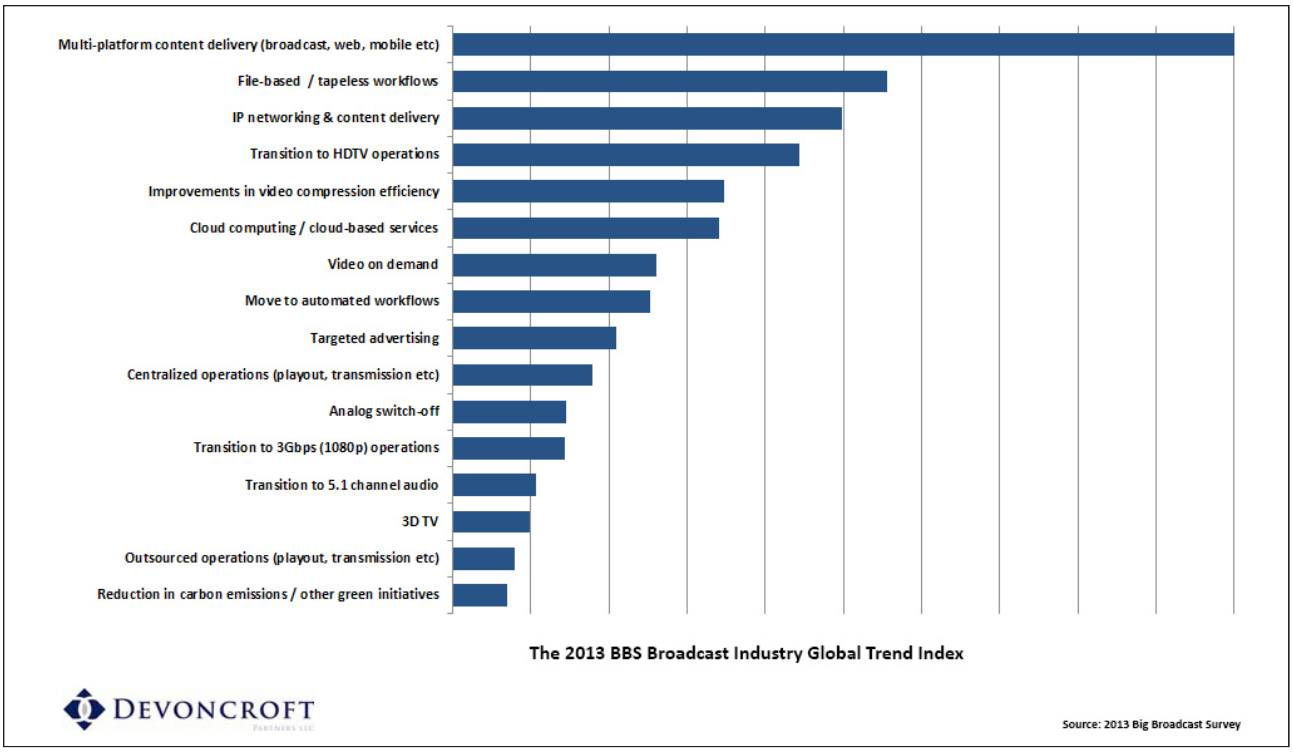
environment, the market for STBs is still showing solid growth, driven partly by demand in emerging economies.

According to new research in 2013 by market analyst company IHS, shipments of set-top boxes for cable, satellite, terrestrial and IPTV digital TV services are set to reach 269 million units this year - almost 8% up from the 250 million units shipped in 2012.

This year (2013) is also tipped to be the most valuable year in the history of the market, with STB revenues expected to grow to US$22.2 billion (€17 billion). In 2014, shipments will grow by another 6% to 286 million units and will increase by a further 1% in 2015 to 290 million – "a market peak for the foreseeable future" – according to IHS. After 2015, shipments are expected to start declining, decreasing by 5% in 2016 and by another 2% in 2017. By that time, however, 'Beyond HDTV' concepts will have started to ramp up.

It should be noted that the forecast made in 2009 for set-top box shipments in 2014 to reach 180 million units is now considered to be a significant under-estimate. The currently forecast figure for 2014 is 286 million units. The set-top box market therefore still offers large opportunities for semiconductor manufacturers to supply components such as audio/video processors, memories, demodulators and tuner ICs. Pace, Motorola and Technicolor are currently the top three set-top box suppliers. As far as the digital TV market is concerned, IC Insights forecasts the market to reach US$16.8 billion in 2014, resulting in an average annual increase of 13% per year over the 2009 to 2014 time period.

The figure below shows the 2013 Broadcast Industry Global Trend Index by Devoncroft. To enable direct year-on-year comparison of trends across different demographics, Devoncroft kept the list of trends in this index for 2013 the same as in 2012. This means that they decided not to include certain new technology trends in the 2013 index, including 4K UHDTV, HEVC, second screen applications, connected TVs, DSLR cameras, Ad-ID, and social TV. Clearly, multi-platform delivery and IP networking are top priorities for the broadcast community.



The table below shows the different segments in the broadcast market (excluding services) and their size in 2010 (figures are from the latest IABM Valuation Report of 2011).

Segment	Segment value in 2010 (M$)	CAGR (2011 – 2015)
Acquisition and Production	2,970	5.2%
Post Production	1,350	4.2%
Content & Communication Infrastructure	1,479	4.6%
Audio	732	4.4%
Storage	3,818	6.2%
System automation and control	528	4.9%
Playout and delivery systems	4,423	4.6%
Test, quality control and monitoring	652	4.7%
Total	15,952	4.8%

The IABM report predicts that by 2015 global broadcaster revenues will grow to US$0.8 trillion, while capital expenditures will be 4% in 2015 (CAGR of 4.5% between 2010 and 2015). The EMEA region (Western Europe, Eastern Europe, the Middle East and Africa) is the largest market in terms of broadcast revenues - the region is set to grow to US$13.6 billion in 2015 (CAGR of 5.0% between 2011 and 2015). Western Europe is the largest region in EMEA, representing 69.0% of revenues. In 2010 manufacturer revenues derived from Western Europe totalled US$7.4 billion.

Expected Achievements/Innovation Foreseen:

- **New video sources and content management**

The next 5 years will see the deployment of 3DTV; the emergence of Ultra High Definition TV, super slow-motion, surround video; and the generation of new content with immersive video in which virtual content and reality are merged together. The management of these new content and video formats on various devices (TV, set-top box, mobile phone, tablet, etc.), as well as mixing these formats in live productions, represent demanding new technical challenges.

- **Ubiquitous access to content**

Access to content anytime, anywhere, on any device. Users are not interested in format transcoding, digital rights management (DRM) or bandwidth issues - they only want to watch or listen to content. As a consequence, there will be a need for high-bandwidth multiple entertainment streams that protect both the content producer (DRM) and the consumer's privacy. Fast video search engines to search for video sequences in huge video data banks will also be needed.
For broadcasters and content providers this will mean having access over public infrastructures to all the necessary video and audio streams needed to produce professionally crafted program material. For outside broadcasts and event coverage, this will be the only way to contain their production costs, because it will reduce the number of production staff and the amount of equipment that has to be transported on-location, and allow the final production to be crafted in a centralized studio. Although divided between two locations, the production will be perceived by users as being one (virtual) program location.

- **Data-centric approach**

Data centricity means seamless access to any piece of data produced by any home device. A large number of consumer devices are currently used in typical homes (PCs, tablets, mobile phones, DTVs, temperature sensors, door sensors etc). Although most of these devices have communication capabilities (IP, Bluetooth, Zigbee, GSM/4G), the data produced by one device is not typically available to other devices. Data-centric approaches require all such devices to be able to share the information they acquire with other devices, regardless of manufacturer or device type. This will allow users to fully exploit the available information, enabling a whole new range of lifestyle related applications. There will therefore be a need for open hardware and software protocols/mechanisms that will free the data confined in one device so that it can be used by others, leading to truly ubiquitous data availability. The heterogeneous and distributed nature of the data repositories, the ability to switch devices on/off at will, and privacy and security issues will all have to be taken into account.

2.3.3 Grand Challenge 3: Cognitive Radio

Vision:

'Cognitive Radio' aims to introduce highly flexible energy-efficiency wireless architectures that support multi-band multi-mode operation.

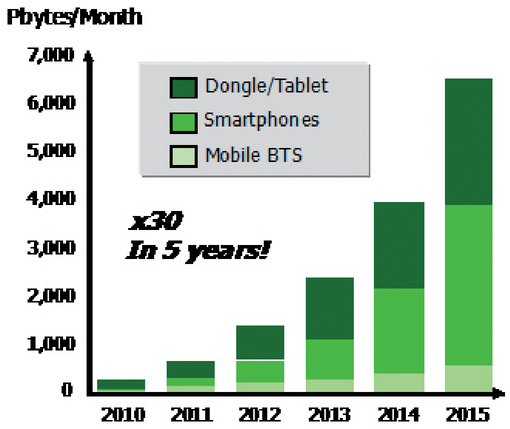
Description:

Over the past 10 years, wireless connectivity has exploded as devices increasingly need to be connected to previously separated systems and networks. These connectivity requirements relate to several different technical domains, including fixed and mobile networks, public and private networks, and telecommunications and ICT systems. In essence, devices should be able to use any combination of these infrastructures to seamlessly tunnel data from source to destination. In the world of digital convergence (the convergence of Information Technologies, Telecommunications, Consumer Electronics and Entertainment), the main driving factors are mobility and continuity/quality of service.

Convergence requires that connectivity links, targeted originally for fixed or pedestrian terminals (for example, WiFi standards IEEE 802.11 a/b/g), can be extended to mobility (for example, the introduction of the IEEE 802.11p 'wireless access in vehicular environments' standard). The associated increase in data traffic is the driver behind the development of wireless technologies that achieve high data rates, high spectral efficiencies and low power consumption. (This holds not only for wireless access networks, it also holds true for fixed optical networks, where Software Defined Network (SDN) concepts enable automatic dynamic and flexible (re-)configuration of photonic transport networks.) For wireless access, the latest connectivity technologies aim to exploit new regions of the RF spectrum, notably the mmWave region (for example, short range at 60GHz compared to current WiFi systems which operate in the 2.4 or 5 GHz band) as recently addressed by the IEEE 802.11ad standard and other consortia initiatives (e.g. Multi-Gigabit Wireless Systems).

Competitive Situation:

The rapidly growing broadband communications market and the development of advanced RF CMOS and Si/SiGe technologies are driving the development of a new generation of transceivers and power amplifiers for use in mobile communication devices. The number of smart phones and small cell base stations is expected to explode in the coming years. Compared to the situation in 2012, smart phone density will increase by a factor of 32 by 2015, and the number of base stations by a factor of 25. Cognitive radio and self-organising network functionality will be needed to improve the spectral efficiency and dynamically optimise network configurations. New concepts in cognitive radio will include spectrum agility (dynamic spectrum management) and cooperative detection, both of which will challenge local processing and transceiver resources. This will require the development of cheap tuneable wideband RF power amplifiers and efficient network processors. For energy reasons, and to limit the amount of processing power needed in base stations and terminals, some processing tasks may be offloaded to the network (network function virtualisation).



According to a recent IBS market analysis, the transceiver market was worth US$6.0 billion in 2010 and is projected to be worth US$15.8 billion in 2018. This market is directly related to the booming demand for smart phones and the need to support multiple protocols, eg, LTE, UMTS, EVDO, EDGE, GPRS etc. The power amplifier market was worth US$3.1 billion in 2010 and is predicted to increase to US$12.2 billion in 2018. The migration from analogue to digital will result in a major transformation of RF functionality, giving European semiconductor suppliers the opportunity to offer innovative new devices. These will include single-package solutions that integrate RF power amplifiers and transceivers, or RF modules that include low power Wi-Fi, Bluetooth and NFC capabilities (where security will become a key area of competitive differentiation). The adoption of CMOS technology for power amplifiers will also result in changes in the vendor base.

Expected Achievements/Innovation Foreseen:

Towards the convergence of fixed and mobile networks, the first **key challenge is the development of RF components capable of handling 2GHz bandwidths** (current WiFi RF modules have to handle bandwidths up to 200 MHz to be compatible with the IEEE 802.11n standard). On top of this, it will be necessary to further advance the development of multiple antenna transmission/reception - so called Multiple-Input Multiple-Output (MIMO) technology - with the aim of increasing the robustness and/or throughput of wireless links. This issue has recently been addressed in the IEEE 802.11n WLAN standard. Due to the number of interfaces that need to be integrated into a low volume device, the RF problem is becoming a real headache in mobile systems. The increasing data throughput resulting from multimedia and Internet browsing on mobile devices is making the situation even worse. Innovative new solutions are definitely needed. For example, highly flexible programmable Tx/Rx chains that can handle different protocols, modulation schemes and bandwidth spectra need to be developed. Spectrum/frequency agile radio will be another very important development, because it provides a way of managing diversity in term of radio interfaces while maximizing hardware and software resources. Such solutions will be able to monitor local radio spectrum utilisation and dynamically adapt the transmitted data rate according to the available radio resources, thus making best usage of available spectrum. Comprehensive system knowhow (the agile radio hardware and the associated software algorithms and protocols) will be crucial, since the ability of agile systems to sense the local RF environment and optimize quality of service in crowded RF spectra will be critical to a good user experience. **The convergence of consumer, computer and communication systems requires more communication protocols to be supported by a single device, with more multimedia operations executed in embedded processors.** More security checks also need to be offered. However, it is the so-called ‘green policy’ - the need to reduce the power consumption of such devices - that represents one of the most technologically challenging design constraints (e.g. deep architecture analysis with focus on ultra-low power, best in class low power technologies, advanced power management solutions, 3D packaging etc.). Two possible solutions will lie in 'cloudification' and Network Function Virtualisation (NFV), both of which can reduce the local processing load, and hence the power consumption, by offloading processing tasks to the network.

In addition to power-efficient signal and data processing, software-defined optical network (SDN) concepts will require high performance photonic elements such as wavelength converters add/drop multiplexers and signal processors. This is an area where SiP assembly technologies will be extremely important.

2.3.4 Grand Challenge 4: Short-range Convergence

Vision:

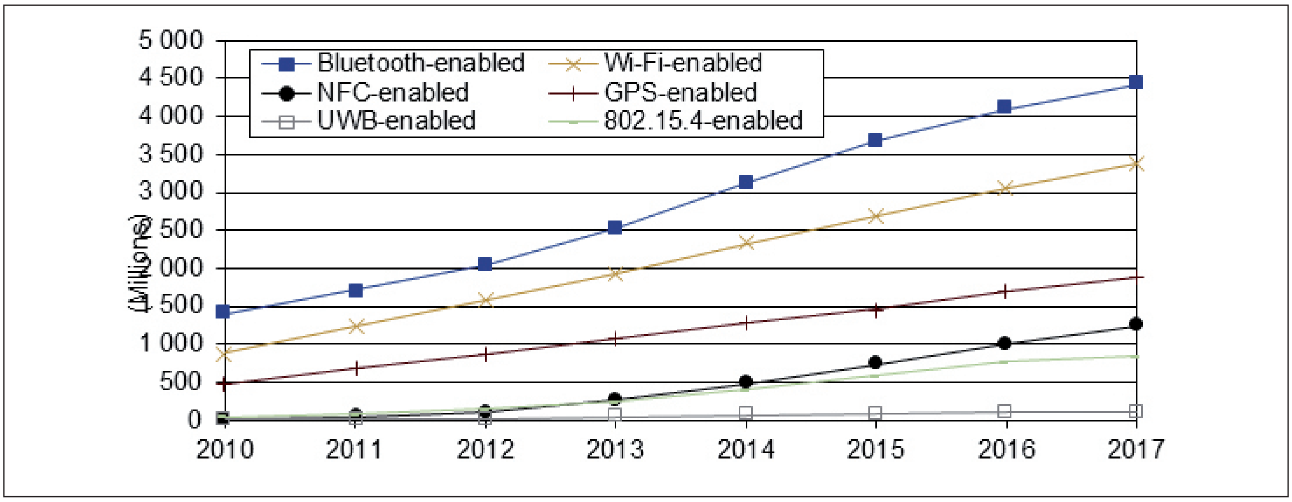
The ubiquity of mobile devices and the deployment of wireless networks offer extensive scope for innovation. The aim of Short-range Convergence is to develop a new class of energy-efficient single-chip systems able to sense, communicate, reason and actuate.

Description:

Recent advancements in wireless communications and sensor electronics have enabled the development of low-cost low-power multi-functional sensor nodes that are capable of communicating over short distances. Tiny sensor nodes, consisting of sensing, data processing and communication components, are able to sense information, such as recognizing human gestures and monitoring environments. For example, body-worn biometric sensors will monitor vital signs such as body temperature, pulse rate, breathing rate etc., and alert healthcare or emergency services of critical events. The Internet of Things (IoT), which will also require machine-to-machine (M2M) communication, will make intelligent smart devices (smart city/building/grid, intelligent car. etc.) ubiquitous, pervading people's environment with computing power. This is a sector where knowledge of the application field is essential for success, making it a good breeding ground for niche business opportunities. In mobile terminals, even shorter range wireless technologies such as Near Field Communication (NFC) and Radio Frequency Identification (RFID) **will boost the number of functions that mobile devices can perform.**

Competitive Situation:

Short-range wireless technologies (e.g. Bluetooth, NFC, UWB, 802.15.4 and Wi-Fi) are **now well established in many electronic devices and rapid growth is forecast for the latest ones, such as NFC and 802.15.4. The volumes of Bluetooth enabled and Wi-Fi enabled devices shipped this year (2013) are expected to surpass two billion units,**



an increase of approximately 20% compared to 2009. Shipments are forecast to total five billion in 2014, according to new market data from ABI Research. Driven by the development of smart autonomous wireless sensors and M2M communication, radio devices are increasingly in demand for short range wireless applications such as building applications, home automation systems, industrial control, medical systems and commercial transaction systems.

Expected Achievements/Innovation Foreseen:

All these applications have their own specific profiles but all face common challenges when it comes to their large-scale deployment and acceptance.

For all of them, **a paradigm shift is needed in the energy management domain.** Further research is needed for ultra-low power analogue interfaces and radios as well as for the digital part. If power consumption can be sufficiently reduced, harvesting energy from the environment should substantially enhance the autonomy of systems and reduce or eliminate their battery requirement. The second area to consider is linked to the necessity to increase the functionality of sensors nodes and their **capability to work in harsh environments.** Low complexity real-time algorithms have to be developed to improve the performance of smart autonomous systems and new network protocols need to be developed and implemented to operate in exceptionally harsh environments (for example, in vehicle or industrial applications). This also means that sensor network protocols and algorithms must possess self-organizing capabilities. The design of sensor networks is therefore influenced by many factors, including fault tolerance, scalability, production cost, operating environment, sensor network topology, hardware constraints, and power consumption. Other important aspects are higher data rates within networks and between base-stations/routers, as well as in connections to public networks and the Internet. Cloudification and virtualization of specific functions may be a solution for energy limitation.

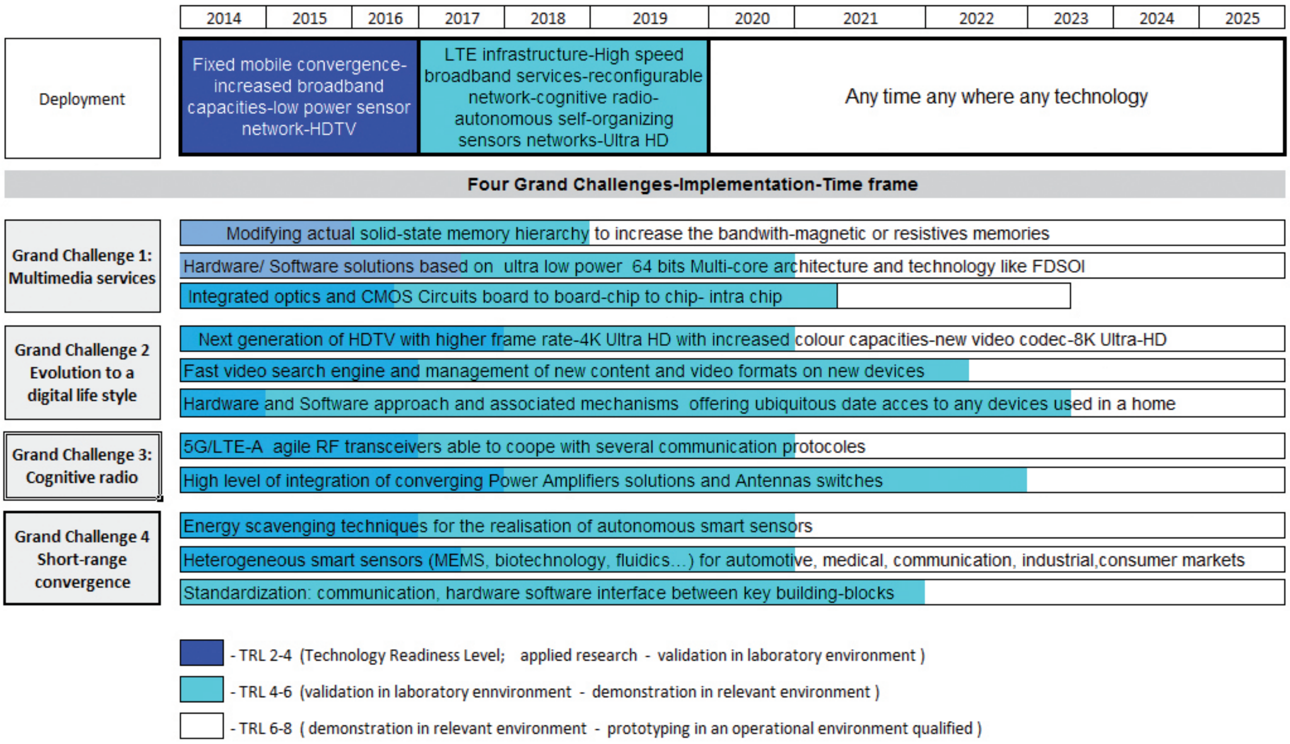
2.4. CONDITIONS FOR SUCCESS

The convergence of consumer, computer and communications systems involves exponential growth in software code and data. In this context, progress in digital CMOS (logic and memory) technology will be a key determinant of success. However, traditional integration based on Moore's law will only be part of the solution. Because of power consumption, flexibility, size and cost, next-generation electronic communication systems will require new technologies and architectures that combine adaptability and performance in novel ways. To tackle these new challenges, specific attention has to be paid to ultra-low power CMOS, CMOS-compatible 3D processes, thin-film technologies, (e.g. SOI, Thin FET), RF and analog mixed-signal, memory technologies, and silicon photonics. The aim is to support multi-standard wireless communications at higher RF frequencies and higher efficiencies.

The need for high-gain/high-frequency transistors able to operate in the 50 GHz to 100 GHz range, coupled with a suite of high quality passive devices (capacitors, inductors, antennas) for the same frequency range is mandatory. These challenges will not be efficiently addressed by a single process technology. Wherever there is a need for high-power, high-efficiency and low noise, BiCMOS technologies will have to be deployed. The never-ending demand for new integrated functions should also be helped by the development of 3D integration techniques that allow the vertical stacking of several chips in the same package. The availability of this capability will, for example, enable the stacking of dedicated function chips to realize highly complex SiP solutions. One of the major trends in mobile communications is multi-standard compliancy, which requires a highly integrated multi-standard Rx-Tx chain right up to the antenna, while also being low cost. Technologies based on SOI will enable the fabrication of high-isolation RF switches coupled with good mixed-signal (analog + digital) device integration.

A second key determinant of success will be memory technology. This is true for cell phone handsets, broadband devices, and networking. In the past, memory technology was associated with a specific market segment (Computer + DRAM, mobile communications + NOR Flash, Consumer DSC + NAND Flash). Today, memory systems include stacks with different non-volatile and X-RAM memories (often with a microcontroller to facilitate interfacing and memory management) in order to fit the needs of convergent applications - i.e. intelligent easy-to-use electronic systems. Memory systems, and their implications in terms of density, technology performance, packaging and interfacing, will become of more and more interest in order to improve overall electronic system performance.

2.5 TIMEFRAMES



2.6 SYNERGIES WITH OTHER DOMAINS

Synergies with the other domains include:

- Low power and RF design will find synergies with the ‘Design Technologies’ domain as well as involving the ‘Semiconductor Process Integration’ domain.
- The heterogeneous 3D integration required in next-generation cell phones and sensors networks will be an issue for ‘Design Technologies’ as well as at process level.
- Silicon photonics solutions will require specific silicon technology improvement and therefore have to be developed in strong collaboration with parties working in the ‘Semiconductor Process’ domain.
- Self-organizing networks and short range convergence will be essential in the ‘Health and Aging’ as well as the ‘Energy Efficiency’ domains.
- Internet multimedia services will also be an issue for ‘Automotive and Transport’ projects, especially with respect to car-to-car communication.

CHAPTER 3
ENERGY EFFICIENCY

3.1 Introduction

As communicated in the European Commission's Energy Efficiency Plan 2011 (Com 2011-109), *"energy efficiency is at the heart of the EU's Europe 2020 Strategy for smart, sustainable and inclusive growth (COM 2010) and of the transition to a resource efficient economy. Energy efficiency is one of the most cost effective ways to enhance security of energy supply, and to reduce emissions of greenhouse gases and other pollutants. In many ways, energy efficiency can be seen as Europe's biggest energy resource. This is why the Union has set itself a target for 2020 of saving 20% of its primary energy consumption compared to projections, and why this objective was identified in the Commission's Communication on Energy 2020 as a key step towards achieving the European long-term energy and climate goals."*

Identified by the European Commission as Key Enabling Technologies (KETs), **micro- and nano-electronics, including semiconductors,** are considered essential to the efficient management of electricity generation and storage, as well as its transport and consumption through intelligent electrical grids and devices.

The European nanoelectronics industry, in cooperation with research facilities contributes with innovative solutions, based on long-term research and innovation at all Technology Readiness Levels (TRLs), to achieve the targets set by the European Commission. Europe's leading market position in energy-related technology is based on a long history of research, and practical results in terms of world-class manufacturing capabilities and large-scale renewable energy source installations. The long term collaborative approach must be continued, with advanced research from the lower TRLs to innovations close to the market (higher TRLs), in order to maintain Europe's competitiveness and manufacturing capabilities in the face of global competition. The global contribution of renewable energy in terms of electricity generation was 20% in 2010, and it is expected to rise to 31% over the coming years. However, within the European Union its contribution is projected to rise to 43% (source IEA, World Energy Outlook 2012, outlook to 2035). In terms of improved overall energy efficiency it is clear that electricity generation, distribution and consumption are some of the most critical areas for research. They are all areas where innovative semiconductor-enabled technologies can provide intelligent solutions to save energy.

Energy solutions that are described as 'smart' (e.g. smart city, smart buildings, smart homes, smart appliances, smart lighting, smart systems, smart grids) all make use of semiconductor-based technologies. Nanoelectronics-based solutions, including sensors to monitor parameters such as temperature, movement, speed or voltage; communication chips to receive and transmit data; memory chips to store information; microcontrollers/processors to process data; power management chips to analyse energy consumption and control energy distribution; and actuators to trigger intelligent energy-saving functions, will be enablers for the required smartness. Smart grid technologies will also enable the more cost-effective deployment of decentralized, cleaner, renewable energy sources such as solar panels and wind turbines. Large day-to-day fluctuations in the energy available from PVs (photo voltaic) or wind turbines demand flexible management of electrical energy through the use of smart grids. At some point in the future, these smart grids will have to cope with the growing need to charge electric vehicles. Together with increased demand for local storage, these requirements provide unique new opportunities to exploit semiconductor technology.

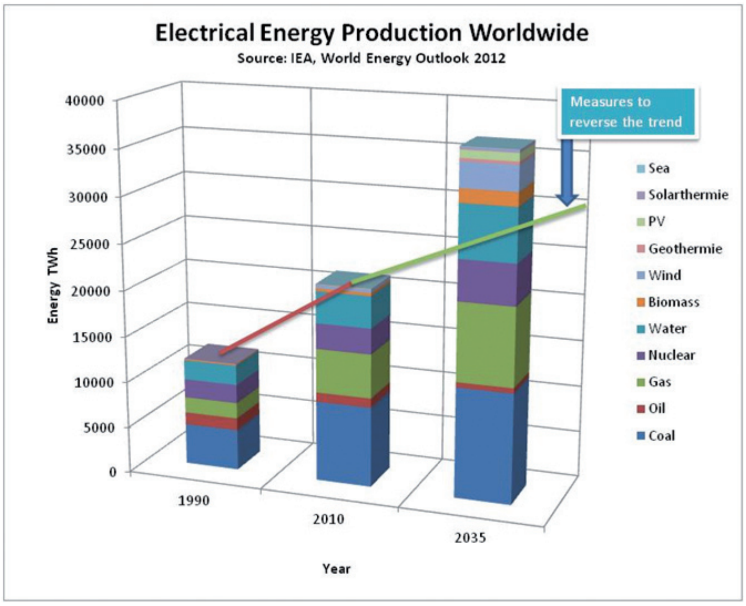
By focusing on micro- and nano-electronics approaches, products featuring efficient power supplies and intelligent energy control could reduce electrical energy consumption in Europe by 20% to 30% by 2020, safeguarding energy supplies. This will reduce CO^2 emissions by an order of magnitude in line with the targets set by the European Commission for 2020 and by the extended Kyoto protocol for the second commitment period up until 2020. It will also limit energy cost increases.

Energy efficiency research is needed in the whole energy chain, from generation to end user.

- Energy losses occur in all segments of the chain:
    - **At the conversion to electrical energy during generation**
        - impact on carbon dioxide emissions
        - impact on installation investment in renewables
        - economic impact due to energy costs
    - **At the distribution – Smart Grid**
        - HV distribution lines
        - DC distribution
        - transmission from regions with energy supply excess to requesting regions over the continent
        - management of oversupply / shortages
        - management of decentralized multiple variable sources
    - **At the end user**
        - conversion losses
        - equipment efficiency
    - **In a connected environment – Smart City**
        - application and societal driven energy use
        - interdependent use of energy

Total electrical energy production worldwide doubled in the years from 1990 to 2010, and in the absence of severe measures to increase efficiency throughout the chain, the outlook suggests a linear increase (Source IEA, 2012). **Other than growth in the installation of renewable energy generation** (growth rates of 20% to 30% were achieved in 2012 for wind or solar energies - *Source Renewables 2013 – Global Status Report),* **the**

only way to limit green house gas emissions is to increase efficiency in the entire chain from source to user. If these efficiency increases are not realized, it is inevitable that the generation of electricity from coal, oil or gas will have to increase in order to meet energy demand.



Electrical Energy Production - efficiency measures and installation of renewables are the only way to limit green house gas emissions from coal-, oil- and gas-fired power stations.

3.2 Relevance for Europe

3.2.1 Competitive Value

European users consumed 3.1 million GWh of electrical energy in 2003, which according to a 2009 study by the IEA (International Energy Association) will increase to around 3.6 million GWh in 2020. Energy efficiency measures have been identified as one of the most important factors in reaching the ambitious greenhouse gas emission targets set by the EC. The other important factor is growth in renewable energy resources.

Energy Efficiency

Over the last ten years, it has become self-evident that innovative semiconductor-based technologies have enabled the saving of more electrical energy than growth in demand over the same period. In addition to the on-going installation of renewable energy sources, such as solar-, wind- or hydro-power, 0.7 million GWh could be saved by the year 2020 through the use of intelligent and innovative electronic components and systems. The potential itself is estimated to be 25% of current EU-25 electricity consumption, of that half the potential being in lighting applications. The implementation of energy efficiency measures will significantly support energy policies and industrial competitiveness in Europe.

To summarize: the energy savings that could be achieved by introducing intelligent power electronics into those application areas shown below is enormous: approximately 25% of the current EU-25 electricity consumption.

Application		**Electricity consumption** [% of EU cons.]	**Electrical energy saving potential**	**Energy saving potential** [% of EU consumption]
Motor control - industrial applications - appliances, HVAC, lifts - traction drives		**~ 50%**	**30 - 40%** **(feasible in ~ 50% applications)**	**5 - 6%**
Lighting		**21%**	**> 70%**	**> 14%**
ICT	Data centres and servers	**2%**	**50%**	**1%**
	Radio base stations	**1%**	**30%**	**0.3%**
	Standby consumption	**4%**	**80 - 90%**	**3.6%**

Energy savings potential
(Source CATRENE Integrated power & energy efficiency Report, March 2013)

The global market for power semiconductors is currently (2013) somewhere in the region of €13 billion per year. With a projected CAGR of 8.3%, it is expected to be worth around €22 billion per year by 2020 (not including controls, the replacement market or breakthrough technologies for power-saving equipment). In 2011, European suppliers had a market share of around 33% in the power module market and 20% in the discrete semiconductors market, giving them an average share of 24% in the global market. Market penetration in Europe is supported by legislation (the elimination of incandescent lighting, limits on the standby power consumption of consumer products, expansion of renewable energy generation and the (re-)construction of energy grids) as well as by consumer demand for reduced-CO^2 products. In most of these domains (industrial, lighting, control and management of energy) Europe has a number-one position, and the number of jobs being created in them is increasing. It is therefore critical to support these efforts and build on existing strengths in the European economy. To reach new levels in energy efficiency, outstanding technical excellence will be needed based on increased R&D efforts involving multi-disciplinary, multi-company, multi-national and multi-application groups.
In recent years (2009-2013), the European nanoelectronics industry has made significant investments in power semiconductor manufacturing in order to prepare for the future. This has not only saved and generated a significant number of highly-skilled jobs in Europe, it has also laid the foundations of future employment in the region. Direct manufacturing investments were made in Austria, Germany, France and Italy to increase capacity, in order to keep pace with increasing market demand and stay at the leading edge in terms of technology.

Renewable Energy
Renewable energy sources are changing the landscape in the electricity generation industry. The supply of energy changes from centralized power stations to decentralized smaller power generators with variable output. This variability and decentralisation have a significant impact on distribution systems, generating lots of opportunities for innovative semiconductor-based solutions in the whole renewable energy generation chain.

Worldwide, 283 GW of wind power and 100 GW of solar PV capacity was installed in 2012, Europe's share of this being 70% for solar PV and around 40% for wind power. PV represented around 37% of all new capacity in the EU in 2012. This rapid rise in the installed base of PV is already starting to affect the structure and management of Europe's electricity system, in some cases resulting in direct competition to conventional electricity producers, and in other cases saturating local grids.
Based on their strong home market, European companies currently have excellent competitive advantage, but in the face of global competition it will be necessary to intensify research into renewable energy sources in order to maintain that advantage.

3.2.2 Societal Benefits

Energy efficiency impacts European society in multiple ways, affecting all domains - public, private and industry. It is the political, social and technical challenge of the current decade. Europe's primary goal is to protect its natural resources and its environment in a sustainable manner. A clear target in this respect is the reduction of CO^2 emissions by preventing energy wastage, either caused carelessness or through the use of outdated equipment. Reducing electrical energy consumption will be critical to meet Europe's target of a 20% to 30% reduction in its total energy consumption by 2020.

Highly innovative technologies guarantee high value employment. With more than one million jobs and many more people indirectly employed in related industries, the renewable energy industry is an important contributor to Europe's economic and social stability.

TABLE 1. ESTIMATED DIRECT AND INDIRECT JOBS IN RENEWABLE ENERGY WORLDWIDE, BY INDUSTRY

Technologies	Global	China	EU	Brazil	United States	India	Germany	Spain
	Thousand Jobs							
Biomass[a]	753	266	274		152[f]	58	57	39
Biofuels	1,379	24	109	804[e]	217[g]	35	23	4
Biogas	266	90	71			85	50	1
Geothermal[a]	180		51		35		14	0.3
Hydropower (small)[b]	109		24		8	12	7	2
Solar PV	1,360	300[d]	312		90	112	88	12
CSP	53		36		17		2	34[j]
Solar heating/ cooling	892	800	32		12	41	11	1
Wind power	753	267	270	29	81	48	118	28
Total[c]	**5,745**	**1,747**	**1,179**	**833**	**611**	**391**	**378[h]**	**120**

Renewable energy as a significant employment factor - more than 1 million jobs in Europe. Source REN21 - Employment data 2012

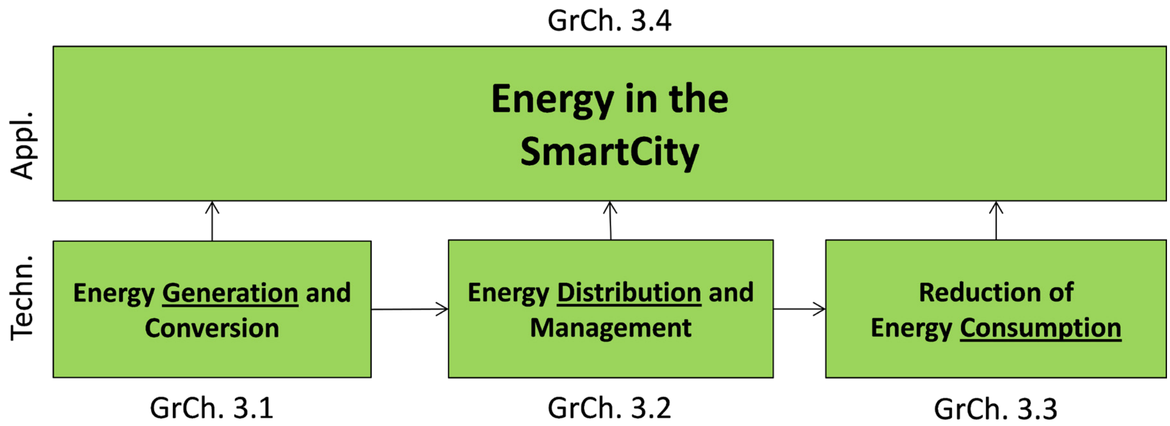
A second aspect of energy efficiency is its financial impact, because prices for energy continue to increase. In Germany, the cost of imported energy reached 3.5% of the country's GDP in December 2012, amounting to around €90 billion for the year as a whole. By comparison, R&D investment currently works out at around 2% of GDP in Europe, with the 2020 EU-28 target being 3%. Money spent on imported energy reduces that available to member states, their population, and their schools and hospitals. In addition, the high cost of imported energy makes industry less competitive, or forces it to move to other areas of the world where energy costs are lower, thereby increasing European unemployment.

The European microelectronics R&D sector must therefore provide innovative technologies and associated ICT solutions to enable the development of energy-efficient products and intelligent power management solutions for industry and private households. The backbone for intelligent power management systems will be the so-called 'Smart Energy Grid' or 'Smart Grid'. The value of smart grids cannot be overestimated, because electricity networks are among the most critical infrastructures in all European countries. Smart grids will help countries to remain autonomous, by guaranteeing their citizens and industries continuous access to electrical energy, while at the same time reducing their dependence on fossil fuels. Last but not least, energy will stay affordable for everyone. Through combined efforts at European level, there is now a historic opportunity to extend the technological leadership of European industry in this field and strengthen its competitiveness. The impact on high-qualification jobs in Europe will be enormous.

3.3 Grand Challenges

A strategy for reducing energy losses and making the most efficient use of energy must define actions throughout the energy chain (generation, distribution and consumption).

As a result, the 'Grand Challenges' for Energy Efficiency have been identified as follows



The Grand Challenges for Energy Efficiency - three technology challenges in the supply chain and a fourth in the application domain, dominated by the Smart City - the place where most people in the world will live.

As depicted in the diagram above, there are **three technological Grand Challenges** relating to the energy supply flow/chain - Generation, Distribution and Consumption - addressing **innovation in technology,** and **one additional Grand Challenge** 'Energy in the SmartCity' that addresses **innovation in the application** of new technologies in various SmartCity applications.

Nanoelectronics-based elements will contribute to energy efficiency at many different points in the energy cycle. With progress in research and evolution in technology there is world demand for higher-order competitive solutions that reduce energy losses and further enhance energy efficiency. There are therefore several levels at which a detailed analysis of nanoelectronics should be considered in these Grand Challenges:

- Direct energy impact during the conversion or use of energy (e.g. converters, motors, energy supplies, etc.).

- Enablers of energy efficient solutions (e.g. sensors, networks with low-power processing elements, and energy harvesters for long term maintenance-free systems).
- Embedded on chip diagnostics, sensors, and drivers to leverage the potential for reducing passive elements or protection and gain the further miniaturization of systems.
- Enablers of energy resource optimization in processes and products, and in the management of smart grids.

3.3.1 Grand Challenge 1: Sustainable and Efficient Energy Generation & Conversion

Vision:

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

Description:

The topic of energy generation can be divided historically into two main application fields: traditional energy generation (e.g. fossil fuel or nuclear power) and energy generation based on renewable sources (e.g. wind, solar, hydropower, geothermal, etc.). In both cases, 'raw energy' is produced in a form that cannot be transmitted or used without conversion. An upcoming application is energy storage to manage over-capacity and under-supply, especially in the case of non-continuous energy sources such as wind turbines and solar cells. When using old-fashioned electronics for rectifying, transforming or converting (AC/DC or DC/AC) electric currents, only around half of the energy can be used. New and much more efficient components will need to be used, and these will at least in part be based on new materials. In order to replace traditional energy generation, everything that can be done must be done in order to reduce the lifetime cost of renewable energy generation to the level of traditional energy sources.

Competitive Situation:

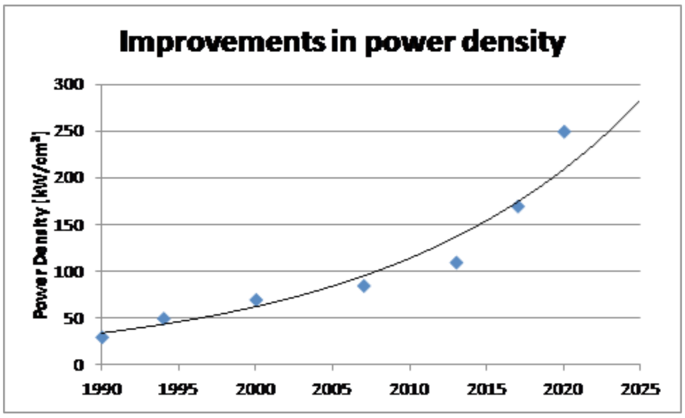
The demand for energy is a simple fact of modern society. The question is how to provide that energy in a resource-efficient affordable way that is acceptable to society. Nanoelectronics are already playing an important role in the generation of renewable energy. Highly efficient conversion will lead to lower costs and reduce the capital expenditure per generated MW to the level at which renewable sources can compete with traditional sources. Introduction of legislative hurdles for conventional power plants, such as that announced by the US government in September 2013 for new power plants to have limited carbon dioxide emissions (preventing the installation of coal-based power stations unless they are fitted with carbon dioxide separators) will mandate alternative solutions.

In terms of nanoelectronics, European based suppliers are in a leading position. Three of them are among the world's top ten suppliers, with a combined market share of more than 20% in 2011 for power semiconductors. Two of them enjoy a combined market share of almost 30% for power modules. With over 1 million jobs (direct and indirect) in

Europe in the renewable energy generation industry (Renewables 21), Europe plays a dominant role both in driving the market for efficient conversion technologies as well as using them.

Expected Achievements/Innovation Foreseen:

- Energy conversion efficiencies of 93% to 99% or more will allow even better use of renewable energy resources. Industrial research has to be done in collaboration with research centres to find solutions that make these levels of efficiency affordable. Research must be targeted at exploiting new materials (GaN, SiC, Diamond), new devices architectures (lateral versus vertical), and innovative new circuit topologies. Even after 'proof-of-concept', there will still be a long way to go before higher conversion efficiencies can be achieved at lower system cost.
- Another aspect is research into device and system lifetime and reliability. The renewable energy industry needs lifetimes for its power electronics of 20 to 30 years. The combination of new materials, such as Silicon Carbide (SiC) or Gallium Nitride (GaN), that enable very high efficiency and extremely long lifetime is challenging. In this area of research, thermal management aspects will also play a crucial role.
- Developing and integrating semiconductors-based solar energy technologies with solid state lighting applications will enable not only sustainable energy resources but also energy efficient lighting applications (for example, for developing countries).
- For the power semiconductor devices used in converters, continuous progress in power density per square mm is required. Significant progress in this area has been made over recent years. However new research is needed that focuses on innovative device topologies, thinner wafers, new materials (e.g. GaN on Si, and SiC), passive elements, and new interconnect technologies and packaging techniques to achieve further miniaturization. Innovation in these areas should result in a continuation of current trends in power density improvement and the reduction of losses.



Achieved and projected improvements in power density (source: Infineon)

3.3.2 Grand Challenge 2: Energy Distribution and Management – Smart Grid

Vision:

Proven availability of energy-efficient distribution of electrical energy based on central and local sources. No risk of black-outs or over-supply to disrupt grids.

Description:

The management, storage and distribution of (electrical) energy offers enormous potential for energy saving. Although Pan-European energy distribution networks do exist, they are often stretched to the limit, with little in-built redundancy to cope with failures. On occasions this has led to large area black-outs. In addition, Europe's current networks were not designed to cope with the widespread distribution of excess supply generated by localized wind or PV sources. The future challenge is to add much more intelligence into the power distribution system. Off-shore and on-shore wind farms, together with a growing number of PV and other decentralized installations, need to be connected to energy users over long distances via networks that can deal with the volatility associated with these new sources of electrical energy. At the same time, greater intelligence needs to be integrated in to home appliances such as washing machines, tumble dryers and refrigerators, so that they can communicate with one another and operate during periods of the day when electricity is cheaper.

Smart energy grids will integrate the management of incoming power, distributed power and outgoing power in an optimal way. This could include intelligently feeding power to a network of (currently) idle batteries in millions of electric cars, as well as local battery storage facilities. However, smart energy grids will only work if their energy distribution capabilities are overlaid by a sophisticated communications network with advanced security, monitoring and payment features. They will also need to operate at all transmission voltage levels (not only in the high-voltage distribution network) in order to ensure maximum energy efficiency in the overall system. Furthermore, smart grids will execute demand/response functions, by actively measuring energy demand in order to minimize brownouts (momentary energy shortages) and balance surplus energy feeds (e.g. due to peaks in PV generation during bright sunlight conditions).

Innovation and technological progress are key drivers in realizing the global shift to a more sustainable energy economy. The increasing contribution of variable/distributed power generation, the scarcity of natural resources, the underinvestment in transmission infrastructures, increasing demand of electrical energy, and the need for increased reliability, availability and power quality are all fundamental drivers for a new generation of intelligent power grids. While today's power grids are based on technology that was primarily developed for unidirectional power flows (from large power plants to passive energy consumers), tomorrow's intelligent smart power grids will incorporate digital control of the power delivery network and accommodate two-way energy flows and two-way communication between customers, suppliers and generators.

By gathering, distributing and acting on information about the behaviour of suppliers and consumers, smart grids will intelligently improve the reliability, efficiency, sustainability, and the economics of a multitude of electricity services, markets, distributed energy resources, and control programs. The smart grid is therefore a core enabler for the future integration of variable-output renewables and distributed power sources; the provision of high quality power to all customers; active barrier-free user participation in electricity markets; and an increase in overall energy efficiency.

Competitive Situation:

According to analyses performed by several leading market research institutes, the development and deployment of smart grids will become an increasingly important business opportunity for a variety of global industries. The Pike Research group expects global investments in smart grids to cumulatively total around US$200 billion between 2008 and 2015 with US$53 billion being invested in the United States alone. Rather than employing a single technology, smart grids will comprises a network of networks that allow real-time two-way communication between utilities, grid operators and users, omnipresent sensing and control, and distributed automation throughout the electrical generation network. Goldman Sachs Group Inc. predicts that smart grid technology will be a key driver of the US$750 billion in incremental spending in the global transmission and distribution market over the next 30 years (source Businessweek, September 2010).

As a consequence, interest among major Information and Communication Technology (ICT) players in smart grids has escalated in recent years and led to large service and solutions providers increasingly edging into the market. The corresponding overall market volume is estimated to be around 100 billion Euros in 2014 alone (source Computerwoche, 2011).

As discussions about energy supply and its environmental impact intensify around the world, there is increasingly fierce competition in the race for market share at all points in the value chain for smart energy grids. Europe is in a good starting position, because all the necessary elements are in place and Europe already has a leading position both in research and in market penetration for most elements of the system. European companies have well-recognized strengths in power electronics and communications, and are leading in smart grid technologies.
Grid automation will be introduced on all hierarchical levels of the electrical grid - i.e. on the distribution grid, on medium voltage distribution networks and in people's homes. The evolution of high-performance reliable smart-grid concepts requires innovation in both nanoelectronics and power electronics, as well as in security technologies, and in self-organizing reliable and secure communications technologies.

Expected Achievements/Innovation Foreseen:

- Energy conversion with efficiencies of 93% or more will allow low-loss transformation of generated electrical power into currents and voltages appropriate for the type and length of power lines.
- For efficient energy transmission over long distances, very high-voltage direct current (HVDC) lines will be installed (e.g. operating at 800 kV). Similarly, for the integration of renewable energy sources (e.g. solar panels) with DC-based lighting technologies (e.g. LED lighting solutions), low voltage lines in buildings will be

required. Highly effective AC/DC/AC conversion will be needed to couple these systems to existing infrastructures.

- To effectively measure and communicate energy consumption in buildings, cities and districts, and information about user profiles and expectations, dedicated sensors and communication networks will have to be developed and deployed.
- Demand/response functionality for stabilizing overburdened smart grids (minimizing brownouts) and managing overcapacity (surplus feed).
- Decentralized energy management systems: virtual battery storage based on reliable, secure, low latency communication links. We foresee small, sustainable mini-grid solutions, supported by solar panel banks and batteries, providing electricity in areas where no stable grid is available.
- Local energy storage and consumption management.
- Communication networks supporting grid control functions - for example, demand / supply management (DSM), clustering of battery storage, islanding, the formation of virtual power stations, protection against intrusion or manipulation to ensure extremely high levels of security, robustness and reliability. Low latency rather than high bandwidth will become a critical performance index.

3.3.3 Grand Challenge 3: Reduction of Energy Consumption

Vision:

The vision for 2020 is to achieve, through the use of nanoelectronics-based solutions, an estimated 25% saving on EU-25 electricity consumption.

Description:

A first and by no means negligible contribution is the reduction of power consumption in electronic components and systems. Well known examples are the reduction of heat generation in the microprocessors used in computers and the demand for long battery life in portable and mobile electronic equipment.
A second contribution that offers the highest absolute energy saving potential is solid-state lighting (potential energy savings in line with those reported by the CATRENE Power Working Group Report, March 2013, section 3.2.1 - i.e. lighting >14% potential savings in EU consumption, followed by motor control with 6% potential savings). According to the Photonics21 SRIA, lighting accounts for 19% of global electricity consumption. Hence, it has the potential to:

- reduce global annual energy costs by more than €300 billion
- reduce global CO^2 emission by more than 1000 million tonnes per year

A third contribution is energy saving at system/application level. Research into advanced semiconductor technologies and energy efficient systems and solutions will enable European industry to provide intelligent technologies and products to drive energy saving in end-user equipment and the total system. Some examples are: intelligent lighting; motor control for home appliances; industrial, automotive and mobile applications; intelligent control of electrical loads; and high performance computing systems. Opportunities in these areas benefit from an ever-increasing awareness that energy efficient systems and solutions are key factors in creating ‘greener’ societies.

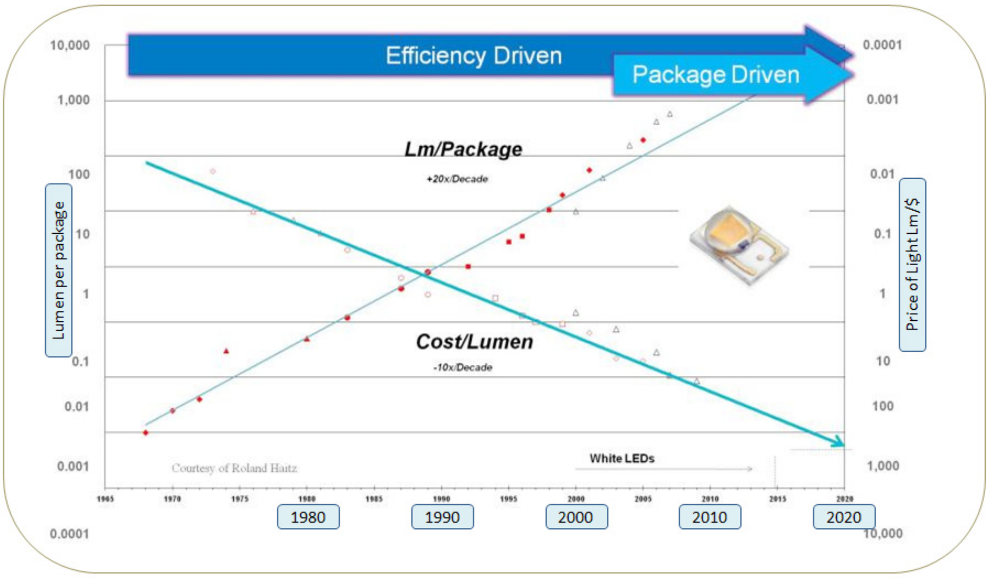
Today, one square kilometre of a modern inner city accommodates 50000 unique subscribers who every day generate an average of 300 GB of data, trigger 800,000 3G-data connections and 45,000 wireless voice calls. In 2007, the worldwide carbon footprint associated with this level of ICT was 2% - amounting to 830 million tons of CO^2 in absolute terms. This is comparable to the carbon footprint of the global aviation industry, and is expected to double by 2020. Around 18% was attributed to data centres and about 25% to telecom infrastructure and devices. The increased levels of data networking brought about by the pervasiveness and ubiquity of broadband connectivity will result in the steep growth of data traffic in the coming years. Tablets and smart phones, which are rapidly replacing conventional PCs, rely solely on wireless connectivity, and are expected to result in an increase in wireless traffic of around 250% by 2015. The ever-increasing level of traffic will also be driven by the virtualisation and ‘cloudification’ of services and applications, as well as by machine to machine (M2M) communications, cyber-physical systems, and a bottom-up ‘Internet of Things’. As a consequence, routing and switching nodes in the network and in data centres will need to be able to cope with a doubling of traffic every 2 years. However, at the current rate of technology development, network energy efficiency is only increasing by between 10% and 15% per year, leading to a significant energy gap. Energy consumption will become a significant cost issue for communications operators and end-users, as well as an environmental and natural resource issue. It is clear from these figures that the performance and energy efficiency of every function in future communications systems (terminals, sensors and networking gear on every hierarchical level) needs to be improved considerably if we want to maintain the steep growth of networking in our society at an affordable cost.

Competitive Situation:

With European companies active in the whole value chain and many of them in world-leading positions, Europe has a good chance of building up a healthy ‘green industry’ around tools and products for reducing energy consumption. European companies have acknowledged strengths in power electronics and in nearly all of its applications. For example, market studies show that Europe enjoys leading positions in the field of power electronics and advanced LED lighting, and dominance in power semiconductor modules for renewable energy sources. European suppliers are also in a leading position for energy-efficient communications equipment. Activities that have been inspired, founded and led by European stakeholders, such as the GreenTouch® initiative and many of the ETSI/ITU standardisation initiatives, exert worldwide influence. By exploiting the latest micro- and nano-electronics technologies and the most advanced system concepts, European companies have already defined and set new standards, raising the bar in performance and energy efficiency. Europe’s R&D institutes are also very active in these domains.

Expected Achievements/Innovation Foreseen:

- Intelligent drive control: technology, components and miniaturized (sub) systems will be developed, addressing the challenges at system and device level for efficiently controlled engines and electrical actuation in industrial applications. The need for R&D includes new system architectures and circuit designs; new components and power electronics technologies; and innovative module, interconnect and assembly techniques.
- Efficient (in-situ) power supplies and power management solutions: These will be supported by efficient voltage conversion and ultra-low power standby. The need for R&D includes new system architectures and innovative circuit and package design concepts, plus specific driver ICs and power components for lighting and industrial equipment. Application areas for highly efficient in-situ power supplies include portable computers and mobile phones, and standby switches for TVs, recorders and computers.
- Low weight power electronics; Advanced energy-efficient power semiconductors, including new substrate materials (e.g. GaN) coupled with advanced thermal management solutions, will allow much smaller, more reliable, and more lightweight electronic units. This will generate unique benefits, as these energy-efficient power electronics will become more portable and mobile, enabling new user-friendly applications. This will particularly benefit **medical applications,** where improved energy management is one of the keys to cost-effective solutions (for example, medical imaging equipment). Energy efficient mobility applications will also benefit.
- Efficient high-performance computing data centres and sever infrastructures.
- Embedded nanoelectronics-based on-chip diagnostics for power efficiency and reliability.
- Technological solutions for control of buildings (indoor) and outdoor subsystems (for example, heating, ventilation, air conditioning and lighting, as well as traffic monitoring etc.) to achieve optimal energy-efficient performance, including connectivity and embedded software for adaptive intelligence. These systems will also provide novel services such as environments for improved wellbeing and outdoor safety.
- Energy efficient and reliable wireless access technologies, self-organising frequency-agile small cell networks, and bionic circuits.
- Highly efficient high-performance routing and switching engines incorporating 3D nanoelectronics-based integrated devices and photonics.
- Energy efficient sensor networks, NEMs and MEMs.
- Technologies to improve LED performance - e.g. in terms of Lumens per Watt, Lumens per price and Lumens per package volume, see the Haitz law for LED



LED progress according to Haitz law

3.3.4 Grand Challenge 3.4: Energy in the Smart City

Vision:

Energy Efficiency in Use – The 'Smart City' is the place where millions of people live and work. By the year 2020, the energy consumed should be precisely that needed. It should not be influenced by over supply, not wasted by inefficiencies, and not subject to bottlenecks in the distribution system. The vision is to have clean and healthy city environments in which energy is used intelligently.

Description:

A city can be defined as 'smart' when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructures fuel sustainable economic development and a high quality of life, with a wise management of natural resources, through participatory action and engagement[2].

This Grand Challenge 'Energy in the Smart City[3]' involves all 'smart' applications for which an energy supply is essential, and goes beyond the mere reduction of energy consumption. The Smart City challenge aims to enable **healthy living, productive working, efficient supply and efficiency in the travel.**

Due to massive urbanization, more than 50% of the world's population lives in urban areas that have reached unprecedented size and levels of wealth. Megacities epitomize the extreme case. Experiencing strong and fast growth, modern cities are confronted with severe environmental and infrastructural challenges that unless adequately addressed could jeopardize the well-being and lifestyle of their populations and adversely affect the cities' economic development. Typical examples include:

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[2] Caragliu et al.2009

[3] http://en.wikipedia.org/wiki/Smart_city

- Traffic congestion and traffic jams
- Scarcity of natural resources
- Pollution
- Energy waste
- Dealing with supply/demand peaks

To address these challenges, city administrations are currently engaged in massive investment plans.

The steady increase in performance/functionality of processing systems and (wireless) networking will enable automated control of all the systems and processes associated with modern urban environments and help to avoid or at least ease the problems. Concepts such as ‘intelligent traffic management’, ‘multimodal mobilityofferings’ or ‘smart production’ not only have the potential to improve people’s lifestyles; they also have the potential to optimize the handling of resources. Intelligent traffic systems can control traffic flows, increase traffic safety, and provide people with real-time updates on the optimum way of reaching their destination. For example, they could coordinate individual journeys that involve transfers from car to train to bicycle with all booking, scheduling and billing being handled automatically and seamlessly (single-point booking and billing). Such systems could also optimize the efficient transport of goods and materials in urban environments. Progress will be based on advanced nanoelectronics processing technologies, communication technologies (inter-human and machine to machine), smart sensors/actuators and power electronics.

Finally, smart production concepts (virtual factories), linked with smart grids and traffic management systems, will help to improve people’s working environment and introduce additional flexibility into the organisation and structuring of people’s work. For example, remote control of production facilities, the alignment of production schedules and traffic flows (commuter traffic), and the clustering of distributed production facilities could optimise cost efficiency and the quality of urban living. Once again, concepts such as machine-to-machine communication, nano- and power-electronics, sensor technologies and security technologies will enable progress in these areas over the coming years.

The ‘Smart City’ challenge’s three *aims:* **healthy living, efficient supply** and **efficient traffic,** can be sub-divided into the following ‘smart’ aspects:

<table>
<tr><th>Challenge</th><th>Aim</th><th>Aspect</th></tr>
<tr><td rowspan="7">Energy in the SmartCity</td><td rowspan="4">Healthy Living</td><td>SmartHomes</td></tr>
<tr><td>SmartOffices</td></tr>
<tr><td>SmartPublicSpaces</td></tr>
<tr><td rowspan="2">SmartLighting</td></tr>
<tr><td rowspan="2">Efficient Supply</td></tr>
<tr><td rowspan="2">SmartInfrastructure</td></tr>
<tr><td>Efficient Traffic</td></tr>
</table>

3.3.4.1 Smart Homes

One of the major concerns of modern society is the need to save energy. While many developments focus on energy reduction in office and industrial environments, the Smart Home concept focuses on energy saving in the home. A substantial part of the energy currently used in homes is wasted by devices that continue to consume power when they are not being used - for example, room lights that are left on when there is no one at home.

By introducing connected infrastructures, information generated by different sensors and devices can be shared, allowing devices to be supplied with information that they can use to operate more energy efficiently. This infrastructure must be easy to install (no new wires), easy to maintain (no frequent battery changes), and interoperable across product types - for example, heating, white goods, brown goods and lighting.

The concept of energy-friendly homes is already appreciated by consumers but they often associate it with a loss of comfort - for example, unwanted dimming or switching off of room lights. If the concept is to be actively embraced by consumers, Smart Home solutions must not compromise comfort; they must improve it. At the same time they must be extremely easy to install.

Sensors are an essential element of the entire infrastructure. In every room, multiple variables will need to be continuously monitored. Ideally all these variables will be measured by a single non-obtrusive sensor module that can be placed on any wall or ceiling in each room. It should therefore not depend on the presence of a mains outlet; it should have its own on-board energy source. To prevent the need for frequent battery replacement, a key requirement for these sensor modules is that they should be extremely energy-efficient, so that their battery life is many years. Even better, they may be able to scavenge all the energy they need from the local environment, which requires all the elements in the sensor node (the sensors, local processor and wireless link) to have ultra-low power consumptions. They should also be extremely reliable. Current PIR (passive infra-red) sensors only react to relatively large motions. They fail to respond when people are in the room but sitting still - for example, watching TV. One way to reduce power consumption is to put the sensor node into sleep mode. However, this can result in poor response times, with users having to wait several seconds before an action becomes noticeable. The challenge is therefore to be both energy efficient and responsive (maintaining comfort level).

3.3.4.2 Smart Offices

For around 95% of an average person's life they are exposed to an indoor climate, either in an office or in their home. Indoor Environmental Quality (IEQ) is a key parameter for occupant health indoors. It has been demonstrated that there is a clear relationship between IEQ and human performance, measured in terms of duration of sick leave, time to execute tasks, and perceived well-being. These performance parameters, particularly sick leave and working efficiency, can also be expressed in terms of salary cost, with people often regarding a comfortable working environment as a positive fringe benefit. Compared to salary cost variability of a few percent, the investment needed to improve the IEQ of a building is small. Reduced personnel costs will therefore be the main driver behind the healthy spaces market. Factors that influence IEQ include dust level, CO^2 level, humidity, temperature, noise level, acoustics, illumination and access to daylight. However, studies have shown that the requirements of a good IEQ vary between individuals. A number of IEQ concepts therefore emphasize a personalized approach.

Research is necessary to measure the parameters that contribute to the climate in a building. An energy efficient setting of the different devices acting on the IEQ is essential. It can well be imagined that many IEQ parameters are related and devices have different working points. Consequently, IEQ settings exist that are close to the optimum without measurable consequences for the occupant. Given this situation, the set of possible IEQ settings can be optimized by reducing the energy consumption of the involved equipment.

The conclusion from existing productivity models is that behavioural aspects, stimulated by factors such as office lay-out, have a greater impact on productivity than the environmental aspects of an office environment. However, individual control of the IEQ will significantly contribute to the well-being of office workers as well as further improving productivity.

3.3.4.3 Smart Public Spaces

For public spaces, such as shopping centres, central or public transport stations, pedestrian areas and public transport systems, the same challenges regarding environmental quality are valid as for the Smart Home or Smart Office. Due to increased urbanization and the growth of ‘Mega Cities’, public spaces must also be smart. The challenge for energy efficiency in the creation of comfort zones is a large one, thinking about today’s practice of open doors and full steam heating or cooling at a entrance portals, independent of the presence of people.

3.3.4.4 Smart Lighting

The introduction of energy-efficient solid-state lighting (SSL) into our world will unlock unprecedented opportunities in digital lighting control. Digital lighting will provide smart illumination when and where needed, adjustable by the user to suit the task in hand or the mood required.

Digital lighting can be created by combining LED light sources with sensors, control systems, algorithms and embedded software systems. In addition, lighting systems of the future will be ubiquitous and managed with fine-mesh networks. Initially, the challenge will be to create lighting systems that provide functional illumination. At a later stage, lighting infrastructures will become part of sensing systems, sharing information with other systems in the environment to provide novel user services based on data collection and data mining. In addition, there are challenges with complex non-functional requirements, e.g. easy commissioning, latency, reliability and data security.

A clear distinction should be made between the two major application domains - indoor lighting as an integral part of buildings, and outdoor lighting as a critical component of urban infrastructures. These two domains clearly have different value chains and target distinct applications and services:

- Indoor lighting will be integrated with heating, ventilation and air conditioning (HVAC) systems, blinds, surveillance and access control systems, and driven by energy efficiency and personal security.
- Outdoor lighting will be combined with traffic management, crowd control and event management in order to improve the accessibility of cities and logistics in urban environments.

In order to realize the potential of digital lighting solutions in these different domains, the development and validation of open system architectures for solid-state lighting in real settings must be high on the innovation agenda. Actions should address specific lighting requirements in relation to the control network, as well as the development of related electronic and photonic devices. Proposed architectures should allow for the interchangeability of components through standardisation of their interfaces. Actions should involve players from the micro-electronics and lighting industries, together with all other parties in the value chain.

From the 2012 update of the McKinsey report 'Lighting the way: Perspectives on a global lighting market' it is clear that control systems offer the highest growth potential in the lighting domain, with sales volumes almost bound to surpass that for light sources beyond 2020.

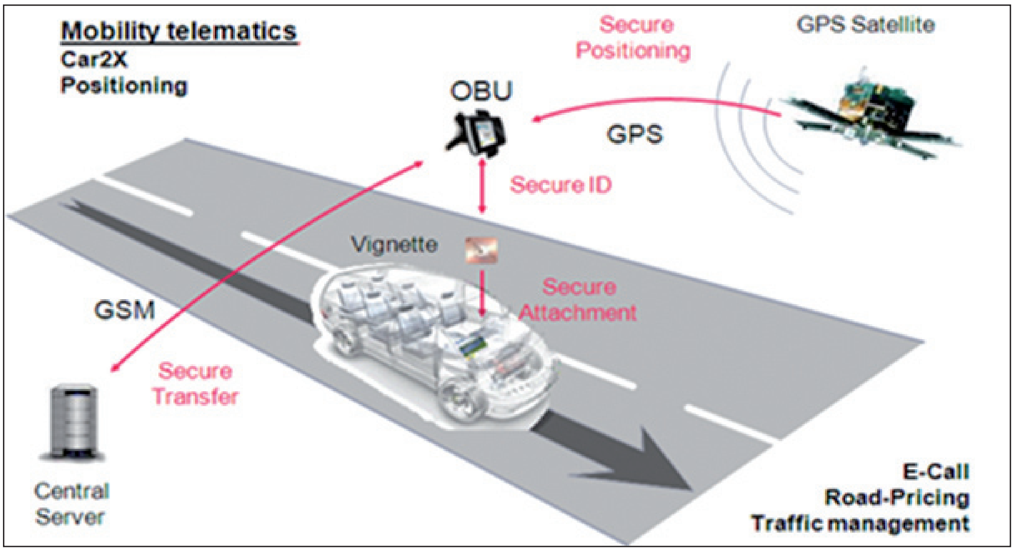
		2011	2012	2016	2020
Total new installation market	M€	46.891	50.179	63.023	75.403
Lamp/module level	M€	4.054	5.093	8.078	10.366
Driver level	M€	3.964	4.44	7.323	10.770
Fixture level	M€	37.08	38.545	43.572	46.561
Lighting control system level	M€	1.794	2.101	4.051	7.705

3.3.4.5 Smart Infrastructure

Traffic infrastructures in the world's megacities often appear to be at the point of collapse under the weight of exploding population growth. Congested roads, traffic noise, the risk of accidents and general stress are all part of people's daily urban lives. Intelligent traffic management and efficient public transport systems will be required to maintain mobility in such crowded urban areas.

Despite double-tier multi-lane freeways, traffic jams lasting several hours are an everyday occurrence in Peking or Shanghai. And every week some 10,000 vehicles are newly registered to join the queues. Ironically, the more mobile the population becomes, the more slowly people can expect to get from A to B. Consequently, metropolitan areas worldwide are searching for sustainable infrastructures and innovative mobility concepts. Authorities in many cities in Asia have already realized that simply constructing more roads, tunnels or overpasses cannot relieve the load on major traffic junctions. They therefore need innovative new concepts for efficient traffic management in both private and public transportation in order to implement sustainable infrastructures.

One important new development that will help to solve today's traffic problems is the 'intelligent automobile'. Cars that 'think' (with in-built intelligence) will be able to take the load off drivers, figuratively 'taking over the wheel' when it comes to choosing the right route or driving in an energy-efficient manner. Such intelligence is enabled by networking systems within modern cars and by extension of these in-car networks to external wireless networks. Vehicles need to get the capability to interact and exchange information with their environment, including car-to-car and car-to-infrastructure communication.



Networking solutions of this kind can enable traffic lights and vehicles to talk to one another and regulate traffic flows. Traffic lights would automatically inform drivers about the right speed to drive through a city in order to minimize the number of red lights they have to stop at. Obstacles such as construction sites, traffic backups or other danger spots will be reported to drivers so that they can change their route. Public transportation would receive priority through traffic management systems with telematics and car-to-car communication enabling them to maintain better schedule reliability.

Competitive Situation:

The ultimate need for the Smart City is rising due to the explosion of urban areas into giga-cities. The Western lifestyle expectations and affordability that these mega-cities bring to more and more people results in the ever-increasing use of energy for purposes such as mobility, communications and lifestyle improvement (air conditioning, food, personal needs, etc). Europe's industry can provide the base technologies required to implement these modern 'smart' highly energy efficient cities. Demand is driven both from within Europe itself (with an increasing awareness of what technology can achieve) and from global markets. Many of the applications are well foreseen and Europe has already established companies that can implement solutions. As a result, the potential market for European companies is huge. With respect to the competition, the most important issue is who acts first by undertaking the necessary research and investment, since success will depend on exploring new ideas and abandoning traditional ones. If it does not enter the market soon, Europe will be out of the game.

Expected Achievements/Innovation Foreseen:

- Cyber Physical Systems (CPS): Distributed and connected sensor / actuator elements for control and management in energy efficient applications.
- Sensors for ambient air quality, for supply chains of goods/food and for traffic flows to minimize energy use.
- Data communications ICs and solutions for the modern connected society: high performance flexible transceivers and network gear supporting energy efficient, secure, self-organising communication grids.
- Insight gathering, multi-stakeholder viewpoint analysis and end-user requirements elicitation, claim validation and user acceptance, as enablers for energy reduction, cost reduction, safety, health and wellbeing.
- Integration of lighting systems with other embedded intelligence systems, such as building management, domotica (home automation), video surveillance, smart grid or traffic management systems (e.g. identifying prerequisites for the sharing of sensor-derived data and user interfaces, assuring seamless integration, integrated control of lighting and HVAC, alignment with the building construction process, and contactless energy transfer to enable flexibility).
- Lighting for wellbeing (e.g. concentration and productivity improvement in schools, offices and industry; people logistics; crowd control; and safety) and lighting for health (e.g. skin diseases, wound healing, brain stimulation, improved hygiene, light therapy, and the prevention and treatment of seasonal affective disorder (SAD), various types of depression, mental disorders, and sleep disorders).
- Large scale demonstration test beds for claim validation: e.g. field tests to roll out new technology in real life and to enable successful market uptake, defining comfort and wellbeing metrics.

3.4 Conditions for Success

At least nine conditions for success have been identified for progress in energy efficiency, including activities related to education.

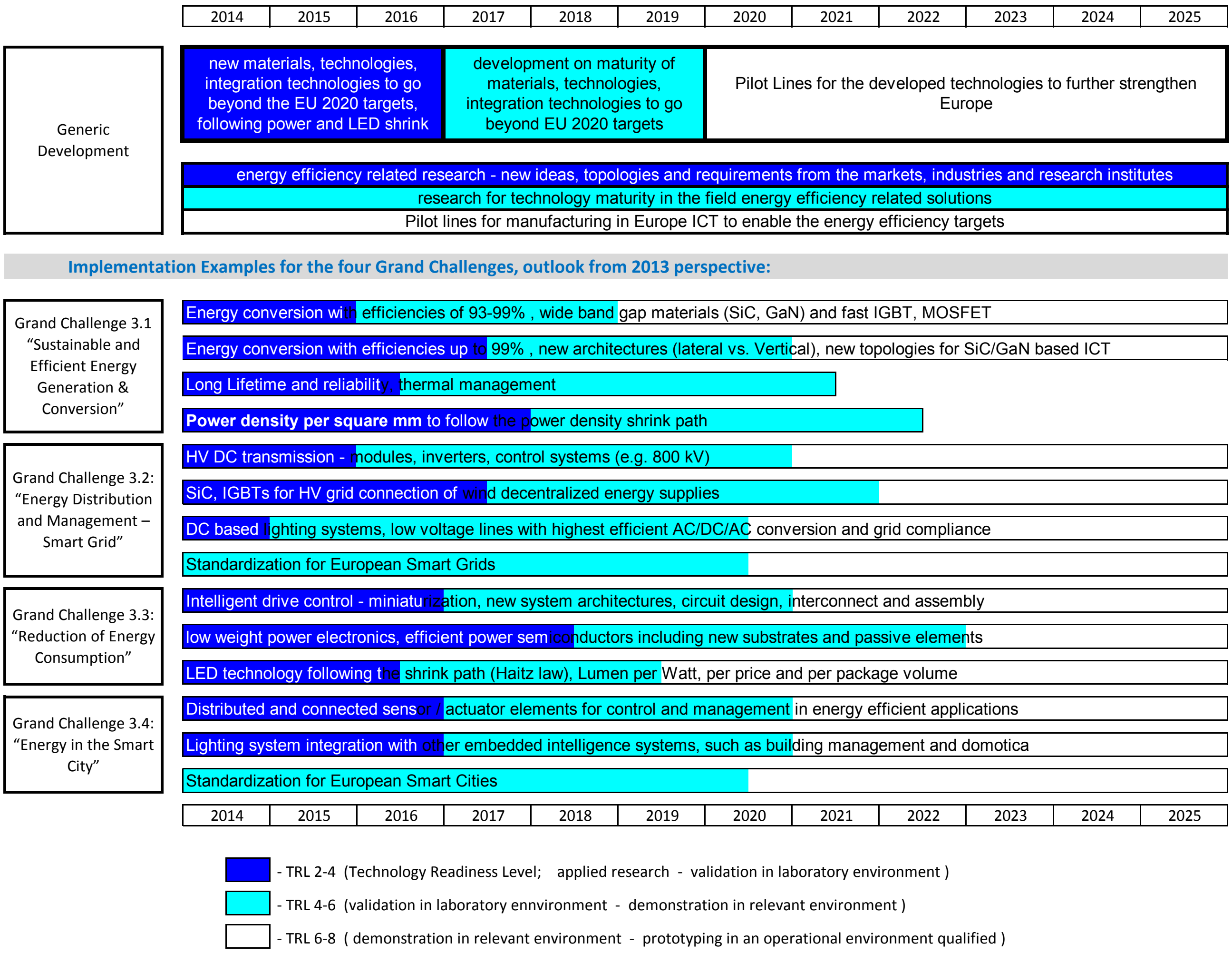
- Technical excellence in the domain of power electronics and communications.
  In order to achieve this excellence, much research needs to be done on innovative topologies, enabling highly efficient power conversion in all user domains. This

includes new materials, innovative system design and high-level quality measures for new semiconductor technologies and circuit topologies.

- Worldwide industry-led standardisation to allow rapid and effective market penetration, such standardisation to be used as a business instrument rather than a policy tool (which could be counterproductive).
- Lean updates to regulatory frameworks for 'motivating' the introduction of energy efficient systems and applications.
- In combination with affordable solutions, introduction of legislative measures to focus on energy efficient generation, distribution and use of energy. Without active promotion of achievements in the energy-efficiency domain, measures may be taken later than they could be.
- Establishment of SSL standards related to thermal, mechanical, electrical and optical interfaces to ensure fast product development and system interoperability, such as the global TCLS and TalQ standards (for programming and lighting management software).
- Acceptance by citizens; this can be achieved by a combination of energy efficiency, affordability, high quality, comfort and ease of use.
- Smart grid technologies are interdisciplinary in nature. Consequently, research policy should stimulate and foster inter-disciplinary activities between stakeholders from the energy industry, the semiconductor industry and public authorities (as owners of infrastructure).

3.5 Timeframes

Overall, current achievements from research for power electronics in terms of increased energy efficiency and power density, as well as the achievements for LEDs in terms of increased lumens per Watt and reduced price per lumen, have to be continued. Doing so will require new research into materials, device topologies, integration technologies and, on the higher TRLs, new investment in pilot lines to prove the capability of manufacturing components, modules and systems.
The EU has set itself a target for 2020 of saving 20% of its primary energy consumption. Research needs to be performed over the whole period on all TRL levels to secure the future of nanoelectronics in Europe:



3.6 Synergies with Other Domains

There are many synergies with different VMS chapters, because energy efficiency can only be applied if energy is generated and used. There is therefore a strong link to:

- Automotive and Transport
    - Drive Control, Traffic Control, Secure Traffic, Coordinated Traffic.
- Communications
    - Smart Grid and Mobile Applications, Communications Networks.
- Health and the Ageing Society
    - Mobile Medical Applications are developing requiring energy-aware infrastructures and equipment. Synergies are evident with sensors in building environments - i.e. power outlet independence, long battery life etc.
    - Energy efficiency in large instruments such as MRIs – power conversion for high power applications.
- Safety & Security
    - An energy-aware society has to monitor presence and user behaviour as well as societal trends. This information has to be protected.
    - Not every energy-efficiency measure can be implemented alone. There is a need for ensuring privacy, integrity and security.
- Design Technologies
    - Design of specific components for energy-saving applications.
- Semiconductor Process and Integration
    - Processes and integration technologies have to be developed to leverage the potential of nanoelectronics, with new materials or new topologies based on new designs for energy-efficient applications.
- Equipment, Materials and Manufacturing
    - New materials have to be investigated and applied in power semiconductors, new materials are needed to implement energy efficient motors, and new materials are required to cope with thermal aspects and hot spots.
    - In the higher TRLs, pilot lines have to be developed to ensure the European supply of nanoelectronics and a European-based supply chain for Europe's needs.

CHAPTER 4

HEALTH AND THE AGEING SOCIETY

4.1 Introduction

Healthcare is a topic that affects all of us personally. Adequate healthcare is generally regarded as a prime societal need. The World Health Organization (WHO) defines health as "a state of physical, mental, and social wellbeing, and not merely the absence of disease". In order to safeguard and increase the quality of life for an increasingly ageing society (see Figure 1), difficult societal challenges have to be solved. The nanoelectronics industry will play an important role in delivering these solutions by developing innovative products, in strong collaboration with the medical equipment and home monitoring industries.

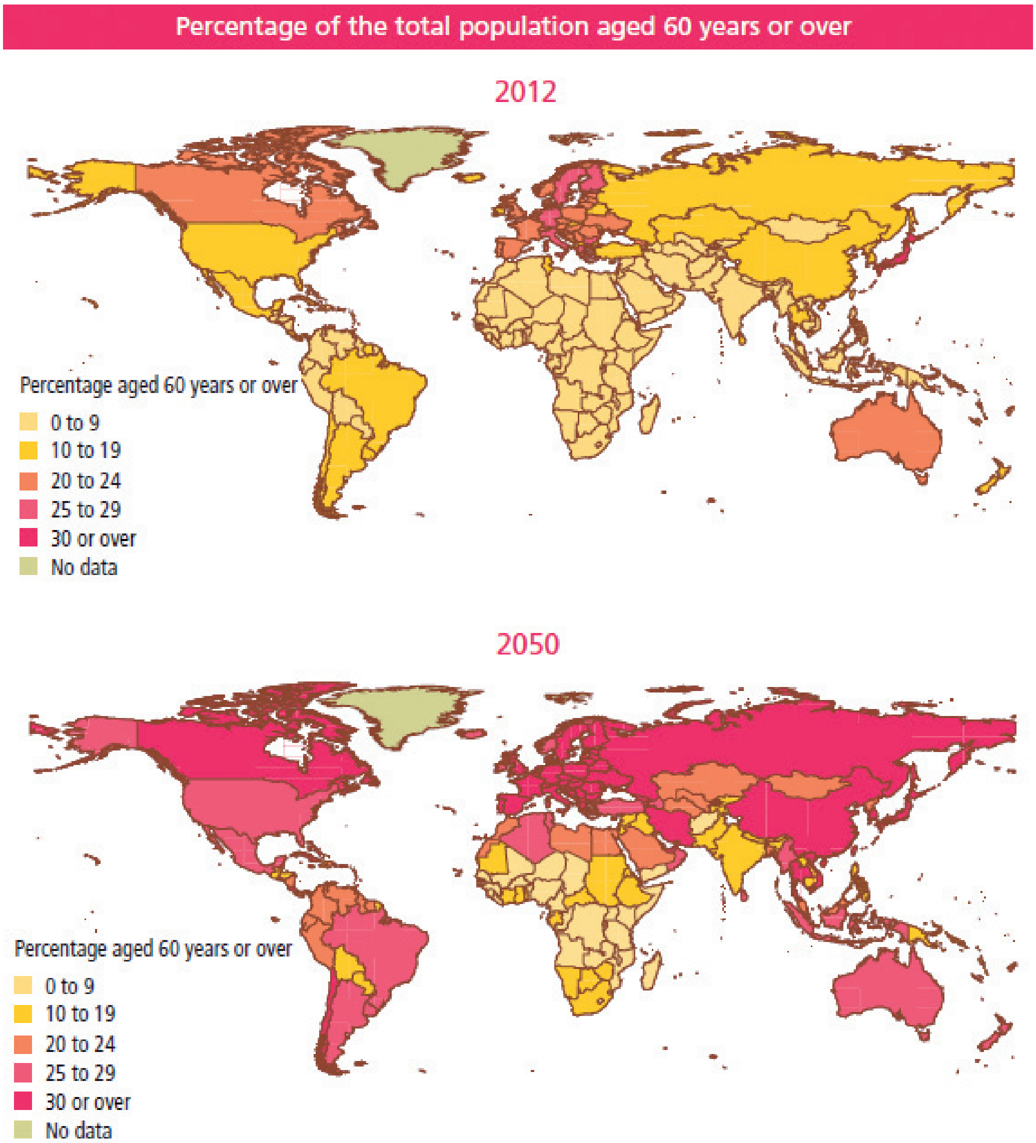


Figure 1: Percentage of the total population age 60 and over.
[UN Population Ageing and Development 2012]

This chapter covers the three Grand Challenges for the medical, ICT and nanoelectronics industries when addressing healthcare needs in an increasingly ageing society.

4.2 Relevance for Europe

4.2.1 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.

4.2.2 Societal Benefits

Dramatic changes in demographics will occur as the proportion of people living significantly longer increases. By 2045 there will be more people over the age of 60 years than people under 15 years, rising from 600 million to 2 billion[4]. According to the European Science Foundation (ESF)[5] the proportion of the population aged 80 years and above will grow from 5% in 2010 to 11.5% in 2050.

In combination with developments in medical technologies and changes in lifestyle due to global economic growth, the prevalence of specific human diseases is drastically changing. There is a large increase in age-specific, chronic and degenerative diseases, such as cardiovascular diseases, pulmonary diseases, musculoskeletal disorders (such as arthritis and osteoporosis), cancer, diabetes, and neurological diseases (such as depression, dementia, Alzheimer's, Parkinson's and schizophrenia) (see Figure 2 and 3). We are therefore moving towards a society in which many more people live with chronic illness, and the associated cost of that illness, both medically and societally, will be extremely high.

OECD Economic Policy Paper No. 6, June 2013, identifies the fact that during the recent economic crisis, the decrease in gross domestic product (GDP) was greater than the slowdown in health expenditure, leading to a sharp increase in the healthcare cost to GDP ratio. Over the next 50 years, an accelerating trend is predicted – the combined public health and long-term care expenditure for OECD countries is projected to rise from its current level of 6% of GDP to 9.5% of GDP in 2060. This is despite the assumption that cost containment policies will be more effective in the future than they have been in the past. In a 'cost-pressure' scenario, which assumes no stepped-up policy action, spending could reach 14% of GDP.

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[4] OECD Health Data 2007

[5] Source: ESF-Developing a New Understanding of Enabling Health and Wellbeing in Europe, Health_Wellbeing_Europe.pd

The European Innovation Partnership (EIP) on Active and Healthy Ageing stated that this is an opportunity for societal and technological innovation and defined three priority areas (see Figure 2).

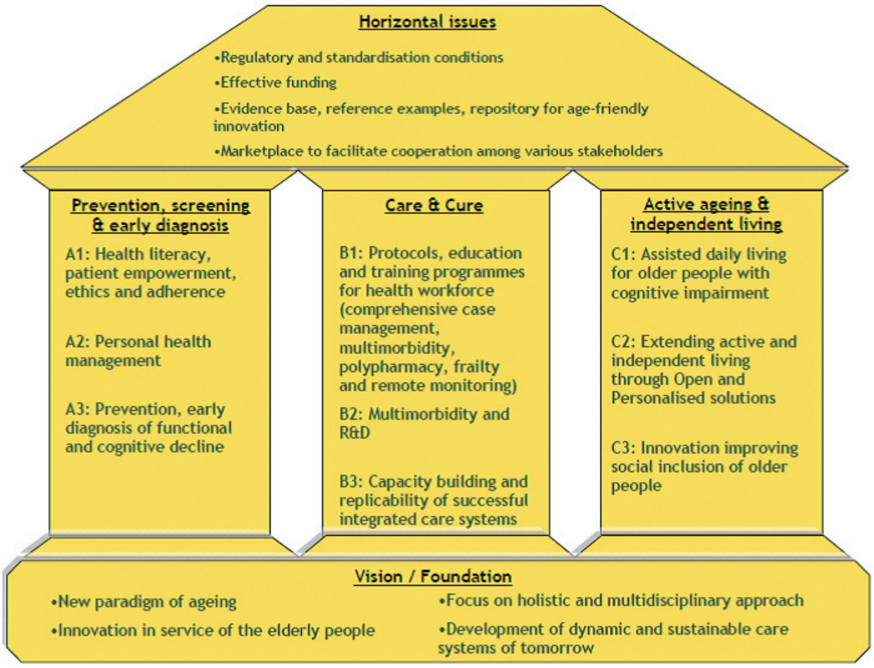

Figure 2: Priority areas to increase the average number of healthy life years (Source: Strategic Implementation Plan for the European Innovation Partnership On Active and Healthy Ageing, strategic_implementation_plan.pdf)

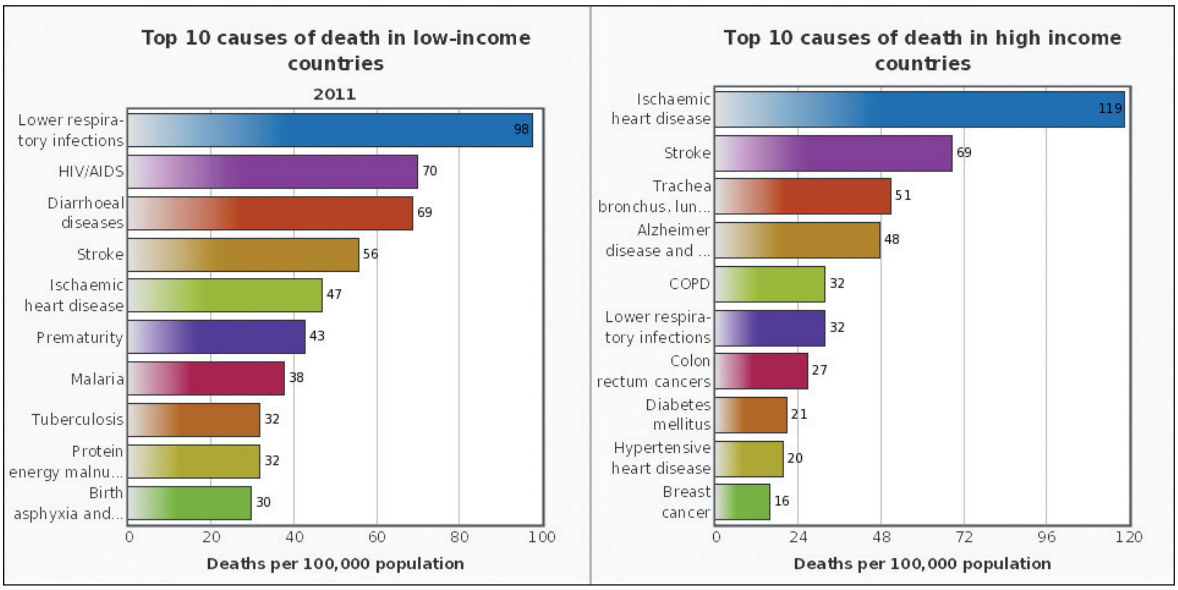

Figure 3: The main causes of death in low-income and high-income countries (Source WHO, 2011).

Furthermore, global economic growth will increase spending on health related services, increase access to healthcare (for a larger number of people) and improve awareness of the available healthcare options. Higher demand, in combination with an ageing society, will lead to a shortage of healthcare professionals. Significant innovations to improve

the efficiency of healthcare systems and the efficacy of medical interventions are needed to address this inherent societal threat. As mentioned by the OECD, hospital admissions must, wherever possible, be avoided for people with chronic diseases.
In order to control health expenditure, a proper balance between home care, primary care and secondary care is essential. In the future, healthcare will become more personalized, participative, preventative and predictive (P4)[6]. This paradigm shift requires both technical and societal innovations and is in line with developments for personalized medicine (Source: ESF Personalized Medicine for the European Citizen, 2012 - *EMRC - Personalised_Medicine.pdf).*

Several societal benefits will be gained by addressing the issues outlined above:
- Personalised multi-parameter risk profiles will be created using nanoelectronics-based solutions for genetic/biomarker testing. These predictive profiles will enable the early identification of potential personal risk factors and behaviours to inform appropriate actions that help to prevent the development of diseases.
- Healthy people, people at risk, and those with chronic diseases will be able to maintain their social and medical independence. People will actively participate in healthcare-related activities, rather than taking a passive role when accessing health services. This will have large social, occupational and cost benefits.
- Healthcare will become more personalised, based on biomarkers and physiological models, so that screening, diagnosis, treatment and disease management are more effective and efficient.
- The use of hospital services will be reduced as a result of smart referral systems, personalised diagnostics and the use of minimally-invasive procedures[7]. The geographical density of specialised hospital services is currently based on urgency. If new diagnostic tests can identify disease in its early stages, the need for urgent treatment will be reduced, allowing the establishment of large-scale disease-specific centres of medical excellence in which costs per patient can be reduced.
- The reduction of medical incidents ('errors') and healthcare inefficiencies, through smart ICT, patient-centric healthcare records and automatic consistency and pharma compatibility checks. Patients will become participants in reducing errors/incidents and in improving healthcare processes.

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

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6 TNO- innovation for healthcare; technological and societal innovation in prevention and care

7 See Health and Technology congress 2012, http://www.hat-event.com/programma/vorige-edities/thema-2012-technology-and-business-development-for-innovative-medical-devices/programma-19-september-2012/track-demand-and-market-development-2/show/188

4.3 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 of the elderly, the impaired, and people with chronic disease by providing healthcare support in an individual's normal environment (home, community, and/or workplace).
2. **Hospital Healthcare:** Reduce the time and cost 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 challenges are shown in Figure 5, which also visualizes the trend towards personalized healthcare.

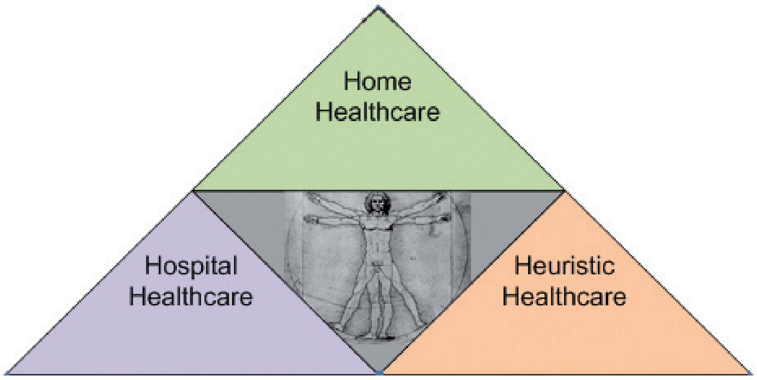

Figure 5: The three grand challenges for patient centric health in the ageing society

	Home Healthcare	Hospital Healthcare	Heuristic Healthcare
Cost effective	X	X	
Accurate		X	X
Efficient		X	X
Easy-to-use	X	X	
Reliable	X	X	X

Table 1: Key requirements for the Grand Challenges

Table 1 depicts overall characteristics and priorities for the different healthcare challenges. All forms of healthcare should be as cost–effective and accurate as possible. However, the 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.

4.3.1 Grand Challenge 1: Home Healthcare

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.

Description:

Achieving the highest quality of life for the elderly, the 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 healthcare 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. 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 (Figure 6). 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 in order to encourage preventive behaviours, such as lifestyle changes, via personalised healthcare portals and electronic coaching tools. 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.

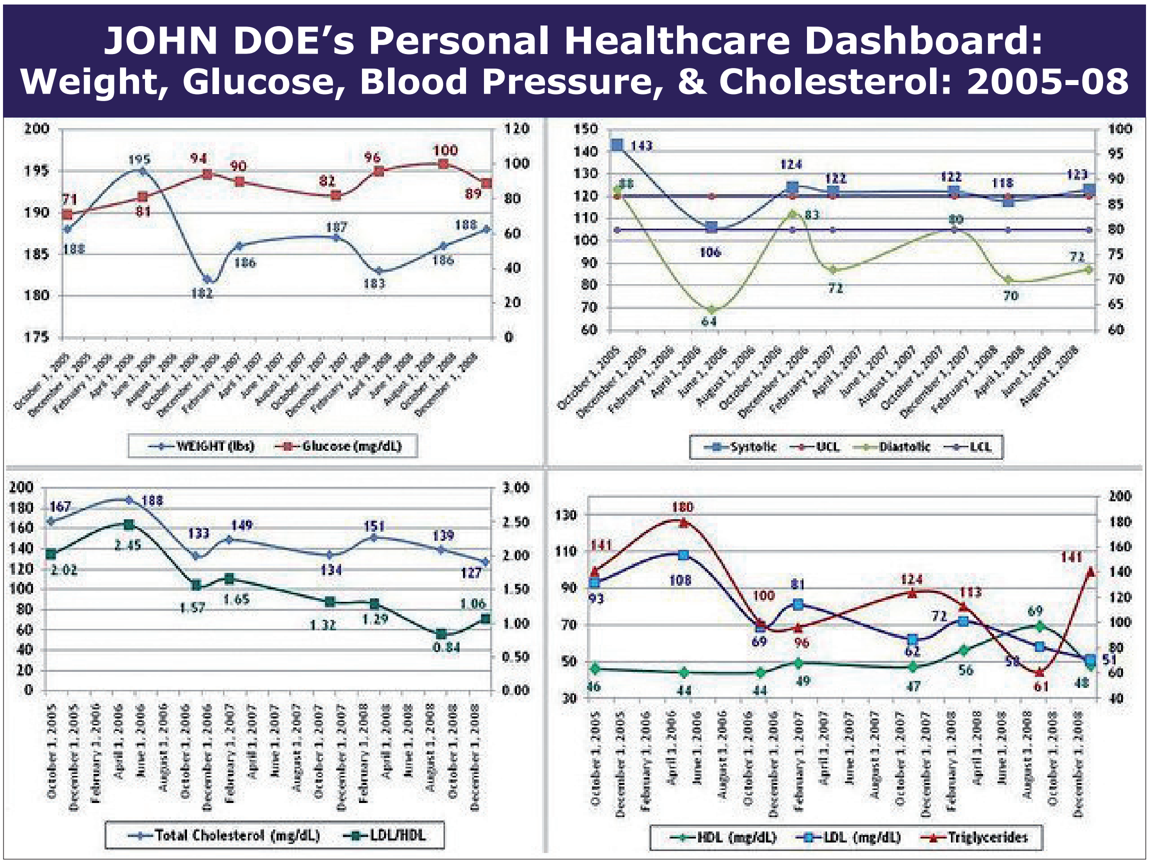

Figure 6: Continuous tracking of important patient health parameters

Competitive Situation:

The increasing prevalence of chronic disease in the ageing society is the primary driver for home monitoring of vital signs. A study published in 2008 estimates that by the year 2020 there will be between 3 and more than 15 million end-users of telecare solutions aged 65 or over in the EU-25 countries, depending on the extent of market penetration.

Mental disorders, especially severe ones (e.g. schizophrenia, bipolar disorder and depression) typically begin in adolescence and are chronic in nature. ICT-based mental health therapy improves healthcare productivity and access to care as it provides therapy with 80% savings in therapist time compared to conventional therapy (Marks & Cavanagh, 2009). The morbidity and mortality of patients with mental health issues is high, with life expectancy almost 10 years lower than the general population (often due to suicide or otherwise). Patients with mental health issues represent between 15% and 20% of the total population and mental health problems are largely under-diagnosed (Katon, 2003). Furthermore, few patients are able to obtain expert consultations. All of these factors demonstrate a clear need for improvement.

Even if only considering people suffering from chronic conditions (i.e. those who are otherwise able to maintain a reasonably normal lifestyle and whose condition can be continuously monitored) the market size for telemonitoring is huge. Chronic disease is the major cause of death and disability both in Europe and worldwide, accounting for 59% of the 57 million deaths annually and 46% of the global burden of disease. As the population ages, the number of people suffering from one or more chronic diseases increases. This places an increasing burden on healthcare systems and social services, and currently affects the quality of life of individuals due to frequent or even continuous hospitalization and social isolation.

As a result of the enormous economic impact the ageing population will exert over the coming decades, there is a growing world-wide market for Independent Living Services and ICT for Healthcare.
The growth rate of the home healthcare market is considerable, even though projections made ten years ago for the domotics telemonitoring market have not materialised. A trend away from static installations towards portable home monitoring devices is visible as smart phones 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.

Expected Achievements/Innovation Foreseen:
The introduction of Home Sensing applications into public health systems will contribute to workload reduction and reduced waiting lists thanks to features such as rapid parameter analysis, rapid analysis for specific targets (chronic diseases), multi-parameter assessment, and ICT-related features. The primary end-user will be the self-managing patient, provided that the level of medical expertise required allows it. Layered alert handling (patient, peer, monitoring service, general practitioner, and specialist) will reduce the workload for highly trained, and therefore expensive, medical staff. Healthcare professionals will be able to access more information (anytime, anywhere) about their patients, with more real-life validity than current dispersed analytical systems allow. As a consequence, improved and more personalised monitoring, diagnosis and treatment practices will be established. Patients will therefore be more confident with public health systems due to several factors:

- Individualized information on the progression of their disease in relation to predictive risk stratification and tailored interventions.
- Electronic support for self-managing healthcare decisions in daily life (anytime, anywhere), thus increasing independence and encouraging participation through 'rich' tailored communications (more effective for influencing behaviours than non-tailored material).
- Reduced time-to-treatment and disease-oriented decision making.
- Optimized health resources and better use of taxation.

Obviously, this requires the development of affordable screening solutions for early diagnosis, preferably at the point-of-care (POC), (bio)sensors, and affordable mobile monitoring of biologic samples and parameters (the "doctor in your pocket"), as indicated in 'Heuristic Healthcare'. One of the ways this can be performed efficiently is via integration of specific tests into a mobile phone application that is linked to a centralised database. Testing an individual's responses to drugs in real time will help to fine-tune therapeutic protocols and reduce side effects. In conjunction with telemedicine, this will result in improved patient coaching and treatment. A further example is the development of affordable 'smart' mobile 3D imaging systems that can be used at the point of care (e.g. by a general practitioner or a small locally-based radiology practice) in conjunction with personalised healthcare (e.g. 'Region of Interest' imaging capabilities).

These Home Sensing systems will include pressure, presence, and motion sensor systems that enable the real-time monitoring of daily living activities (DLA), as well as fall detection for patients who live alone. The remote sensing of variables such as blood glucose or hydration levels will enable elderly people to live more independently and with greater safety. For people with limited mobility or impaired vision/hearing, electronic assistants will be developed to make challenging daily tasks easier to complete. In general, the wellness, security, independence and participation of the elderly and of those living with disabilities will be increased.

Commonly used technologies for tele-rehabilitation include:
- Video-conferencing
- Sensors (e.g. motion sensors for determining position in space and rate of movement; physiologic monitoring sensors that can track or check blood pressure, pulse rate, blood oxygenation or body temperature; electro-cardiogram sensors for heart rate; contactless sensors to measure fatigue; electromyogram sensors for monitoring abnormal muscle activity; electroencephalogram sensors for monitoring brain electrical activity)
- Vision-based activity recognition
- Virtual reality (VR)
- Haptic systems
- Robotics

Smart devices will also help to monitor the healing process. Indicative examples are:
- e-Inhalers for rapid and accurate drug dosage
- Smart electronic band-aids for wound healing, pain relief and skin rejuvenation

- Smart automated drug-delivery systems, based on MEMS actuators coupled with low power control logic and energy scavenging
- Smart band-aids with motion sensors, including accelerometers for determining position in space and rate of movement
  (e.g. to monitor the behaviour of patients after an operation)
- Portable robots for tele-rehabilitation

The efficient use of health technology embraces several key areas in each country's health system. From the social perspective, it can empower informal or family caregivers, who are often overloaded due to emotional involvement and lack of healthcare knowledge. From the economic perspective, this initiative permits healthcare at home, which relieves pressure on hospitals and allows them to focus on acute patients and patients requiring specialised treatment. Furthermore, it improves the quality of life of older people by increasing their level of independent living, even in the case of individuals who are dependent on long-term care. Finally, telemonitoring measures key clinical parameters in close to real-time, providing a better basis for decision-making and, if necessary, rapid intervention. For the latter, fast localization, effective communication channels (RF) and reliable power management (batteries) are all essential.

4.3.2 Grand Challenge 2: Hospital Healthcare

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.

Description:

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) (see Figure 7 for an impression).

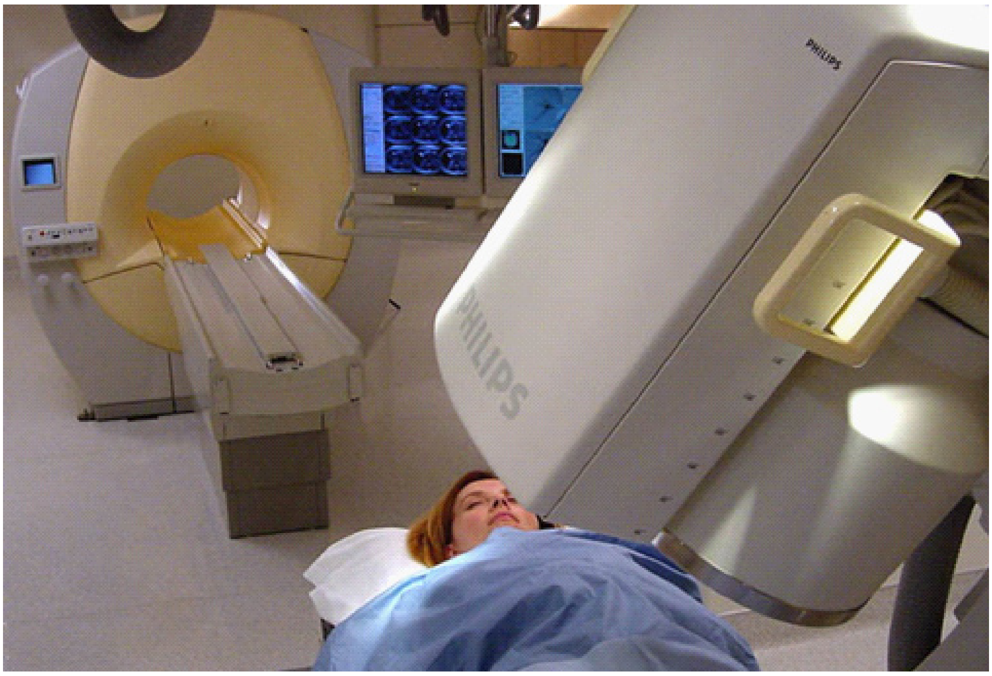

Figure 7: Research setup for interactive interventional procedures

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 [8]. As a result of societal demand and industrial trends, continuous market growth is forecast.

Global spending on medical imaging equipment exceeded US$23 billion in 2013[9] 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 the 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 [10].

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8 EC, DG Information Society and Media, ICT for Health - Aug. 28, 2009

9 TriMark Publications, "Medical Imaging Markets", 2013

10 TriMark Publications, "Medical Imaging Markets", 2013

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 Toshiba Medical Systems (based in Asia). Although not large global 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.

Ten large companies (of which three are from the EU) dominate the medical device market with 43% of market share. Overall, there are around 25,000 medical technology companies in Europe. It has been estimated[11] that almost 95% of medical technology companies are SMEs, the majority of which are small or micro-sized. Europe has a positive medical device trade balance of €14 billion (2011), more than a two-fold increase on 2006.

The European medical device market is expected to grow from US$74.2bn in 2011 to US$114.2bn in 2022[12]. Throughout this period it will remain the second largest medical device market in the world market. Moderate growth in the region will be driven mainly by the ageing population and an increase in Europe's migratory population. This will in turn lead to an increase in the need for devices treating neurological disorders and skeletal repair - e.g. joint replacement.

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.

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[11] Source EUCOMED 2013

[12] Source Vision Gain 2012

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.

Expected Achievements/Innovation Foreseen:

Diagnosis

Improved and combined image detectors lead to increased efficiency, greater precision and the earlier detection of disease. These improvements enable increased image resolution, higher data rates, better registration of multimodal imaging data, wider electromagnetic spectrum coverage (e.g. infrared light), compensation for organ motion and greater precision in detecting the properties of the imaging signals. They can lead to earlier detection of symptoms, and/or minimize harm to the patient. For example, physiology and anaesthesia data can be combined with images using physiological models. In this context, more precise and earlier detection will allow significant dose reduction for patients. In addition, multifunctional contrast agents will be useful in combining several diagnostic systems and in increasing the sensitivity and specificity of diagnostic systems. Another example is the spatial distribution of several switchable miniaturized X-ray sources, based on cold cathode technologies, to allow the design of stationary detector 3D medical imaging systems that minimize constraints on the patient. For screening purposes, imaging systems have to become cheaper, faster and more accurate for point-of-care applications, e.g. in a general practitioner's office. Where they rely on X-ray imaging, they should also minimize the patient's and the operator's X-ray exposure.

Therapy

Better targeted therapies will be achieved by combining miniature devices, such as sensors and actuators, flexible electronics and imaging, with therapy. Image-guided interventions will aid in diagnosis, therapy planning and treatment, allowing the minimally-invasive placement of diagnostic and therapeutic devices such as catheters, stents, ablation tools and replacement heart valves with the help of advanced image analysis and navigation techniques. New multifunctional coatings will be developed to increase patient safety and add additional functionalities to therapeutic devices such as stents (e.g. for improved drug delivery, reduced risk of infection, increased imaging sensitivity). Reductions in the size of medical devices, achieved by component integration, flexible electronics, or both, will enable novel interventional procedures. Real-time testing of an individual patient's response to specific drugs will help to fine-tune and individualise therapeutic protocols and reduce side effects, which in conjunction with telemedicine services will provide better patient coaching. Minimally invasive or non-invasive treatment techniques such as High-Intensity Focused Ultrasound (HIFU), RF and deep brain stimulation and neuronal communication will particularly benefit from image-guided surgery, miniaturization of control logic and real-time patient-specific protocols. Another possible enhancement could be the development of alternative technologies that eliminate the risks associated with using high-activity radioactive sources and nuclear materials (e.g. in nuclear therapy or blood irradiation therapy), by replacing these sources with innovative non-radioisotope based technologies.

Localisation
Localisation (also called positioning or navigation) can enhance the security of people being telemonitored, especially when they need urgent medical help. When deployed within hospitals, it can also improve their logistics - for example, in the case of emergencies, identifying where the nearest clinical experts and specialised equipment are located.

New clinical-user functionalities
In the continued drive for greater efficiency and patient safety, hospital staff are supported in their daily clinical work by an ever-increasing array of technologies (e.g. ICT, robotics, man-machine interfaces, and sensors). In the continued drive for greater efficiency and patient safety, new clinical needs can be addressed by new clinical functionalities through a multi-disciplinary approach involving the diverse kind of jobs available in a hospital, together with innovative technologies and lessons learnt to optimize their daily use by non-specialized staff.

4.3.3 Grand Challenge 3: Heuristic Healthcare

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 biopsy analysis results will be strongly accelerated via digital pathology imaging.

Description:
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).
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.
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.

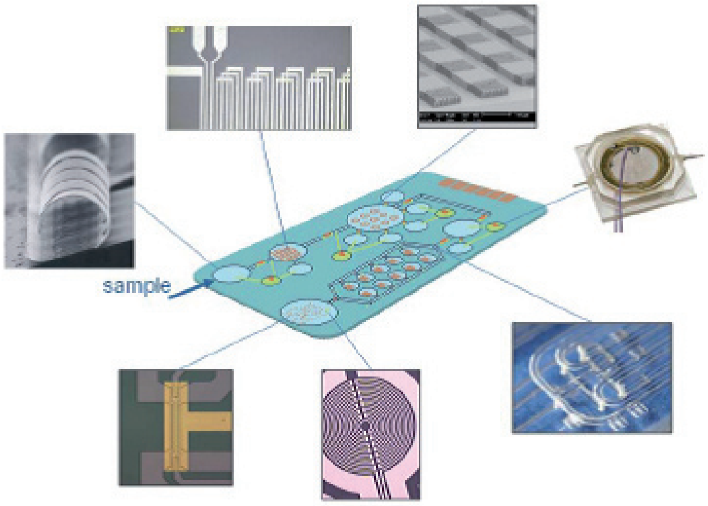


Figure 8: Illustration of a diagnostic cartridge based on heterogeneously integrated MEMS-based modules on a common substrate

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.

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.

Expected Achievements/Innovation Foreseen:

The examinations needed for the determination of real-time response to drugs and for quasi-continuous health monitoring (the "doctor in your pocket") must be minimally-invasive to avoid repeated trauma inducing non-compliance in patients. This goal requires the screening of the most promising fluids, starting with saliva, urine, tear and/or sweat, through to peripheral blood. In combination with biomechanical parameters and other physiological parameters (e.g. core temperature) the acquired test data may provide additional control over measurement context. For the development of biosensors this requires:

1) Integration of MEMS, optical, biochemical, electro-chemical or other readout principles in nano-devices.
2) Wireless interoperability of data with a patient-oriented database system.
3) Finding new, specific and more reliable panels of bio-markers.
4) Finding highly specific receptors for these markers.
5) Integration of the required biomarker tests in a cost-effective and reliable test package (e.g. lab on a chip) that delivers quantitative results in a short time (i.e. a few minutes) for the required biomarker panel (e.g. micro-fluidics and polymeric packaging).
6) Applied research on improved bio-compatible materials.
7) Reliable evaluation of results based on deterministic and probabilistic physiological models.

This will result in point-of-care tests that can be used either by the patient (home care), by a GP or centralized lab (primary care), or by specialist doctors for acute diagnosis (secondary care). In the context of an ageing population, biomarkers related to chronic diseases are of prime interest. For less developed countries, infection related biomarkers are very promising[13].

[13] from WHO-Priority Medical Devices 2010, *WHO - PMD - 9789241564045_eng.pdf*

High-throughput analytical platforms that address the discovery of new drugs via screening procedures will play a role in treatment areas with high economic value, such as immunotherapies and other biological drugs. The MALDI[14] technique will be developed further due to its high degree of multiplicity, specificity for complex systems, and fast detection. Detecting toxicities on as many classes of cell as possible (while supporting the required therapeutic effect) requires the implementation of many thousands of assays in parallel. This task includes the handling of delicate cells in order to detect the desired effects.

4.4 Conditions for Success

The grand challenges cannot be solved by technology alone. Before new 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, the 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, micro-fluidics and actuators can be combined in ways that help to overcome this resistance. In particular, (electronic) interoperability of different clinical equipment and devices in the context of electronic patient records is another condition for success to which technology development can greatly contribute. Co-development of solutions with medical staff and patient organisations can also help to avoid resistance and can greatly improve the speed of market acceptance and increase the chances of successful medical approval.

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 (biomarkers, health ICT, home healthcare, etc.), will enhance Europe's innovative potential.

[14] MALDI: Matrix -assisted laser desorption/ionization: a soft ionization technique of mass spectrometry

4.5 Timeframes

4.5.1 Overview Table

The table below provides a summary of the key technology innovation areas for each healthcare Grand Challenge in the context of the different stages of the Care Cycle:

<table>
<tr><th rowspan="2">Care Cycle stage</th><th colspan="3">Grand Challenges</th></tr>
<tr><th>Home Healthcare</th><th>Hospital Healthcare</th><th>Heuristic Healthcare</th></tr>
<tr><td>Prevention</td><td>Domestic accident detection, personal health (and wellness) management</td><td>Infections and early stage diseases</td><td>Risk profiling based on biomarkers or genetic profiles</td></tr>
<tr><td rowspan="3">Early diagnosis</td><td>Telemedicine, home diagnostic monitoring, point-of-care screening devices</td><td>Early screening of diseases and screening imaging systems</td><td>Biosensors</td></tr>
<tr><td rowspan="2">Non-invasive measurement of parameters, e.g. blood, and (de)hydration</td><td>Improved image detectors</td><td>Highly reliable tests</td></tr>
<tr><td>Clinical validation Multifunctional and selective contrast agents</td><td></td></tr>
<tr><td rowspan="6">Targeted therapy</td><td colspan="2">Smart automated drug delivery</td><td></td></tr>
<tr><td colspan="2">Implants (e.g. deep brain stimulation, multifunctional coatings)</td><td></td></tr>
<tr><td rowspan="2">Smart devices (e-inhalers, bandages, new responsive biomaterials)</td><td>Smart intervention devices</td><td rowspan="2">Heuristic algorithms for personalised treatment</td></tr>
<tr><td>Image guided intervention</td></tr>
<tr><td colspan="3">Real-time response to drugs,
personalised pharma prescriptions and personalised medicine</td></tr>
<tr><td colspan="2">Patient safety; pharma-compatibility; treatment consistency verification</td><td></td></tr>
<tr><td rowspan="3">Remote supervision</td><td colspan="3">Multi-parameter sensors
Adherence to long-term therapies</td></tr>
<tr><td>Secure/private tele-monitoring networks</td><td></td><td>Polymeric IC packaging</td></tr>
<tr><td>Monitoring and emergency alerts</td><td></td><td></td></tr>
<tr><td rowspan="2">Fastest access</td><td colspan="2">Localisation techniques</td><td></td></tr>
<tr><td colspan="2">Personalized health data</td><td></td></tr>
<tr><td rowspan="2">Fast drug screening</td><td colspan="2"></td><td>Efficient screening of drug potential with bio-electronic devices</td></tr>
<tr><td colspan="2"></td><td>High degree of multiplex detection</td></tr>
</table>

4.5.2 Roadmap/Timing

When setting targets for the next decade, it is essential that research, development and innovation are performed on a wide variety of topics to address all three Grand Challenges for healthcare in the ageing society.
To illustrate this, some *key examples* are given below:

Home Healthcare:

- Domestic accident detection, personal health (and wellness) management
- Telemedicine, home diagnostic monitoring, point-of-care screening devices
- Non-invasive measurement e.g. blood parameters and (de)hydration
- Smart devices, e.g. e-inhalers, bandages and new responsive biomaterials
- Secure/private tele-monitoring networks
- Adherence to long-term therapies
- Monitoring and emergency alerts
- Localisation techniques

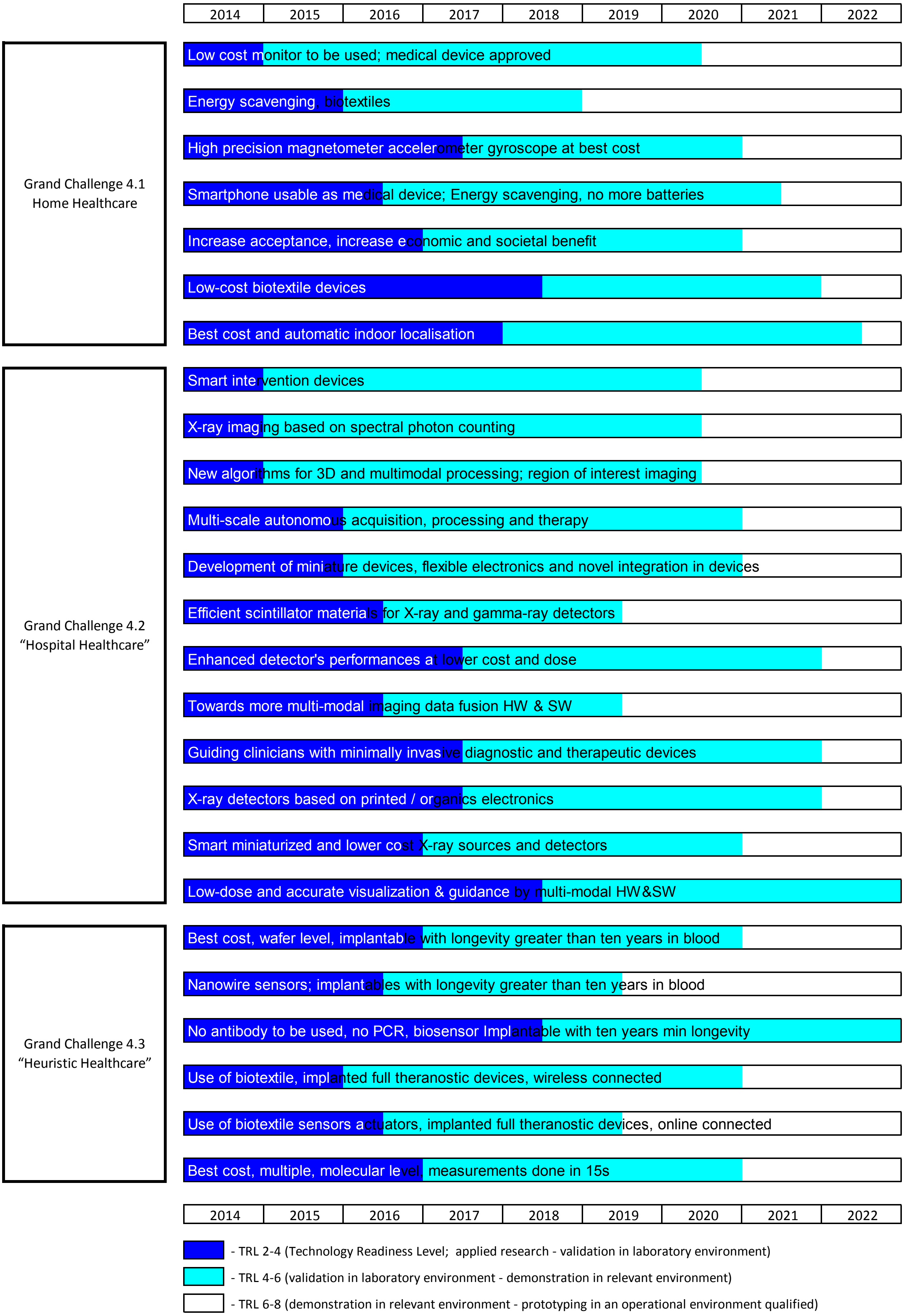
Hospital Healthcare:

- Improved image detectors
- Advanced X-ray imaging
- Multifunctional and selective contrast agents
- Early screening of diseases and screening imaging systems
- Multi-modal, low X-ray dose, accurate visualization and guidance
- Implants - e.g. deep brain stimulation, multifunctional coatings, etc.
- Smart automated drug delivery
- Smart intervention devices
- Image-Guided Intervention
- Personalized health data

Heuristic Healthcare:

- Improved biosensors
- Risk profiling based on biomarkers or genetic profiles
- Heuristic algorithms for personalised treatment
- Real-time response to drugs, personalised medicine
- Patient safety, pharma compatibility and treatment consistency verification
- Efficient screening of drug potential with bio-electronic devices
- Multi-parameter sensors
- Polymeric IC packaging

All of the topics mentioned above can be studied at all Technology Readiness Levels (TRL) 1-8, but these will be different for each research topic and will vary over time. The timeline below further illustrates this with examples of possible Research and Development and Innovation:


2014
2015
2016
2017
2018
2019
2020
2021
2022
Grand Challenge 4.1
Home Healthcare
Low cost monitor to be used; medical device approved
Energy scavenging, biotextiles
High precision magnetometer accelerometer gyroscope at best cost
Smartphone usable as medical device; Energy scavenging, no more batteries
Increase acceptance, increase economic and societal benefit
Low-cost biotextile devices
Best cost and automatic indoor localisation
Grand Challenge 4.2
“Hospital Healthcare”
Smart intervention devices
X-ray imaging based on spectral photon counting
New algorithms for 3D and multimodal processing; region of interest imaging
Multi-scale autonomous acquisition, processing and therapy
Development of miniature devices, flexible electronics and novel integration in devices
Efficient scintillator materials for X-ray and gamma-ray detectors
Enhanced detector's performances at lower cost and dose
Towards more multi-modal imaging data fusion HW & SW
Guiding clinicians with minimally invasive diagnostic and therapeutic devices
X-ray detectors based on printed / organics electronics
Smart miniaturized and lower cost X-ray sources and detectors
Low-dose and accurate visualization & guidance by multi-modal HW&SW
Grand Challenge 4.3
“Heuristic Healthcare”
Best cost, wafer level, implantable with longevity greater than ten years in blood
Nanowire sensors; implantables with longevity greater than ten years in blood
No antibody to be used, no PCR, biosensor Implantable with ten years min longevity
Use of biotextile, implanted full theranostic devices, wireless connected
Use of biotextile sensors actuators, implanted full theranostic devices, online connected
Best cost, multiple, molecular level, measurements done in 15s
2014
2015
2016
2017
2018
2019
2020
2021
2022
- 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)

4.6 Synergies with Other Domains

There are many possible synergies between Healthcare & the Ageing Society and other VMS chapters:

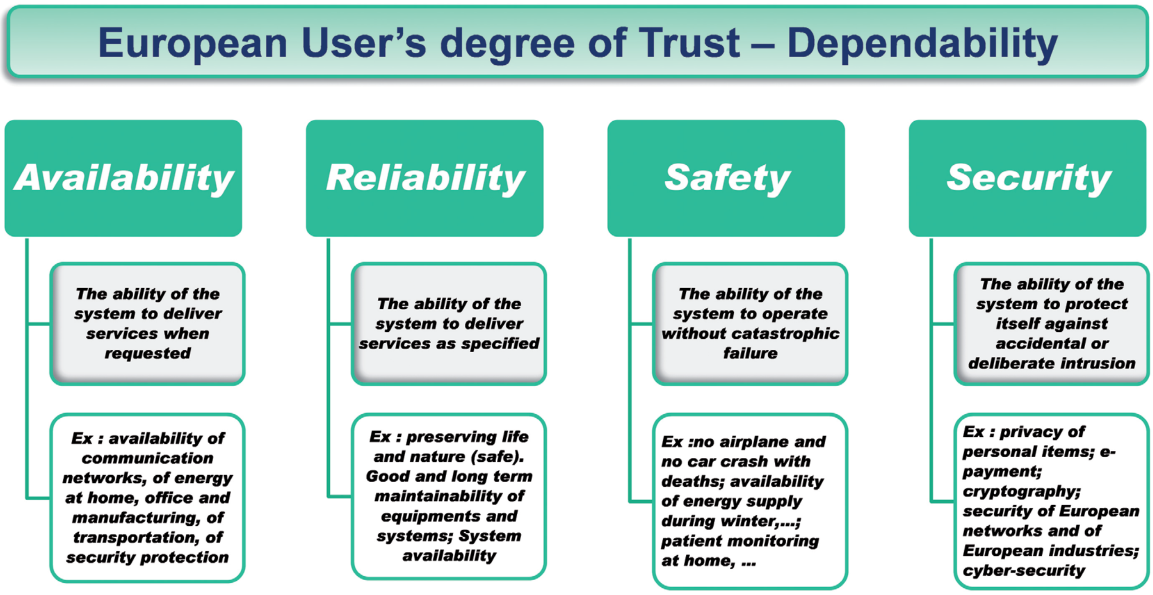
- Automotive and Transport: – health and wellness technologies can be deployed in automotive settings to improve safety (e.g. sensor networks that monitor a driver's vital signs and act accordingly). In addition, medical imaging systems could benefit from new electronic power sources developed for electric and hybrid vehicles.
- Communication & Digital Lifestyles: – the 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. Additionally, there could be synergies between the technologies used in LTE terminals to support safety on the road and those used for safety in the home. Furthermore, the exchange of high-resolution life science images and data will require fibre optic broadband technologies.
- Energy Efficiency: – low-power techniques can be essential for healthcare monitoring systems that use 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: – as drug delivery and surgical interventions become automated, intrinsic safety has to be guaranteed. A large amount of patient and non-patient data has to be collected, transmitted and stored securely. Privacy needs to be guaranteed at all times.
- Design Technologies: – the 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.
- Silicon Process and Integration and Equipment Materials and Manufacturing: – 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.

CHAPTER 5

SAFETY & SECURITY

5.1 Introduction

A significant part Europe's current world-wide leadership in the production of electronics is in the provision of solutions that require safe and secure operation.
Safe and secure systems are essential for personal and financial security, information privacy, health and well-being, accident prevention, protection against violence and associated adverse impacts.
This chapter describes safety and security applications that affect the daily lives of ordinary people and require the development of new technologies. The applications discussed reflect people's ever-increasing reliance on broadband Internet access, easy safe transportation, smart energy distribution, and trust in safety critical applications (e.g. vehicle control), industrial plant safety, e-payment, consumer protection and homeland security.



One of the most important properties of European systems and applications is their dependability, which determines the user's degree of trust in them. However, as illustrated in the diagram above, there are different pillars to dependability. Rather than being separate, these are increasingly being combined, such that systems operate as users expect and do not fail in normal use:

- **Safety** is the system's ability to operate normally or abnormally without the risk of causing human injury or death, and without damage to the system's environment - i.e. safety is concerned with ensuring that systems do not cause damage, irrespective of whether or not they conform to specification. Safety can be achieved by building features such as hazard avoidance, hazard detection/removal and damage limitation into applications. Aircraft, trains and cars used to be the main drivers of 'safe' solutions, but today the majority of new applications demand safe operation.

- **Reliability** relates to conformance to a given specification and/or delivery of service, and is becoming increasingly important as technologies get more complex and heterogeneous. It should be noted that safety and reliability are related but distinct.

- **Security** is a property that reflects a system's ability to protect itself from accidental or deliberate external attack. Security is becoming increasingly important as systems are networked so that external access to one system via another (e.g. via the Internet) is possible. Security is an essential pre-requisite for availability, reliability and safety - for example, safety validation relies on demonstrating that a particular system is safe. Banking, network security and smart cards have this requirement in common. In general, safety is now cross-correlated with security, because systems are becoming more connected and people are becoming more mobile.
- **Deployment** of numerous new technologies and associated value-added services raises the challenges of security and privacy. At infrastructure level, security features will need to incorporate techniques for authentication and access control, intrusion detection, robust and secure system design, and secure communication with strong resilience capabilities. On the other hand security and privacy architectures will have to be defined and that address identity protection and its management in private and public areas. In addition, trust will have to be addressed in order to have security technology integrated and widely accepted to create the necessary level of confidence needed for a successful deployment of digital technologies and associated services.

This chapter describes the nanotechnology developments that are required to ensure the safety and security compliance of European electronic components and systems. More applications, more automation, and more connectivity bring new challenges, for which nanoelectronics can contribute to effective solutions.

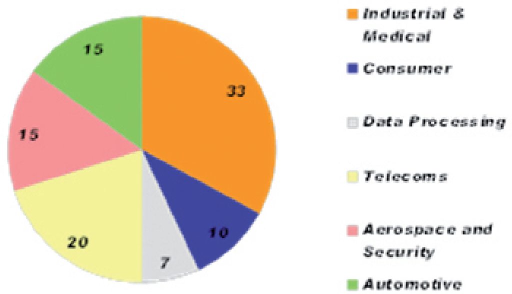
5.2 Relevance for Europe

Safety and Security and is part of the Horizon 2020 (H2020) objectives, both in terms of industrial leadership and the societal challenges: secure societies, secure and efficient energy, protection of resilience of critical infrastructures and integrated transport.

5.2.1 Competitive Value

Statistics show that we live in a much safer world, yet there is still a constant demand for increased safety and security in virtually every aspect of our lives. Ubiquitous security is a major challenge for the information society, because tremendous quantities of data circulate and are stored all over the world, and are available from anywhere at any time. It is clear that safety and security not only constitute a major market in themselves: they are also generic enablers for many other applications and support many related services.

Application sectors	European share of WW electronic production
Industrial & Medical	29%
Aerospace and Security	30%
Automotive	27%
Telecoms	13%



Europe has always been strong in safety and security: with large country-based or European level applications such as e-payment, e-health and ID; large systems companies active in safety and security; and large European equipment actors leading solutions for automotive, aerospace, industrial and medical. Equally importantly, Europe has world-beating semiconductor suppliers and research institutes that lead in enabling technologies for applications such as USIM cards and secure microcontrollers.
In 2012, Europe produced €225 billion (~16%) of the €1400 billion worldwide value of electronic products. Europe leads in four main sectors: Industrial and Medical 29%, Aerospace and Security 30%, Automotive 27%, and Telecoms 13% of the worldwide market. The pie chart above shows the distribution amongst the sectors of the €225 billion market within Europe, for wich industrial and medical is 33%, aerospace and security 15%, automotive electronics 15% and telecom 20%.
All the leading sectors need to be compliant with safety and/or security requirements.

This safety and security must be based on standards and technologies that European public authorities can rely on in terms of maintaining Europe's independence - i.e. in general, they should be based on standards accessible to the open market or 'open-source' (not controlled by a single organization). Furthermore, security is not a static attribute. It changes constantly with respect to what to protect, how to protect it, and what threats to protect it against.
In this context, two major challenges exist for European solutions:

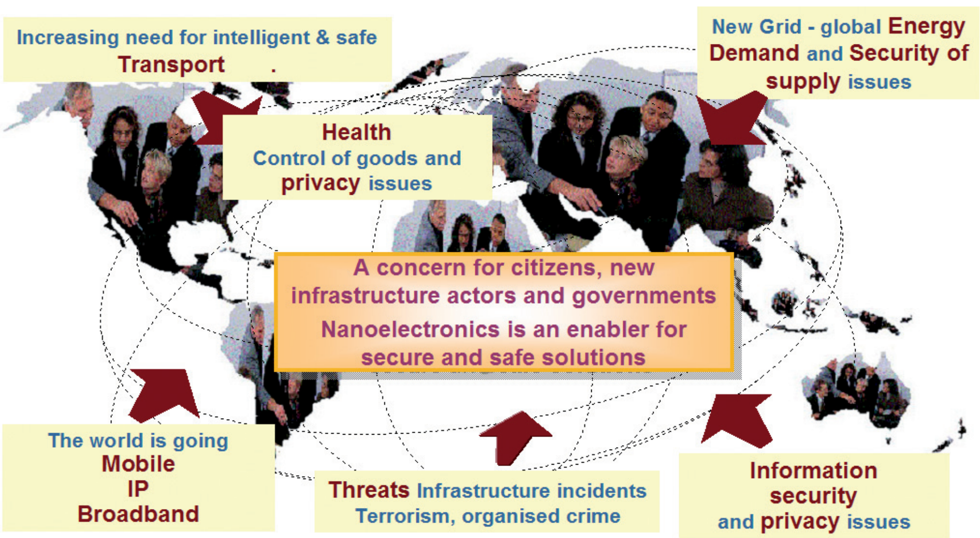
- Safety and security of new European applications and infrastructures
- Enabling technologies and building blocks for trust, safety and security

5.2.2 Societal Benefits

Europe's citizens and consumers, as well as its public authorities, need to build enough trust that new technologies and products ensure their security, safety and privacy.

- Electronic systems safety aims to prevent dangerous failures and control them if they do occur. Examples are anti-lock braking and engine management in cars, signalling systems in railway or traffic infrastructures, aircraft flight control and production plant monitoring. There are also many life-critical applications in healthcare.

- Security reflects itself in citizens' demand for safety and security at home, at work, and on the move, and in public authorities' need for protection against crime and terrorism. However, this is always accompanied by the need for personal protection without restricting an individual citizen's liberty or privacy, which means that safety and security systems need to be reliable, easy to use and capable of safeguarding the privacy of end users.
- Regarding IT security and privacy, virtually everybody is aware of new threats every day. Statistics show that Internet users worldwide are constantly exposed to identify theft, that malware infects many personal computers, and that citizens lose significant amounts through Internet fraud.
- It is becoming ever-clearer that unless they chose to pay for security, consumers avoid the use of new services if they do not have sufficient trust in the whole chain. This not only applies to personal devices, but also to existing and future infrastructures such as transportation systems. On the other hand, consumers do not always enjoy full transparency about the security of devices or services.



5.3 Grand Challenges

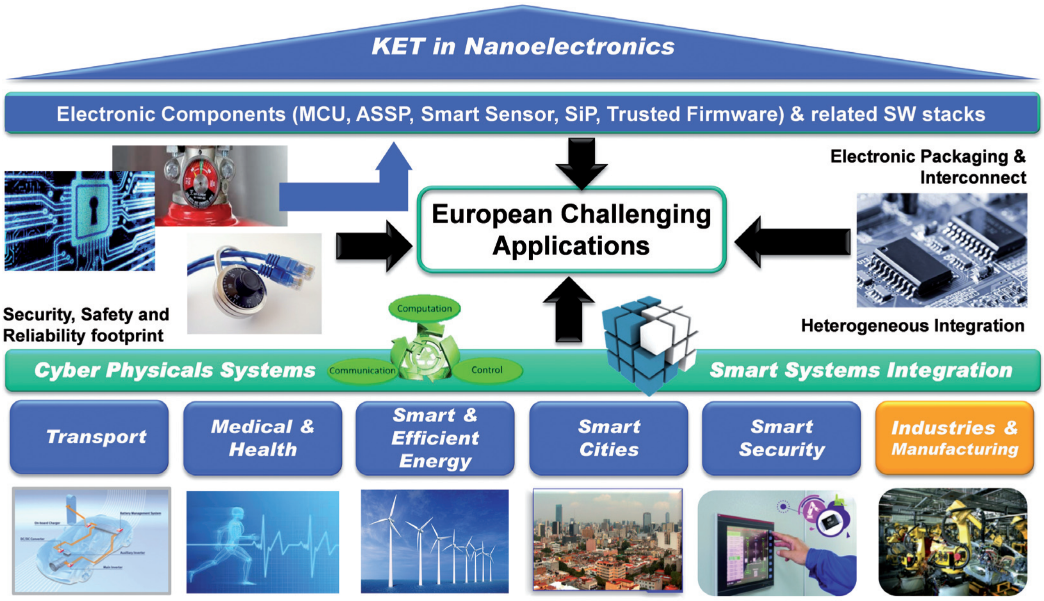
5.3.1 Grand Challenge 1: Securing the European Challenging Applications

Vision:

Take advantage of European leadership and expertise in electronic safety and security to define, develop and implement the required safety and security in new challenging European application domains and stay ahead of world competition.

Description:

In all new application fields, electronic control and data exchange demonstrate an obvious need for more security. Guaranteeing that software program integrity is preserved during product life, ensuring solid mutual authentication of communicating parties, and maintaining the confidentiality of sensitive data are some of the key protection targets. Irrespective of the application domain, similar concerns are appearing. However, the overall definition and implementation of security measures may change significantly according to the ecosystem, regulatory environment (for example, it may be very different between transport and healthcare), target cost and budget.



Automotive and Transport

In transportation (automotive, city transportation, railways and aviation) safety is critical. Security combined with trust and safety requirements, together with system integrity and traceability, are mandatory. Greater mobility and the increasing volumes of traffic require more safety in traffic. Electronics is the enabling technology to develop smooth access control when traveling, better safety in traffic and co-operative traffic management. Increased use of new protection technologies is necessary to protect today's complex systems against errors and malicious internal/external influences. New Deep Submicron (DSM) technologies are bringing new technical challenges, such in signal integrity, reliability, trust and safety/security compliance.

Health & the Ageing Society:
Supporting elderly or dependant people to live in their own homes, and minimizing their level of institutionalization, will require continuous monitoring of their activity levels, vital signs and other relevant parameters.
Collecting, communicating and filtering this information will require a highly trusted chain of systems featuring fully dependable electronics and strong data protection to respect privacy.
To keep the cost of European healthcare systems under control, a network that provides Europe-wide access to medical data will be essential. The data on this network will need very strong protection against unauthorized access, while maintaining fast access - for example, in medical emergencies. Data protection of this secure network infrastructure will require the development of new concepts for data storage and access management.

Energy Efficiency and Smart Energy Grids
In the field of energy efficiency and smart energy grids, the key application will be the definition and use of a smart grid system that manages the overall distribution network and protects it from undue external control. Liked to that, the collection, distribution and use of customer-usage profile data has to be strongly protected in order to ensure privacy and avoid massive fraud. Remote control by users or by the overall management systems not only has to be resilient to many different security threats (e.g. wrong access, billing fraud), it also has to protect people's safety (e.g. the danger to people if home equipment is incorrectly driven either by fraud or failure). Energy networks also constitute a critical infrastructure. To a large extent, the existence and prosperity of communities depend on them. They therefore need protection against foreign intervention as well as against natural system deficits e.g. design and software errors. Furthermore, strong protection is necessary against possible large scale cyber-attacks depriving regions or countries of electricity with potentially disastrous economic and societal impact.

Smart Cities
Cities have to manage their continued evolution despite budget constraints, decreases in natural resources and increased demand for a safe and secure environment. This will lead to the massive deployment of solutions geared toward implementing so-called 'smart cities'. It will cover solutions for transportation and parking, security, police, e-Governement, e-Health and hospitals, energy and water distribution, and communications etc., based on interconnected networks and decision/control centres. One of the challenges is the creation of new tools and methods to provide smart cities with a high level of security and privacy against cyber-attack. The answer is to create adaptive and upgradable security solutions that can be used to secure electronic systems and applications.
These security solutions will need to incorporate techniques for authentication and access control, intrusion detection (including weak-signal mining and processing), robust and secure system design, and highly resilient secure communication capabilities.

Communication
Network security, availability and reliability are essential features for the functioning of societies and economies. Cloud computing will become the common resource for mobile yet connected people. Securing services or data and providing proper evidence of protection is therefore becoming increasingly important and difficult in advanced, open, wireless and fully mobile devices. End-users, OEMs, ISVs, content owners, service providers and operators have different, sometimes diverging needs, and should have differentiated privileges towards terminal resources. Robust stakeholder segregation, security policy enforcement and mutual assets isolation is a challenge in increasingly open computing devices exposed and vulnerable to new malware, software and hardware attacks on a daily basis. Increasing interoperability, trust and flexibility requirements bring with them standardization and security evaluation challenges. Finally, the ever-increasing complexity of security measures should remain transparent to end-users, which places additional demands on security performance and efficiency.

Smart Security
Europe's citizens live in a technological society where most communications and transactions are performed electronically. Society therefore depends on the error-free operation of embedded computing systems in transportation, wireless networks, industrial plant, and critical infrastructures (airports, public transportations, utilities, networks, distribution, etc.) and in future, in applications such as body networks for home healthcare monitoring.In additon, proper identification of users (e-ID for both citizens and consumers) is needed to avoid fraudulent usage, and adequate management of these identities is required to avoid identity theft and the associated consequences, as well as ensuring end-user privacy.
All electronic systems, machine-to-machine interactions, goods, and critical infrastructures are vulnerable to a range of threats. European citizens operate in an open society and enjoy very high levels of mobility both in personal and professional activities. Together with society as a whole, they need to be protected against fraud and information attacks, deficits in highly complex modern installations and the endangerment of critical infrastructures.
In addition, privacy of the end-user data needs to be ensured. As a consequence, systems that protect against vulnerabilities in a cost/effective manner have to be provided, and these systems also need to target security without restricting people's mobility and without disturbing their daily lives. Furthermore, security needs to be implemented in a convenient way in order to avoid making processes too complex or time consuming - e.g. performing and authenticating transactions.

Smart Manufacturing based on Cyber Physical Production Systems
If orders fluctuate excessively either in quality and quantity, and the availability of production capacity cannot be estimated in advance, conventional centrally-controlled manufacturing systems quickly reach their limits. Small batch sizes and quickly changing product mixes require a highly intelligent, networked and decentralised production approach – with automatic, simultaneous replenishment of individual parts and complete transparency of the order process. This decentralised manufacturing control approach focuses on mobile, embedded and wireless elements, so called Cyber Physical

Systems (CPS), or better still in this context Cyber Physical Production Systems (CPPS). In these innovative autonomous production scenarios, the data necessary for the manufacturing process should be exchanged on a local level between production cells and the product itself. Key elements of this 'object-centred' production will be on-board digital product memory to provide and continuously update manufacturing information during the production process and during the product's life cycle. All the product information and the necessary processing steps are stored in the CPS memory, which makes it an active element in controlling production.

Security Demands in Smart Manufacturing
The implementation of smart manufacturing concepts will not only result in more flexible production, it will also result in more highly flexible value chains. This increase in flexibility will mainly help to satisfy the increasing demand from customers for individual product/service configurations and faster delivery. Flexibility in this context means:

- Companies will have to open up and adapt their coverage within the value chain to the individual business model
- Flexibility of production systems

The solution is ICT-based smart factories, which are able to react to customer demand with extremely high agility. This will also require further links into ERP-systems, CRM, SCM etc., to create flexibility not only in manufacturing but also in production control. Cyber physical production systems form highly connected systems with numerous participants, such as ITS systems, automation systems, production machines and, course, people. Between all of these participants there will be intensive data exchange, which will often be time critical. Such systems will be realized and accepted only if reliable solutions are implemented that protect process know-how and at the same time prevent manipulation and sabotage. Security measures within today's production facilities are by comparison extremely weak or non-existent.
Actual threats to industrial systems in particular could include the illegal use of remote maintenance terminals, online attacks via office or enterprise networks, attacks to standard components in the ICS network, denial-of service attacks or the introduction of viruses via removable memories (USB sticks, external hard disks, etc).

High Priority Research Areas:
Europe is currently the worldwide leader in safe and secure electronic products. It is therefore extremely important to integrate security, safety and reliability footprints in newly developed nanoelectronics programs.
In addition to the Grand Challenge 2, four application-level techniques are demanded to address Challenge 1.

Protection Profile
Approaches to defining secure solutions are well known in banking and communication applications. However, for the applications envisaged in H2020, which will be ever-more connected, protection profiles need to be defined to suit ad-hoc technologies and techniques (as part of Challenges 1 and 3).

For each use case, the assets need to be identified, and the associated threats and risks analysed and described. The corresponding security requirements can then be derived. Based on those security requirements, the necessary tools for enhancing and characterising security can be developed. Hence medium/long-term research focusing on new metrics of security is encouraged. This would contribute to quantifying the level of trust which is currently a subjective value. The formal and theoretical approaches using threat and protection models could bring a strong support to practical tests in order to validate the metrics.

Cyber Security and Information Privacy

Information assurance and cyber security are clearly elements of any trusted IT system but in future new techniques need to extend more widely than the classical concepts of confidentiality, integrity and availability. Increased connectivity, mobile working and interaction with control and monitoring systems all require good information assurance. The European emphasis on the privacy of individuals is an equally prominent driver. There are many issues in this area that are in need of short, medium and long-term research-led solutions. These include: Privacy (Confidentiality as well as non-traceability), provenance of information in very large systems and the integrity of processing (Integrity and authenticity), reliability and resilience in resources and connectivity (Availability), and ad-hoc protection against emerging threats (e.g. malware, botnets, etc.). New solutions for embedded systems such hardware-enabled trust architectures and trusted computing are welcome.

Trusted Computing as a Generic Technology for Security

The Trusted Computing Group has been working since 1999 on defining the security components required to introduce and integrate security in to IT-Systems, mainly targeting the PC and Notebook domains. Trusted Computing is a standardized and cost efficient solution, which needs to be extended and adapted to form an optimal and reliable basis for safety critical systems, such as critical infrastructures, automotive systems and smart grids. Europe has excellent high-level competencies in these domains as well as in Trusted Computing, because wide support from industry, research institutes and the public community has already been established. The gap between the traditional PC and industrial or embedded systems will increasingly disappear because of the perpetual increase in performance, capabilities and connectivity of these devices. Trusted Computing is therefore a generic and available concept that provides the basic technology for the commonly required functionalities such as authentication, device integrity, authorization, availability, reliability and long-term stability and continuity. It is therefore essential and efficient to bring an elaborated and recognized technology like Trusted Computing into the embedded and safety-critical domain in order to establish a common, open and generic solution for security critical data and operations. Research on these topics will place European industry and society in a leading position in respect to these domains and will strengthen Europe's role as a solution provider for the integration of security in industrial and embedded application domains.

Usage of Consumer Technologies in Safety and Security-critical Applications:
Many applications adopt and integrate consumer-rooted technologies in safety/security critical applications. Typical examples are connectivity technologies such as ZigBee and Bluetooth, or consumer 'terminals' such as Linux- or Android-powered mobiles or gateways. A significant challenge is then related to the typical lack of safety and/or security-oriented design, validation, testing, and certification during implementation of these technologies. However, through their de-facto adoption, these technologies are often becoming a critical part of the 'attack surface' for smart systems. For example, a ZigBee or Bluetooth stack often ends up becoming part of the attack surface of a security-critical application such as e-Health, yet it is typically impossible to really assess and compare the security robustness and trustworthiness of such stacks (implementations). Proposals at both the standardisation level and the implementation level are required.

Mission Profile of Electronic Systems in New Applications
Most of the electronic components and packaging developed for consumer products are designed for use in home or office environments, not for use in complex, harsh environments where long lifetimes need to be guaranteed. A 'constraint engineering' approach is needed to address reliability and robustness challenges with new device technologies and packaging techniques, involving the complete supply chain. Environmental stresses and strains from real operating conditions in the target application will need to be validated at component and assembly level. For this, a good knowledge of use conditions (mission profile) is necessary. The failure mechanisms and modes of new technologies should be fully understood. Acceleration models to determine the prognostic health of products after they are deployed will also need to be developed.

- Define the mission profile that impacts individual electronic components and packages (e.g. operating temperature range and gradient, humidity, etc)
- Develop new assessment methodologies for comprehensive coverage of the complex associated reliability risks without having to run very expensive reliability and qualification tests; new profiling algorithms for 'combined loading' reliability tests in order to determine risk specifications; and new test and evaluation algorithms.
- Develop schemes and system-level tools for Prognostic Health Management: identify key indicator factors, develop new prognostic algorithms and define their implementation.

Competitive Situation:
Europe has always been a leader in developing large innovative applications at European level, based on industrial OEM and systems industries such as automotive, energy management, transportation, health, and security. However, early initiatives for new applications, such as security and smart energy grids, have already started in the US and Asia and are growing at the same rate or faster than in Europe. The industries involved have already recognized the absolute need for trust and security, which represents an opportunity for European actors provided they are quick enough to respond.

Considering the growing demand for mobile connectivity, identity and data protection, health and transport services, e-banking and e-government and, moreover, for global security as a whole, it is essential that Europe maintains and enhances its technical leadership in these areas. Doing so will be the only way for Europe to continue providing hundreds of millions of people with the means to communicate, travel, work, and purchase goods/services in an enjoyable and secure environment, through the delivery of products and services that convince users of their quality, functionality and resistance against internal and external errors and influences.

Expected Achievements/Innovation Foreseen:
The targeted achievements are numerous and relate mostly to the other chapters. For Safety and Security, four main metrics can be identified:

- Trusted execution, computing and connectivity for embedded systems and complex information networks and computing systems.
- Secure execution, management, personal privacy in new Europe-wide applications.
- Validation, verification and proof of safe and secure devices (trust provided to end users and customers - for example, OEMs, cities, etc.).
- Maintenance of European actors as worldwide leaders in the production of safety and security compliant electronic solutions.

5.3.2 Grand Challenge 2: Enabling Building Blocks Technologies for Trust & Security and Reliability & Safety

Vision:
Together with European semiconductor actors and European security and reliability experts, to develop the Building Blocks and Technologies for trust & security and reliability & safety add-ons to provide secure and safe enabling devices.

Description:
Semiconductor technologies and nanoelectronics have direct relevance to safety and security functionalities in information technology, consumer goods, citizen practises, secure payment, wireless communication, energy distribution, an individual's health information (e.g. electronic patient records), transportation, complex machinery and equipment, and secure access.
At the same time, new semiconductor technologies as well as alternative design and system integration techniques are contributing to the advancement of the core capabilities needed for IT and embedded systems - for example, sensing, data and signal processing, computation and communications. In addition to these, some critical features and building blocks will be required for the foundation of secure and safe nanoelectronics devices.
If safety and security are to become generalized in applications, a methodology for integrating basic security blocks in complex systems (e.g. microsystems such as SoC, or macrosystems), coupled with tools for proof, early validation, simulation, etc., have to be developed. This will lead to the development and implementation of so-called 'Secure by Design' approaches.

Trust has to be achieved by measuring the integrity of the hardware and software associated with processing platforms to ensure the construction of trusted platforms, for which operational integrity is preserved even in networked environments. Trust is also necessary to protect secure systems against sophisticated attacks and report their integrity status to companion systems. Trusted implementations are already emerging to protect PCs, mobile communication devices and servers, as well as to protect embedded systems such as vehicle or industrial control systems against attacks from external agents and error propagation from internal sources (e.g. residual software implementation errors).
Because virtually all products are produced by assembling subcomponents from various sources, subcomponent authentication and integrity checking is a key element in the fight against piracy. Evidence suggests that some subcontractors, such as software houses or fabless companies, may have sometimes fraudulently modified products (Trojan like).

High Priority Research Areas:

Following these guidelines, this chapter suggests the promotion of a pan-European effort on generic technologies in the following fields (the list is non-exhaustive):

Secure enablers on top of the baseline semiconductor technologies

- Impact of new technologies (e.g. FD-SOI, 3D IC, SiP).
- Next-generation, large, secure non-volatile memories (NVM) to protect the confidentiality and integrity of information during storage and to achieve higher data rate connectivity. This should include extensions from multiple-key management to public-key encryption.
- New ultra-low power NVM memories with fast access times to enable hardware-based security nodes in every device.
- Attack and probe resistant silicon cells and design processes.
- New sensor-based approaches for protecting against cloning and counterfeiting.

Design-time security - a new paradigm:

- Construction of secure physical building blocks via design-time automation.
- Design of secure software libraries via compile-time analysis and strengthening.
- Design-time evaluation of side-channel security for cyber-physical systems.
- More efficient design of trustworthy secure building blocks and libraries.
- Increased effectiveness of protection via automated applications.
- Formal proof-of-protection.

The related medium/long-term research directions:

- Finding integration points in current EDA tool chains to introduce security-oriented design steps.
- Integrating automated security analysis procedures in to the current compilation pipeline.
- Developing architecture-level support for secure program execution.
- Testing for vulnerabilities at design time, and providing early feedback to designers.

Cyber-Physical Security Building Functions

- New architectures for intrinsically resistant components (resistance to fault

injection, flat signals emission, etc.).
- Embedded sensors technologies for safety and security.
- Very small area integration security algorithms e.g. for authentication and digital signing.
- Component authentication, such as PUF technologies (Physically Unclonable Functions).
- Secure new high data-rate interfaces for M2M, contactless interfaces and RFID.
- Zero-power smart secure object (i.e. energy harvesting storage).
- New secure MCU, cryptographic MPSoC and hardware-enabled trust components.

The related medium/long term research directions for cryptography:
- High-speed authenticated encryption algorithms in the Terabit/sec range.
- High speed implementation of cryptographic algorithms (e.g. for cloud applications). Some concrete research challenges address the design and implementation of cryptographic protocols that are highly parallelizable, because this would significantly improve the efficiency of cryptographic implementations.
- Design and implementation of public-key protocols that offer forward secrecy and achieve demanding performance requirements such as tens of millions of public key operations per second.
- Optimized energy requirement and footprint of cryptographic algorithms for 'Internet of Things' (IoT). Ultra light-weight, low-energy solutions will be needed.
- Context-dependent optimization of cryptographic algorithms. For example, the adoption of modern cryptographic techniques in JavaScript could significantly increase the cryptographic capabilities of web browsers.
- Design cryptosystems that offer very long term security (e.g. in the order of 50 years).
- Practical implementation and design of novel cryptographic technologies such as fully homomorphic encryption, functional encryption, and secure multi-party computation. Implementation of these schemes would improve the overall security and privacy level of cloud computing applications and would reduce the risk of having a single point of failure in systems.
- Development of advanced zero-knowledge protocols as well as novel group signature schemes and identity or attribute based encryption schemes. New applications involving these techniques would be smart metering, road pricing, cloud computing, e-voting, etc.

The related medium/long-term research directions relating to better resistance to attacks:
- Efficient, lightweight countermeasures against side-channel leakage and fault attacks.
- In the context of cloud computing, efficient protection against attacks performed at the virtual machine level or below, and against timing attacks.
- Secure design and development of leakage-resilient cryptography. There is also a need for provable security against physical attacks.
- Novel obfuscation technologies such as whitebox cryptography.
- Development of advanced cryptographic tools, such as Physical Unclonable Functions.

- Countermeasures to detect and repair hardware manipulations (such as hardware Trojans).

Trusted Protocols and Tools - embedded stacks for connectivity and exchanges

- Bring security as a service (for authorization and key management in remote sensors and embedded systems).
- In M2M introduce IPV6, secure exchanges and remote management.
- Trusted operating environment to deal both with safety and security compliance architecture.
- Protection of software at real time, at low power consumption and low silicon footprint.
- New reliability methodologies, techniques, and approaches.
- New assessment methodologies for comprehensive coverage of complex heterogeneous reliability risks (not just for HW but also embedded SW and HW/SW interaction) at minimum effort.
- Signal integrity techniques and improved EMC protection/shielding.
- Design-for-Reliability (DFR) techniques with new technologies and heterogeneous assembly; Silicon ageing of DSM technologies to be examined versus duration of life required by industrial applications.
- Development of schemes and tools for the Prognostic Health Management of final products: this includes the identification of key reliability indicator factors, new assessment and prognostic algorithms and their implementation in components, etc.

The related medium/long-term research directions:

- Understanding the 'Physics of Failure' in new technologies (DSM, NVM, high power devices, etc.).
- Development of virtual reliability techniques and their implementation in the development cycle in order to avoid difficult and long hardware prototype testing in the targeted mission profile: (virtual testing, virtual prototyping, virtual FM(M)EA, etc..).
- System-level modelling of failure for next-generation components.

Competitive Situation:

European semiconductor companies and OEMs are world leaders in the provision of secure and safe devices and systems. With the globalisation of safety and security, it is important for European actors and stakeholders to drive mainstream safety and security technology and develop the necessary safety and security add-ons.
Europe's industrial machinery, production system, transportation, security, healthcare and automotive industries are developing ever-more complex solutions to fulfil customer expectations and user needs worldwide, which has resulted in continued capturing of worldwide market share. For continued enhancement of such systems, Europe needs integrated trusted safety and security technologies to preserve and give its industry a differentiating advantage over other economic regions.

Expected Achievements/Innovation Foreseen:

Dealing with improved security, such as secure cloud services, servers, embedded systems and personal devices

- Security based on known and tested cryptography.
- Next-generation MCUs with improved security and larger embedded NVM for embedded software stacks.
- Improved trusted virtualization and compartmentalised operating systems; Multi-level security.
- Universal trust anchors for personal computing, M2M and communication devices.
- Multi-form secure tokens.
- Integrated trust and security hardware and firmware features for embedded computing platforms.
- Security deployment in new applications such as smart grids, smart cities, e-health etc. (with heterogeneous systems for smart mobility, smart objects for e-Transaction and embedded M2M).

Dealing with new power electronics. One big trend is ever-increasing power dissipation in power components. The main fields are: RF communications, energy generation and transmission, e-mobility (cars), factory of the future (machine control), and civil engineering (lighting, home automation).
More and more components that make use of smart sensors and high-performance multi-core processors will be created for use in these fields. These short distances will improve the performance of these systems by increasing speed and reducing energy consumption due to parasitics, and allowing closer and more complex interaction and more comprehensive recognition of the field of operation.
A consequence of this trend, low power sensor and data processing elements will be directly integrated into the same package together with control circuits and power switches. This increases the diversity of materials that need to be joined together in the minimum of space. As a result, the reliability risk factors are expected to change as follows: increases in maximum operating temperatures, increases in the magnitude of temperature cycling (>350K over operating cycles), simultaneous exposure to multiple loads (e.g. thermal, mechanical, vibration, shock, drop, particulate contamination (e.g., sand, metal chips), chemicals (water, salt, oil, emulsions), and in relation to EMC, higher voltages, currents, fields and pulses). Reliable solutions are required to resolve these issues.

Dealing with miniaturisation in new materials and new packaging. Another trend is the direct embedding of components into materials and objects. The main fields are: communications and the 'Internet of Things', bio-medical systems and ambient assisted living. In addition, virtually any kind of construction industry component (smart bricks/tiles, smart hood, etc)
This will involve direct sensing (temperature, pressure, radiation, chemicals etc.) with minimum shielding, and at a multitude of places instead of a few measurement locations. It will also involve comprehensive communication between a large number of objects (e.g. for collision avoidance), and direct actuation (e.g. noise reduction, photonics). There are several reliability risk factors to resolve, such as tighter mechanical

constraints; thermal insulation and heat removal; greater exposure to chemicals; mechanical, electrical (EMC) and thermal shock; and multiple simultaneous loading. A typical example is an IC embedded in polymer (smart cards, smart labels, smart fiber reinforced structures) but it could also be embedded in cloth, concrete, clay, asphalt, glass or ceramics etc.. Reliable solutions are required for such applications.

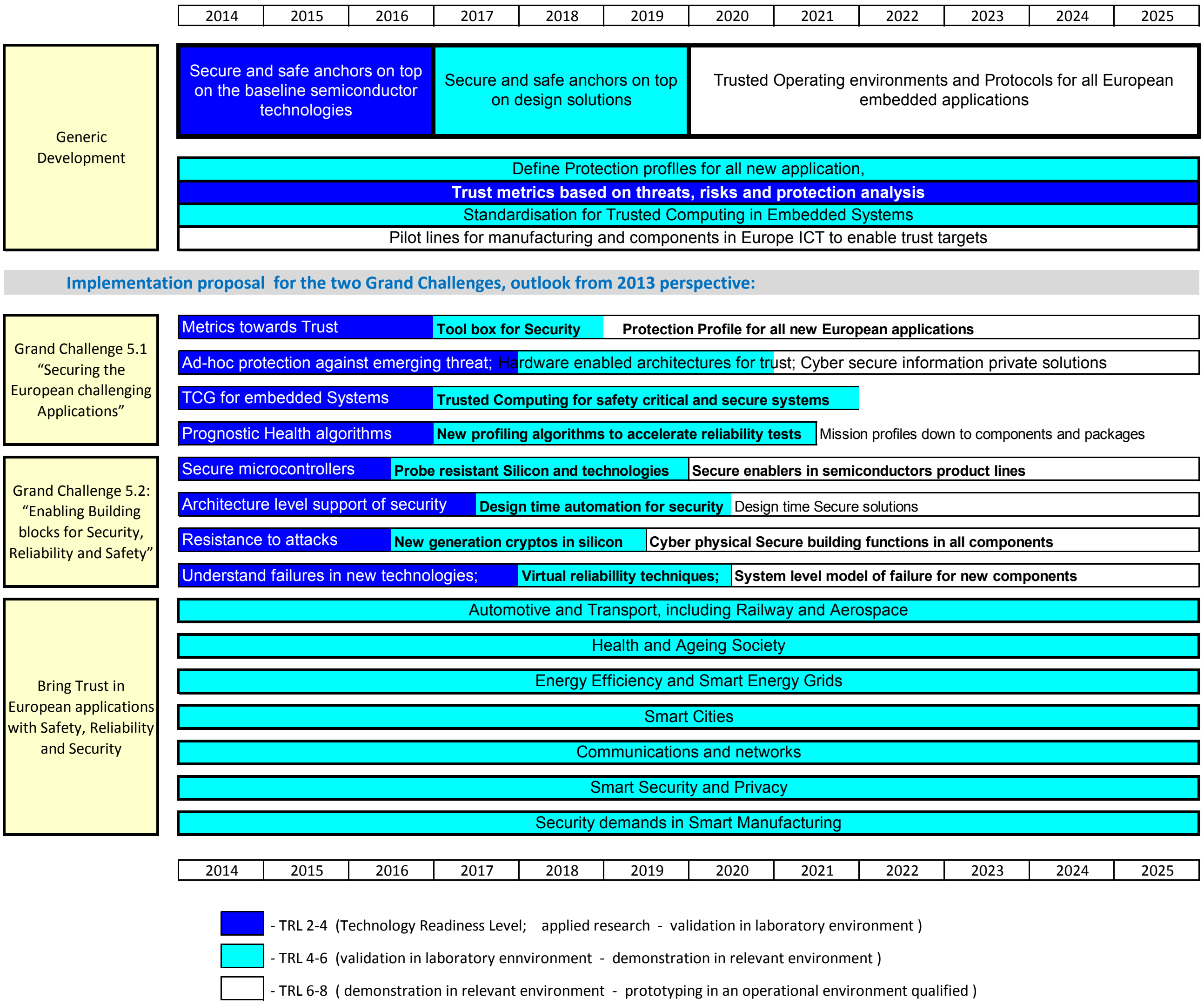
5.4 Conditions for Success

Innovative new applications bring new engineering challenges that will require new technologies to be defined and assessed in collaboration with application ecosystem specialists - for example, in the energy distribution, communications, car connectivity, transportation infrastructure, health and e-government applications.
Without a significant level of commitment and support, leading design and manufacturing industries in the safety and security field will either leave Europe or lose their current leadership positions.
Of course, it is proposed to capitalise on existing Europe led technologies and develop them further in these new contexts. Increased cooperation with high level research institutes aimed at influencing and developing worldwide standards will benefit European export industries.
The availability of nanoelectronics manufacturing in Europe, and overcoming the ‘valley of death’ for new ideas, are also conditions for success.
Automotive, aviation and medical equipment suppliers already have a great deal of know-how in dealing with safety requirements. This know-how needs to be further developed and transferred to new application domains.
Trust also depends on the ability to evaluate the security level of devices and systems. Europe is the worldwide leader in this domain, because of its technical capabilities and the existence of an effective ecosystem (national certification authorities, evaluation laboratories, stakeholder groups for standardization, etc). This ecosystem has to be supported and the added value of certification has to be promoted and defended.

5.5 Timeframes

The two Grand Challenges in the Safety & Security domain will be developed in parallel with different timeframes:

- Challenge 1 is to develop, in line with new applications, ways of ensuring safe and secure operation. New applications need to benefit from 'best practice' security, such as that used in banking and e-payment, and 'best practice' safety such as that used in aircraft and cars. Europe's citizens and customers will demand more trusted solutions (provided in continuous or incremental steps) as new threats appear.
- Challenge 2 timing is to be developed jointly with research labs and actors in the European Semiconductor Process & Integration and Design Technology domains. The technology items cover short, medium and long term needs.



5.6 Synergies with Other Domains

The 'Safety and Security' domain is transversal to all other application domains, and the related technologies need to be developed together with the 'Semiconductor Process and Integration' and 'Design Technology' domains.

CHAPTER 6

DESIGN TECHNOLOGIES

6.1 Introduction

The European Commission and Member States strive to maintain the leading position of Europe's micro- and nano-electronic industry, mainly because it is a key enabler of European competitiveness in important industries such as automotive, energy, health, information technology (IT), and security. Gaps in the innovation chain have to be closed and leading-edge research has to be translated into economic success. The contribution of Design Technology to reaching these goals is tremendous. It is the link between ever-increasing technology push (More Moore (MM), and More-than-Moore (MtM)) and the innovative new products and services that are needed to fulfil societal needs for mobility, security, health, communication, education, entertainment, and safety. Design technology enables the specification, concept engineering, architectural exploration, implementation, and verification of micro- and nano-electronics-assisted systems. It includes design flows, tools, libraries, IPs, manufacturing, process characterizations and methodologies involving hardware and software components. Effective design technologies are the only way to transform ideas and requirements into manufacturable and testable implementations. They are key to increasing design productivity, reducing development costs and time-to-market, and adhering to safety and reliability requirements.

6.1.1 Design Productivity and Extension of Design Scope

The process of translating technology into innovative products and applications continues to be bottlenecked by the fact that design technology is not sufficiently prepared to handle the following three Grand Challenges: managing complexity, increasing diversity, and the rising criticality of reliability and yield. These trends are not only driven by further shrinking in the size of technology structures, but also by the diversification and application of different semiconductor technologies within a single product, as illustrated in Figure 1.

Current and future products such as mobile communication devices and cyber-physical systems (CPS) incorporate manifold semiconductor technologies including digital application-specific integrated circuit (ASIC), analog mixed-signal (AMS), radio frequency (RF), sensors-actuators (e.g. MEMS - Micro-Electro-Mechanical Systems), high-voltage, smart power devices and embedded software. This can also be seen in the automotive and consumer electronics domains, where there is additional pressure on silicon developers and manufacturers to adopt leading-edge silicon technologies. Escalating design costs, the ever-increasing size of development teams, and frequent time-to-market delays, are clear indicators of a bottleneck in the design process.

In the development of many future products, additional application requirements such as robustness (e.g. for safety critical applications or to cope with the increasing scale of integration), low-power capabilities and new safety standards (e.g. ISO 26262) must also be supported. For example, energy-aware design and design-for-reliability need to be firmly anchored within new design technologies. At present, accurate predictive methods for the power consumption and lifetime/reliability of highly complex systems are not available.

	Early Generations of Integrated circuits	Last 15 years	2020
Application/ Product Requirements	Price/Cost Bug free	Price/Cost SW Reliability Savety ISO 26262 Compliance Low Power Consumption	Price/Cost Application SW Compatibility OS Compatibility Reliability Compl.: ISO 26262; EAL6+ Safety Security Low Power Consumption Performance
Technology Requirements	Si-area Performance Yield	Performance Yield Si-area	Multi Technology Support New Technolgies: SiC, SoI Yield Si-area
Driver/Products	PC, Processor Memory ASIC	Mobile Phone Automotive ICs Entertainment	Internet of Things/Comm. Smart Grid, e-mobility Ambient Ass. Liv./Health
	Technology-driven	**------>**	**Application-driven**

Figure 1: Semiconductor evolution from technology-driven to application-driven

Clear actions must be taken to address these challenges: to improve the link between technology and applications and to fast-track the introduction of innovative new products. For future electronic systems, broad, expandable and seamless design technology support for integrated circuits (IC), system-on-chip (SoC), system-in-package (SiP), and printed circuit board (PCB) development will be needed to significantly improve design productivity and effectiveness.

6.1.2 Application Driven Design

As a consequence of the ever-increasing integration capabilities of MM and MtM, an increasing number of the functionalities required in an application are being realized in SoCs or SiPs. The result is that additional application know-how is necessary to design components that best fit in to the application hardware, while at the same time taking into account aspects of their environment (for example, operating temperature or application specific standards like ISO 26262) and typical or critical application scenarios, often called use cases. So the interaction between original equipment manufacturers (OEM), tier-1 system houses and semiconductor companies needs a new quality of cooperation and data exchange that facilitates co-design of IC, package and PCB. The starting point to support this exchange of information is to have new methodologies that ensure consistency between engineering requirements, specification definition, mission profiling and dedicated use cases for different performance analyses. Analyses, such as power consumption, thermal estimation, etc., will need to be based on appropriate properties for modelling these phenomena, together with standardized formats and interfaces, to allow virtual prototyping. Interoperability between all system models - for example, virtual platform, performance model, power and temperature models - will be necessary to build a consistent representation of the system.

In the design of future electronic systems, IPs (intellectual property blocks) and subsystems must become the next easy-to-use building blocks for the efficient design of ICs, SoCs, SiPs and PCBs. Today's bottleneck in design productivity is due to the lack of common standardized methodologies, specifications, characterization data, formats, and tooling for functional descriptions. This is especially true for the description of important non-functional properties such as reliability, security and power consumption.

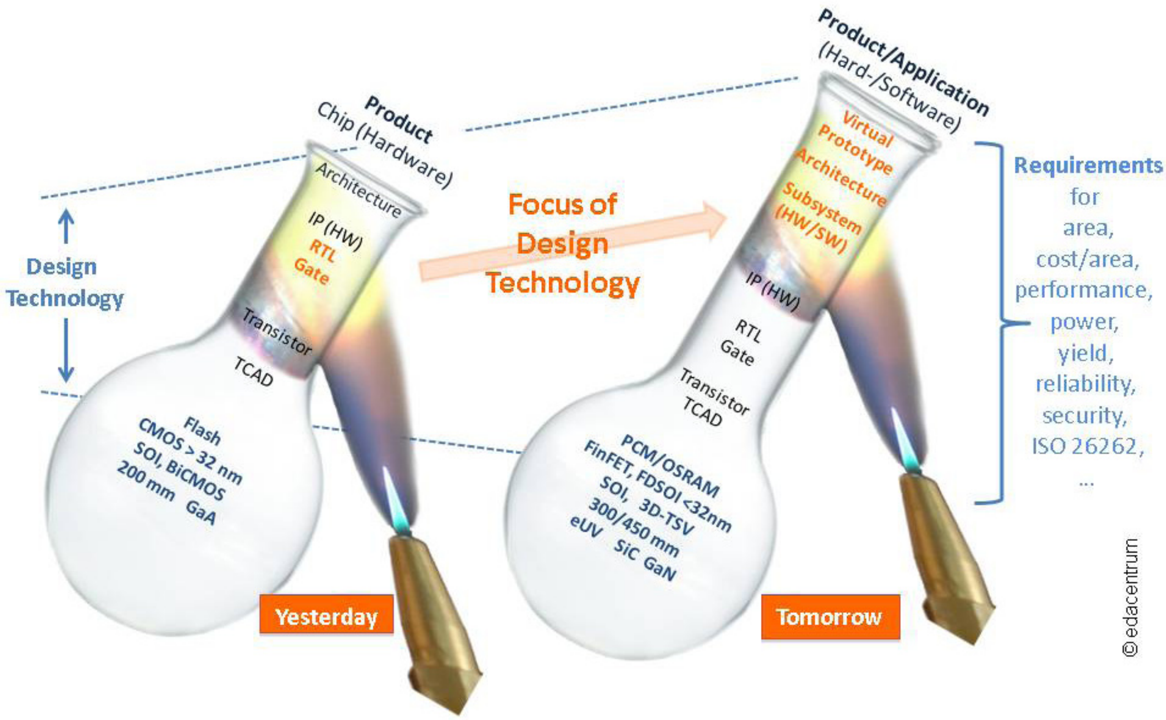


Figure 2: The innovation chain requires a shift in design focus

These aspects and requirements, which are illustrated in Figure 2, indicate that the focus in product development has to be elevated from technology-driven to application-driven design. Application requirements, such as power, reliability, security and safety, become dominating design targets. Hence, the focus of design has to be shifted from transistor-/gate-/register transfer level (RTL) to higher abstraction levels - i.e. architecture and system level. Virtual prototyping, taking into account performance, power and thermal modelling etc., are new design paradigms that need to incorporate hardware, software, application requirements and use-cases. Virtual prototyping will form a basis for architecture/IP/subsystem evaluation and continuity down to silicon level. In this way, virtual prototyping will become key to incorporating non-functional type requirements into design technologies.

6.2 Relevance for Europe

6.2.1 Competitive Value

To compete with low labour-cost countries, it is of upmost 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. The crucial importance of time-to-market is pointed out in Figure 3, which illustrates the revenue penalties for a product between early market entry (curve A) versus a delayed product entry (curve B); the area under each curve reflects the revenue. For example, a one-month delay (D) can result in a 44% loss of revenue in fast moving markets for products (such as laptop or tablet PCs) with a product life of six months (2W).

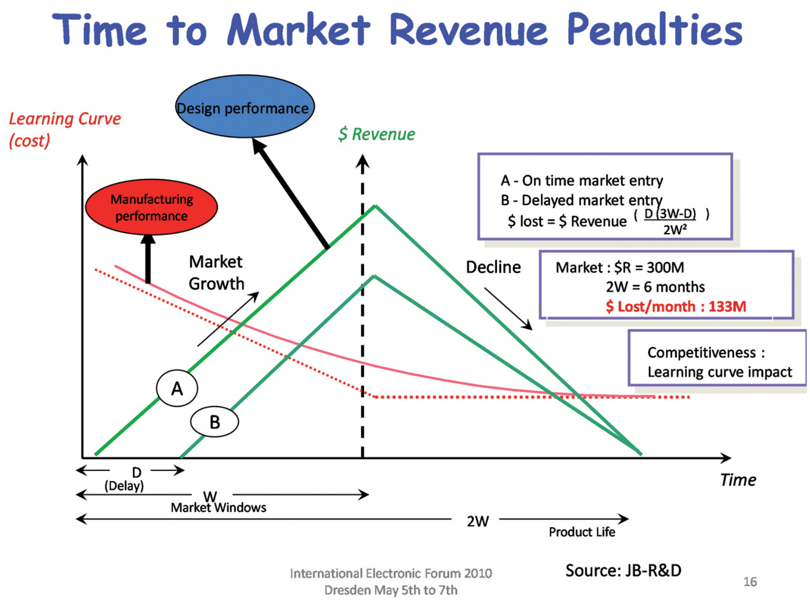


Figure 3: Time-to-Market Revenue Penalties (shown at Int. Elec. Forum 2010, Dresden, Source JB-R&D)

Electronic systems are the key drivers and enablers for European high-tech products. Design technology therefore has to take into account all the accomplishments provided by the fast growing MM and MtM trajectories. A seamless design platform for handling the highest functionality/complexity and integrating emerging technologies to suit new application specific requirements is essential.
Currently, the capability of design technology faces severe shortcomings, which are addressed in the three grand challenges described in section 6.3. These shortcomings are very much positioned in the system-level area of design. Europe has strong competencies and a remarkable track record in developing advanced system-level design methodologies. It also has world-class universities and research institutes, electronic design automation (EDA) vendors and system houses.
As soon as the European semiconductor industry, in collaboration with these other players, overcomes the shortcomings of current design technologies, European Industry as a whole will be able to benefit from the progress made in innovative electronic components and systems.

6.2.2 Societal Benefits

By enabling critical applications in areas of real social relevance, such as health, communications, security, and transport, design technology has a strong social impact. "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"[15]. The impact of information and communications technology (ICT) has been particularly evident in specific high-tech sectors, such as Europe's strong transport (automotive, avionics, railways, etc.), telecom and security industries, and in high growth potential areas such as healthcare and services for the elderly. All these sectors are critically dependant on dedicated design solutions that typically integrate many different multi-functional blocks, including sensor technology, and also require high performance, high reliability and low power consumption. Meeting these multiple requirements means achieving a very tight integration between architectural design and technology. Properly applied design methods and tools will improve the reliability of semiconductor devices and reduce the costs of final products, making them available to a wider market. One example of the impact of semiconductor design capabilities is the reduction in casualties made possible by the widespread adoption of safety features in the car industry (for example, ABS, airbag and EPS systems.). This was made possible by massive reductions in component cost, together with increased device reliability, both enabled by continuous improvements in silicon and design technologies. Only the continued development of improved methods, tools, IP and design flows will allow the continued production of high quality products in Europe.
There are massive market opportunities, but the products needed to exploit them have very specific and challenging requirements such as:

- Integration of heterogeneous features (electrical and non-electrical)
- Real-time data processing
- High performance: computing capability and data bandwidth
- Low-power consumption
- Very high reliability, beyond that guaranteed by the physical technology alone
- Fault-tolerant behaviour
- Support for advanced softwares, such as fully-featured operating systems and virtualizations
- The ability to support a wide range of new and evolving applications throughout the product lifetime
- The capability to adapt to changing conditions

All these requirements cannot be achieved by technology alone. They can only be achieved by proper design that compensates technology limitations. To be able to embed the physical and application constraints in the design, while keeping pace with rapid evolution of the market and the pressure of societal challenges, the previously mentioned design technology bottleneck must first be removed. Novel design approaches are needed to address the following three Grand Challenges in Design Technology.

[15] 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)

6.3 Grand Challenges

6.3.1 Grand Challenge 1: Managing Complexity

Vision:

Standardized and flexible design flows that start at system-level and take account of hardware and software components to build sophisticated feature-rich innovative products of superior performance and quality.

Description:

The aim of 'Managing Complexity' is to develop solutions for managing the design of complex chips. These chips can incorporate several billion transistors with highly complex clock and power trees, driving several hundred types of IP blocks and subsystems - e.g. multi-core processors, memories, inputs/outputs (I/O) and dedicated functions/hardware accelerators. These IP blocks and subsystems come from different sources and are capable of running multiple large software routines. More and more of these SoCs will merge different application domains, for example:

- o Automotive, communication and medical (e.g. 'The-Car-That-Cares')
- o Automation and internet (in Industry 4.0)
- o Medical and security/internet (in telemedicine)

The on-going trend towards the integration of higher complexity SoC and SiP solutions is becoming a major challenge for the design community, both in terms of system complexity associated with the on-chip integration of different IP's and subsystems, and in terms of silicon complexity related to parasitic effects and variability in advanced CMOS (complementary metal oxide semiconductor) processes. The inclusion of programmable components ("multi-core arrays" and "many cores") is adding a further level of complexity, by introducing hardware-dependent software, embedded software, and application software components as critical elements in the design process. Architectural level design, and the possibility of evaluating different options by making choices at the highest level of abstraction, is becoming a critical issue in attaining the required performance. An increasing number of large IPs and subsystems are required to fulfil the system requirements, and these have a large influence on overall design time and costs. Specifically, the reuse *of coarse-grain subsystems* that pre-integrate hardware and software for system functions (as encapsulated objects) - for example, audio, video, modem or connectivity - can boost design productivity. If properly enabled by appropriate methodologies, tools and standards, reuse of such subsystems will help to address the design complexity problem. Having an open infrastructure and market for subsystems and other valuable IPs (see Challenge Number 2) is an important element in enabling the extended functionality of next-generation systems. This alone could provide significant business opportunities for innovative European companies.
One major achievement in electronic system level (ESL) has been the progressive deployment of virtual prototyping at the industrial level over the last five years.
The architectural models developed were an enabler for early embedded software development and validation, as well as functional verification activities for the chosen hardware (HW) architecture. This success stimulated new modelling demands, such

as early performance estimation (bandwidth, latencies, etc.), non-functional property evaluation (power, timing, thermal, security and safety, reliability, robustness, etc.) to allow performance evaluation of the overall architecture. Heterogeneous virtual platforms are also required to describe and simulate complex systems and their associated use cases. Extended virtual platforms therefore have huge potential in facilitating the early and fast optimization of future complex systems and enabling fast time-to-market for feature-rich products.

The specifications, design and implementation of complex systems also require the development of a complete environment that guarantees the efficient transfer of information, and common definitions and understanding between actors working at the different levels of design abstraction. For example, power estimation for a subsystem is typically done at a low-level design stage, but crucial decisions based on these estimations need to be made at platform or architecture level.

In order to keep pace with the design productivity requirement for highly complex next-generation systems, the challenge for the coming years will be to develop new methodologies, tools , standardized formats and description language(s), allowing the design focus to move to system level abstraction.

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:

- Specifications: engineering requirements, mission profiles, use cases, executable specifications
- Design Eco-Systems based on standards: common methodologies for functional and non-functional properties; open, extendible
- Extended Verification Coverage: functional, non-functional (e.g. power); use cases - virtual prototyping, strong links to verification and test
- Reuse: digital, analog IP, subsystem, standards
- Ultra-low-power hardware design and efficient software for low-power systems

Addressing these domains should help to solve the most critical issues identified below.

Competitive Situation:

Large EDA companies currently provide standard tools for logic synthesis and layout optimization. However, higher design levels are not well covered, even though some initiatives that are trying to move the design entry towards higher levels of abstraction do exist. For example, high level synthesis (C to RTL) is slowly gaining adoption in IP design teams, but there is no unique tool covering all the required design types. Furthermore, additional verification steps occur at RTL level, such as code coverage and property checking, that do not occur at the higher abstract level. Elevating these checks to the higher abstract level will prevent the need for further debugging at RTL level, where the synthesized code is more difficult to understand. A 'C' based design ecosystem has still to be created.

It should be noted that three major trends in electronic design will change today's design practice dramatically:

1) Software content is increasing exponentially, due to the introduction of multi-core/many-core based architectures.

2) Low-power designs are mandatory for many current and future products to handle performance-power-thermal requirements.
3) Although many (linear) analog functions are now being handled digitally, some important analog functionality remains and this slows down simulation speeds at system level.

To cope with the intrinsic complexity of systems, the upcoming challenge 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.

The most critical issues to be covered are:

- Specifications: engineering requirements, mission profiles, use cases, executable specifications to solve the inconsistent semantic of the specifications description and the missing design information that cause design iterations.
  - Specifications and application related constraints (e.g. ISO 26262) are not linked well enough during the design processes of verification, implementation, validation, and test.
  - Capture of specifications and use cases covering not only the functionality of the system, but also its performance and non-functional properties such as robustness, environmental conditions, etc., is missing.

- Design Eco-System based on standards: common methodology for functional and non-functional properties; open, extendible.
  - Share sign-off system models between system houses and semiconductor companies.
  - Create a unified design ecosystem to support system integration that takes functional and non-functional properties into account when evaluating the performance of different system architectures.
  - Efficient high level synthesis.
  - Efficient use of new multi/many core architectures with new approaches such as Globally Asynchronous Locally Synchronous (GALS), crossbars and Network-on-Chip (NoC).
  - Efficient use of current system development practices by facilitating system integration and increasing model simulation speeds by several orders of magnitude to tackle extremely complex systems.
  - Creation of a unified environment that allows efficient sharing of fragmented data, located in various places and using various formats, at all points in the design process, from system level to final SoC implementation. Current design flows result in critical assessments being made too late compared to the time at which design decisions need to be made, degrading hardware implementation efficiency for very large SoCs and necessitating software workarounds that delay time-to-market and degrade performance.
  - Efficient management of design-for-test (DFT) for complex SoC.

- Extended Verification Coverage: functional, non-functional (e.g. power); use cases - virtual prototyping, strong link to verification and test.
    - o Facilitate interoperability between virtual prototype models and tools including non-functional property estimation and techniques to manage non-functional properties.
    - o Create strong and consistent links between hardware and software design, silicon validation and test development.

- Reuse: digital, analog IP, subsystem, and standards for the efficient integration of IPs and subsystems.
    - o Improve productivity of platform integrator. It is crucial to have an effective means of efficiently integrating pre-verified and pre-integrated subsystems. However, the semantics to express this integration is still an open issue.
    - o Capture of the completeness and robustness of IP blocks is required to compare IP blocks and choose the best options.

- Ultra-low-power hardware design and efficient software for low-power autarkic (self-sufficient) systems with energy scavenging capabilities or extremely long battery power lifetime (including the design process covering power supply) cannot be efficiently developed using existing design flows.

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.

A non-exhaustive list of required innovation is:

- Specifications: engineering requirements, mission profiles, use cases, executable specifications to be consistent with all design domains, including hardware & software (HW&SW) design, applications, verification, validation and test.
    - o Modelling and generation of executable models, from system to architectural level and below, covering both functional and non-functional aspects of a system as well as restrictions and specific application contexts in the design process (e.g. the new functional safety standard ISO 26262).

- Design Eco-System based on standards: common methodology for functional and non-functional properties; open, extendible.
    - o Modelling of functional and non-functional aspects of a system.
    - o Multi/many cores: the maturing and evolving of new architectures to organize computing power in close alignment with the target application.
    - o Data interoperability and efficient data sharing at all stages in the design process, from system level down to SoC implementation, in order to eliminate errors and design inconsistencies.
    - o Software design: OSs and virtualization, parallel programming models, compilation tools, trace and debug environments, etc.

    - Improve high level synthesis (Transaction level modelling (TLM), C, etc.).
    - Improve hardware implementation efficiency for very large SoCs by making critical assessments sooner in the design cycle, for instance at RTL.

- Extended Verification Coverage: functional, non-functional (e.g. power); use cases - virtual prototyping, strong link to verification and test;
    - System level modelling enabling system verification (covering functional and non-functional attributes, as well as test scenarios generated from system level use cases).
    - Formal verification of the design at different abstraction levels.
    - Fast simulation speeds to verify complex systems at different abstraction levels
    - Efficient DFT implementation from IP/Subsystem to completed SoC.

- Reuse: digital, analog IP, subsystem, standards.

- Ultra-low-power hardware design and efficient software for low-power system
    - Ultra-low power hardware/software co-design of autarkic (self-sufficient) systems with energy scavenging capabilities or very long battery lifetime.

6.3.2 Grand Challenge 2: Managing Diversity

Vision:
Having a consistent and flexible design flow for complex heterogeneous systems, supporting IC, package and printed circuit board co-design.

Description:
The aim of 'Managing diversity' is the development of design technologies that enable the design of complex system-on-chip and system-in-package solutions incorporating heterogeneous devices and functions.
The drivers behind higher integration levels in semiconductor components are cost, form-factor, energy saving, communication, connection speed/overhead, and reliability/robustness. This applies to both digital and heterogeneous non-digital devices (for example, devices that include combinations of power, analog and mixed signal (AMS) subsystems, communication (RF or optical), and sensors and actuators (e.g. MEMS) based on multi-physics (mechanical, bio, optical, chemical devices).

The various challenges are summarised below:
System integration
SoC, SiP and 3D stacking, with various combinations of the aforementioned devices, well aligned to the PCB environment, are becoming mandatory to achieve the required size and performance targets.

Dimensional challenge
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.

- Interference problems arising from NMMI solutions cannot be handled properly by existing methodologies. For example, a centimetre-line will work as an antenna influencing nanometer-size circuit elements (basic chip-package-board problem), and this will no longer be manageable without dedicated effort. In addition, the utilization of ultra-thin wafers will lead to new coupling/interference problems. Utilization of upcoming 3D interconnect technologies, e.g. through silicon via (TSV), will require new design technology solutions to perform system partitioning, floor planning and routing.
- 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, which then control power devices operating at several hundred/thousand volts in battery/transmission systems. Different expertises, methods, tools, development environments, algorithms, etc., will need to be used cooperatively in order to arrive at optimal system solutions.

Architectural Challenge
Only efficient and well-defined interfaces between non-digital functions and data processing components will enable the full integration of heterogeneous systems and help to meet cost and reliability requirements. The integrated solution must be designed as a single system, but current methodologies and tools are lagging behind in terms of being able to cope with system specifications, architecture exploration and evaluation, system optimization, and efficient implantation and verification at system level. Today, most systems can only be integrated/implemented by using different technology variants, or combinations thereof, at lower levels of abstraction, leading to less than optimum system architectures. To guarantee the selection of 'best-fit' technologies for chips, packages and boards, different analyses have to be performed to check for optimal performance in terms of cost, functionality, power management and related thermal aspects, reliability and other application requirements. All these architectural studies need to be performed in parallel, requiring highly innovative and highly efficient methodologies and simulation tools.

Verification Challenge
Europe's design skills have to enable product competitiveness in terms of cost/price, functionality and performance. Because even minor design errors can lead to extreme cost increases and time delays resulting from the need to execute redesign loops, verification methodologies have to guarantee a very high level of error/fault-free design at all integration levels: chip, package, board and firmware/software.

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:

- *Standards-based Design Eco-Systems that accommodate heterogeneous components*
- *Full integration of SW-development, analog/RF, power devices and sensors/MEMS*

in system design flows

- *Extended Verification Coverage for heterogeneous (e.g. AMS) systems: functional, non-functional; use cases - virtual prototyping; link to test*
- *3D-Design*
- *Consistent and complete co-design of IC, SiP, PCB*

Addressing these areas should help to solve the most critical issues identified below.

Competitive Situation:

At the moment, major EDA companies focus mainly on tools and design flows for digital devices, which make up 75% of the world's silicon chip market. Tools also exist for board design and package design, but they are not integrated into chip design environments, and no commercial solution is available for complete system design (chip + package + board). Support for mixed analog/digital functions is also poor and limited to RF design and analog/mixed-mode design, with severe limitations regarding complex devices. Big companies normally use partial solutions, often developed in-house, which often suffer from standardization and support problems.

The lack of commercially available 3D design-flows (they are still at prototype level) and the missing support for heterogeneous applications hinder the broad application of SiP and stacking technologies in many application domains - for example, medical and automation. Yield, heat, and mechanical stress will remain critical issues.

To enable future complex (e.g. cyber-physical) systems, the most important issues to be covered at this point in time are:

- *Design Eco-Systems based on standards extended to heterogeneous components.*
    - Support for multi-die/multi-technology systems and the use/reuse of bare-die-IP (e.g. electrical, physical, mechanical, and power interfaces) defining standards and models.
    - Manage various constraints (electrical, thermal, mechanical, etc.) over the whole design flow paying special attention to high speed, high voltage, high current and high power systems.
    - Development of adequate methods and tools to exploit the benefits provided by emerging technologies and devices such as SiC (Silicon Carbide), FinFET (Fin-Shaped Field Effect Transistor), SOI (Silicon-on-Insulator), FD-SOI (Fully depleted SOI) and subVt-design.

- *Full integration of SW-development, analog/RF, power devices and sensors/MEMS in system design flows.*
    - Develop Spice-like and behaviour models to integrate into design flows.
    - Better support of power electronic design (spice-like exact power transistor models, and behavioural models).
    - Manage interference problems in high frequency clocking systems for high dynamic range, low noise, AMS systems.
    - Support design for very high frequency (THz) operation.
    - Circuit and layout synthesis, automation of design, verification, and silicon validation for analog system components.
    - Support low-impedance connectivity auto-routing for all implementation layers (chip, package and board).

- *Extended Verification Coverage for heterogeneous (e.g. AMS) systems: functional, non-functional; use cases - virtual prototyping; link to test.*
    - o Define high level models for heterogeneous system descriptions.
    - o Develop virtual platforms of complex systems at the ESL level.
    - o Production test on die and at system level especially for analog and RF in complex mixed-signal systems. Independent patterns are still generated at design and production test level. An extension of the built-in self-test (BIST) approach is needed.

- *3D-Design is still in an early stage and needs improvement to manage a system implemented in several tiers in terms of:*
    - o System architecture definition and implementation (place & route using TSV (through silicon via), standardized design rule description on package level (enabling dies and package design rule checks (DRC).
    - o Parasitic extraction methods (for all 3D stacked dies) and electrical analysis of parasitic effects in SiP (cross talk, electromagnetic compatibility (EMC); thermal analysis of SiP and joint thermal-mechanical-electrical simulation).
    - o The influence, for example, of fast TSV current changes that can directly modify the behaviour (Vth) of transistors. This leads to a design challenge that has never been addressed before.

- *Consistent and complete co-design of IC, SiP, PCB*
    - o Co-design ecosystem based on standards to handle the increasing interactions of various worlds (chip, package and PCB) and joint simulation (IC/discrete devices) handling multi-standard tools.

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 platforms targetting heterogeneous SoC and SiP. Platforms enable the delivery of reusable IP for microsystems and other heterogeneous systems.

A non-exhaustive list of expected achievements is:

- *Design Eco-Systems based on standards extended to heterogeneous components*
    - o Improve verification, validation, testability and repair, allowing interaction/pattern reuse between the different abstraction levels.
    - o Packaging coarse-grain heterogeneous IPs/subsystems to facilitate their system integration.
    - o Better design tools for functional and non-functional properties such as heat generation, temperature, reliability, and their propagation within the system.
    - o New emerging technologies such as SiC, FinFET, FD-SOI, subVt-design, etc.
    - o Bare-die IP's used in 3D and SiP based systems.

- *Extended Verification Coverage for heterogeneous (e.g. AMS) systems: functional, non-functional; use cases - virtual prototyping; link to test.*
    - o Virtual Platforms for heterogeneous systems to improve system coverage.
    - o New test strategies for complex SiP and 3D-TSV solutions considering both the interface to testing equipment and testing approaches for non-digital functions at die and system level.
    - o Common pattern generation for both design and production test levels.

- *Full integration of SW-development, analog/RF, power devices and sensors/MEMS in system design flows.*
    - o Describe sensors, actuators, power devices and other heterogeneous system components at different design abstraction levels.
    - o Describe and simulate AMS and RF systems (intermediate abstraction levels).
    - o Describe and simulate at system level non-electrical components (multi-physics: mechanical, optical, etc.), nanoelectronic components (sensors and actuators/ high voltage) and the mixed systems (HW, SW) in which they are used.

- *3D-Design.*
    - o Robust floor-planning that allow efficient exploration of 3D stack configurations early in the design flow (at RTL), so that the optimal stack configuration is known before physical implementation begins.

- *Consistent and complete co-design of IC, SiP, PCB.*
    - o Design technologies for implementing heterogeneous SiPs and 3D-stacks (3D parasitic extraction, 3D-DRC).
    - o Design technologies that take account of electrical, thermal and mechanical constraints throughout the entire design flow for chip, package and board level co-design using multi-scale simulation tools.

6.3.3 Grand Challenge 3: Design for Yield, Reliability and Robustness

Vision:

Consistent design technologies ensure yield, reliability, and robustness for sophisticated feature-rich innovative products of superior performance and quality.

Description:

'Design for Yield, Reliability and Robustness' targets the development of design technologies to increase yield and compensate the effects of parameter variability, parasitics, ageing, and soft errors. It also addresses the reliability of semiconductor devices to enable the production of systems with the necessary robustness.

IC designs are impacted by different variability types due either to manufacturing or functional behaviours, such as random process variations (doping, etc.), variability due to device implementation (lithography, multiple patterning, density, interconnection), variability due to block/IP environment (supply/substrate voltage perturbations, thermal

variation, package/board), and the ageing of devices and interconnects.
As SoC size increases, the impact of process or implementation-related variations is becoming more and more critical for library design. For instance, simple flip-flop cells may be instantiated millions of times in a SoC and must behave correctly under all conditions to ensure design robustness.
Following CMOS scaling to deep submicron regions, the intrinsic device reliability of transistors can no longer be guaranteed. 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, however, critical applications in fields such as automotive and aerospace, security, and health will require very high levels of reliability. In this context we must distinguish between yield, which is defined as the percentage of functionally correct devices at production time over the entire range of applications; reliability, which relates to the availability of this functionality over lifetime; and robustness, which defines the level of 'persistent against all disturbances'. Appropriate models to address reliability must therefore cover physical degradation effects at technology node level (negative-bias temperature instability (NBTI), positive-bias temperature instability (PBTI) and hot carrier injection (HCI)) over a very long time period. Yield, reliability and robustness are becoming closely related and can no longer be guaranteed by improved production processes or design methods only. New design technologies must treat testability, yield, reliability and robustness holistically, starting from the application level, through the system and architectural level, and down to technology level, ensuring good coverage of parameter spreads, parasitic spreads, reliability and aging effects at device level. This approach can be complemented with yield optimisation using tools that are capable of cross-checking the data coming from process, test and design. The specific application domain and context will set the requirements. Specific compliance standards (for example, ISO 26262 and EAL6+) that need to be fulfilled will influence the design methodology. For a reliable and robust implementation, top down design-for-reliability and robustness has to start with the specification and the mission profile of the application and affects the whole design process thereafter. In the other direction, models and procedures are required to propagate reliability information upwards, starting with characterization at transistor level up various levels to the top system/architectural level.
One additional point is the fact the scale down of CMOS technology leads to strong sensitivities to electrostatic discharge (ESD), electrical over stress (EOS) and EMC.

High Priority Research Areas:

The success of the grand challenge 'Design for Yield, Reliability and Robustness' will require special attention to be given to several high-priority research areas, including:

- *Consistent methodologies and new approaches for reliability and robustness for HW, OS, and application SW.*
- *Consistent analysis, modelling, and descriptions/formats for reliability at all levels of abstraction.*
- *Reliability, yield, and robustness fully integrated in Design Eco-Systems.*
- *Reliability sign-off for HW.*
- *Monitoring, prediction and diagnosis.*

Addressing these research areas should help to solve the most critical issues identified below.

Competitive Situation:

Europe has very strong system houses producing complex high-tech designs for strong European industries, such as its aeronautics, automotive, healthcare, and communications industries. For safety critical applications reliability is essential, but it is also very important in applications such as communication backbones where service interruptions are unacceptable. As a result, Europe's industries are continuously pushing for electronic systems with more features and new capabilities in order to maintain their world-leading positions and their reputation for quality and reliability, which differentiates them from the competition. However, this inevitably means that system complexity is continuously increasing and with that comes the increased probability of design errors. In the automotive sector, for example, it has already become clear that the need for more computing power (e.g. for advanced driver assistance systems (ADAS)) is now so strong that the traditional maturing time before technologies are regarded as useable in automotive applications has to shrink in order to maintain Europe's competitiveness.

At the moment, variability is mainly handled at cell level using Monte Carlo simulations, which are relatively expensive and extremely time consuming. However, circuit design variability is managed by design margins, which have to be optimized with regard to process variability.

Some newer approaches attempt to include reliability and variability in compact models. In the presence of parametric degradations that directly influence the performance of blocks, further progress is needed in moving to compact model-based simulation flows and in covering analog and mixed-signal circuits. Tools and flows should also cover important interactions between components (EMC, thermal management, etc.), and address interface reliability issues between the blocks that form the complete system. New design approaches must also be developed to increase and verify device testability, both for digital and non-digital functions, with improved or new links to test equipment. Efforts have to be strengthened in order to meet the special needs of European industry: heterogeneous system integration, unsurpassed quality for even the most complex electronic systems (especially for safety critical applications); and extreme reliability and robustness.

Europe will only maintain its competitive advantage if it actively addresses the design technology challenges described below.

Expected Achievements/Innovation Foreseen:

Increase system reliability and robustness using methodologies, tools and design flows that simultaneously optimize designs with respect to process variability and lifetime-related parametric degradation. Develop methods and tools to faciliate monitoring and diagnostics.

A non-exhaustive list of the main expected achievements is as follows:

- *Consistent methodologies and new approaches for reliability and robustness for HW, operating system (OS), and application SW.*

- *Consistent analysis, modelling, and descriptions/formats for reliability on all levels of abstraction:*
    - o Models that account for variability, reliability and robustness.
    - o Comprehensive models for relevant degradation effects (NBTI, PBTI, HCI).
    - o Models and standards, including identification of variability and degradation related risks.
    - o Validation of systems taking into account expected system usage and operating modes.
    - o Faster simulators to handle complex circuits and the large number of influencing parameters as well as methods to handle non-uniform distributions.

- *Reliability, Yield, and Robustness fully integrated in Design Eco-System:*
    - o Design for compliance in safety and/or security critical applications (e.g. ISO 26262, EAL6+).
    - o Ability to handle mixed criticality - e.g. in automotive applications where safety critical and entertainment components interact (e.g. displays).
    - o Design-for-Manufacturability (DFM), Design-for-Yield (DFY) and litho friendly design (LfD) to increase yields.
    - o Improvement in critical aspects: ESD, EOS, latch-up, EMC, electro-migration, IR-drop, thermal and mechanical stress at SoC and system levels.
    - o Dedicated tooling approaches for aggressor events (ESD, etc.).
    - o Development of error robust circuits.
    - o Avoidance, recognition and handling of errors at physical, logical, block, SW, and application levels.

- *Reliability Sign-off for HW:*
    - o Sign-off for reliability and robustness at block and system levels.

- *Monitoring, prediction and diagnosis methods and tools:*
    - o Online-monitoring, evaluation and reconfiguration of electronic systems.
    - o Development of dedicated in-situ reliability monitors for detection of the most relevant failure mechanisms.
    - o Development and integration of a HW/SW monitoring sub-system for the management of ageing in complex SoCs.
    - o Diagnostic schedules from system to IC, standards for the diagnosis of interfaces within IC and between IC and systems.
    - o Identification of weak/hot spots and/or critical components.
    - o Prediction of failure in time (FiT) rates and expected/remaining lifetime for complex (heterogeneous) systems.
    - o Failure detection, localisation and repair during applications.

- o Design and diagnosis tools for fast and efficient yield learning.
- o Analysis and metrics for robustness and reliability (based on mission profiles and failure models).

6.4 Conditions for Success

- Availability of funding for projects targeting the development of basic design tools, flows, standards, IP and subsystems for widespread use (not related only to specific applications).
- Active involvement of all actors in the supply chain.
- Wide European participation to achieve critical mass and standardized solutions.
- Project continuity in order to match the evolution of design methodologies to technology developments and increased application demands.
- Close cooperation between industry and research institutes.
- A plentiful supply of well-educated graduates who are able to apply the techniques outlined above and maintain the required pace of innovation.

6.5 Timeframes

All three Grand Challenges need to be met in parallel, since all the elements are required to design reliable new applications.
A detailed analysis of the requirements of Design Technology is given in the European EDA Roadmap, periodically updated with the support of the CATRENE organisation. This document provides a roadmap for 16 main design technology components. An indicative roadmap for some major tools and flows is reported below.

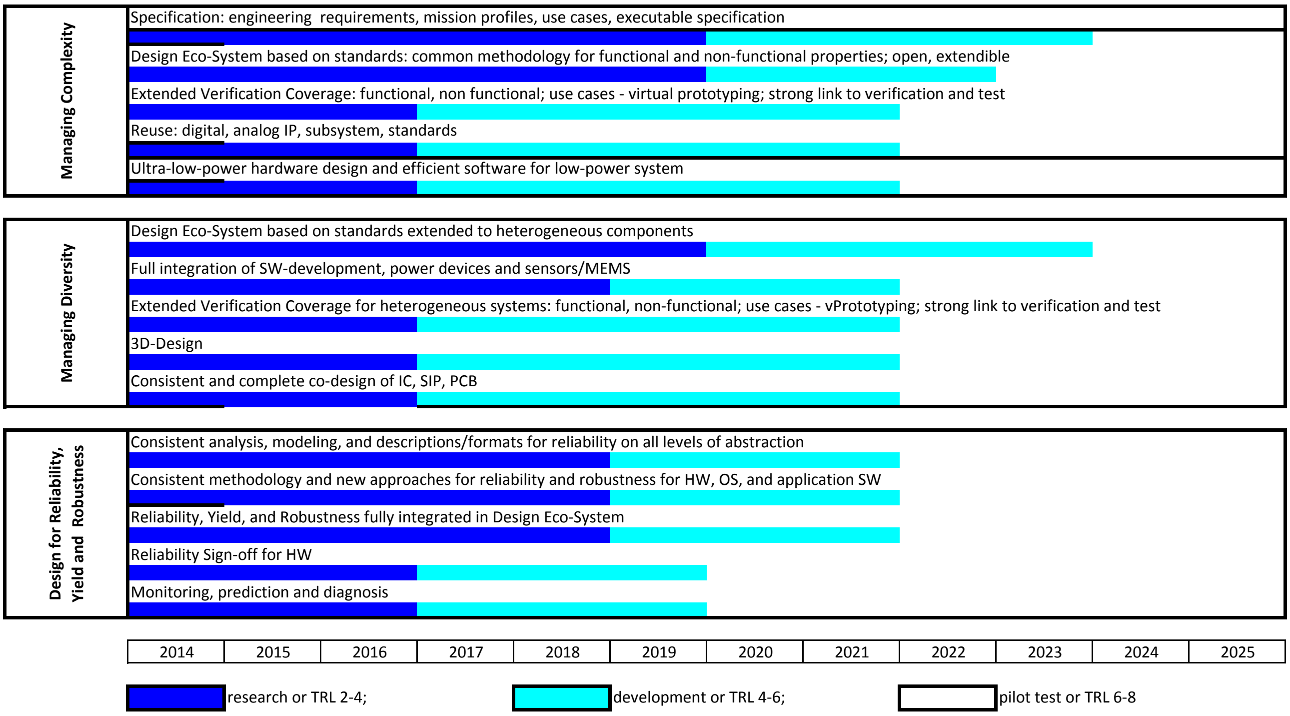


Figure 4: Design Technologies Time Frames

6.6 Synergies with Other Domains

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 & the Ageing Society'.
- Design for complexity includes tools for reducing power dissipation, which is essential for 'Communications' and 'Health & the 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 & the 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.

CHAPTER 7

SEMICONDUCTOR PROCESS AND INTEGRATION

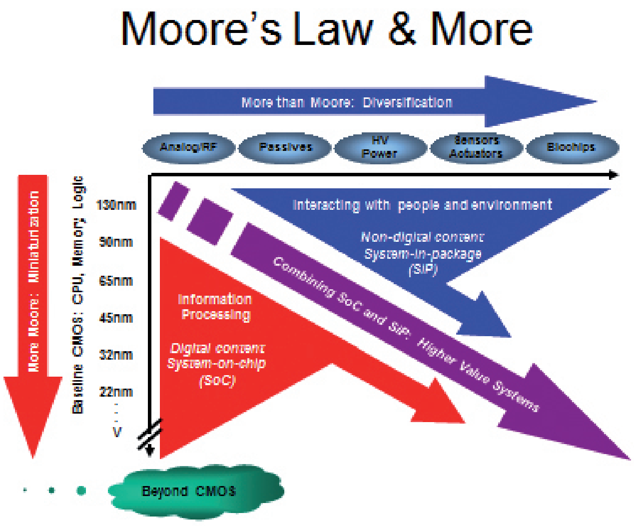
7.1 Introduction

A significant part of the semiconductor industry's success over the past few decades is due to the fact that generic semiconductor technologies are used in a wide range of applications, allowing the huge associated R&D cost to be shared among many different market actors. The same applies to today's semiconductor process development in nanoelectronics. It is driven by pure technological progress and can benefit many different application domains.

Exponential growth in the microelectronic industry has always been closely linked to the continuous scaling of geometry size in logic and memory technologies in line with Moore's Law. That technology trend continues in the world of nanoelectronics and is usually referred to as *'More Moore'* (MM).

Due to the penetration of ever-more integrated electronics into an ever-increasing range of volume applications, the number of semiconductor technologies targeting functions that are different from pure data processing (logic and memory) is continuously increasing. These types of technology are commonly referred to as 'More-than-Moore' (MtM) and typically cater for electronic domains such as sensors, actuators, RF-applications, optoelectronics, biochips and application-specific memories.

However, as shown in the illustration below, the two approaches - *'More Moore'* and



'More-than-Moore' - cannot be neatly separated. Sensors and actuators, for example, will require an analogue interface and a logic circuit for data acquisition, processing and transmission. This combination of MM and MtM, often referred to as 'Moore and More' (MaM), will require new dimensions of complexity management. In many cases, the tight integration of MM and MtM components will require the integration of several heterogeneous chips in a single multifunction package, adding a new level of complexity. Only mastery of both technologies will allow the successful integration of systems that are able to meet the demands of the latest applications. Engineering skills and tools to manage multi-physics interference topics, combined with close links between semiconductor research institutes and application companies, will be needed to achieve the right performance mix. Europe's unique research expertise and application know-how will be a key differentiator for the European semiconductor industry.

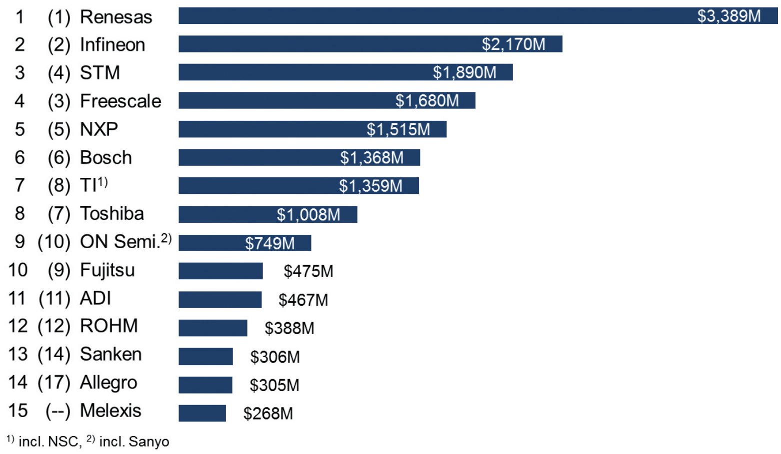
In addition, the continued pursuit of Moore's law in order to reduce unit device cost is at the same time enabling higher levels of complexity as larger amounts of logic, graphics and memory can be combined on a chip. This will allow lower power consumption which, in particular, is driven by the increasing demand for mobile electronics. This evolution towards lower power consumption and higher complexity at reduced cost requires leading-edge innovation at the smallest of dimensions, often at the atomic scale, and demands the very best that Europe's physicists, chemists and engineers can deliver. The methods and materials they develop will not only be applicable in the MM category, in many cases they will also provide breakthroughs in MtM technologies. Semiconductor-based sensors have already been made possible, and economically viable, as a by-product of technologies originally developed for More Moore.

The semiconductor technologies described in this chapter can be divided into three categories:

- **miniaturization** to achieve much higher integration densities coupled with lower cost and lower power consumption per function. This is the main innovation driver for MM, and is crucial for digital data processing and storage, which represent more than 70% of turnover in the IC industry worldwide (i.e. about US$200 billion in 2013). However, it is also the main driver for most MtM technologies and, as a natural consequence, also for device packages. The MM technical roadmap is defined on a worldwide basis by the ITRS[16] and will not be detailed further in this document.

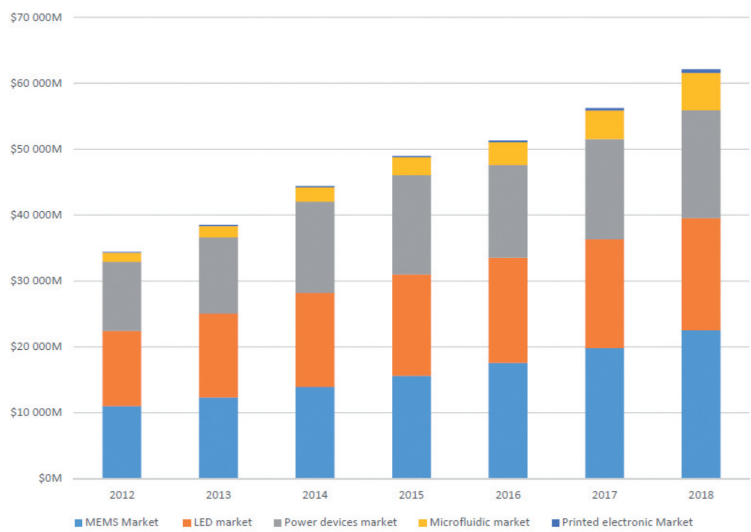
- **diversification and differentiation** in the spectrum of semiconductor technologies. Application-specific technologies are in many cases a key differentiating element in the value chain of successful new products. In some domains, such as automotive and industrial electronics, Europe is dominant (see the figure below) based on smart combinations of MM and MtM technologies - for example, microprocessors with embedded memories, smart power devices, and integrated sensor systems -where dedicated applications require specific process solutions. This is especially true for interfacing electronic systems with the outside world and managing their energy/power consumption. The 'More-than-Moore' segment represents between 15% and 25% of the microelectronics market (see figure on the next page).

[16] The Int'l Technology Roadmap for Semiconductors (ITRS) is available at http://www.itrs.net



Worldwide sales of top 15 companies in the automotive semiconductor market; on the left ranking in 2012 (2011 in brackets). Total worldwide sales of these top 15 in that market (2012) is US$17,337 million (62%) (Source: strategy analytics, Bosch)

- **heterogeneous integration** of components from different origins and fabricated using different technologies in a single package (the associated cost accounts for between 5% and 25% of the total cost of a complete semiconductor product). This approach not only allows the integration of electronic functions, it also allows the integration of non-electronic functionalities e.g. mechanical, optical, or (bio-)chemical tasks for optoelectronic or lab-on-chip systems.



The More-than-Moore segment of the semiconductor market is expected to increase to over US$60 billion or approx. 20% of the market (Source: J.C. Eloy, Yole Développement, at ITRS Workshop, April 2013)

The **diversification and differentiation** and **heterogeneous integration** trends do not yet benefit from a widely accepted roadmap (only some aspects of MtM technologies have been recently included in the ITRS). Their technical content is therefore detailed below.

It is only by combining and mastering all three R&D directions that the European nanoelectronics industry can offer competitive system solutions that address Europe's needs.
Depending on the application, miniaturized and diversified technologies will be

integrated at wafer level (i.e. as ‘System-on-Chip’ (SoC) solutions), in a package (i.e. as ‘System-in-Package’ (SiP) solutions) or as smart combinations of SoC and SiP in order to combine computing power and additional functionalities.

7.2 Relevance for Europe

The technology roadmap is global, but it is a clear priority for Europe to remain ‘state-of-the-art’ in MM and MtM in view of the enabling role played by these technologies and their close integration in products. Maintaining this status will not only allow progress in the design and production of electronic goods, in terms of cost, scaling, power/energy consumption and functionality, it will also provide technical solutions for many of Europe’s major societal challenges. Developing and mastering semiconductor technology will support a strong and competitive manufacturing base in Europe, resulting in significant job creation over the whole electronics value chain.

7.2.1 Competitive Value

Over the last 20 years, Europe has emerged as one of the key R&D players in nanoelectronics and smart system integration. This technical excellence and leadership should be maintained through a major program of research and development in generic semiconductor processes.
Micro- and nano-electronics have been recognized by the EC as one of the Key Enabling Technologies (KETs) that “*enable process, goods and service innovation throughout the economy and are of systemic relevance*”. By driving the development of generic semiconductor technologies, Europe has the potential to develop new standards that address major emerging markets (e.g. electric cars, smart grids, etc.). Without taking ownership of this key enabling technology for Europe, the solutions for many of Europe’s major societal issues will depend on the goodwill of non-European players in supplying the appropriate electronic components.

7.2.2 Societal Benefits

The solutions to major societal challenges (energy, security, the ageing society, the digital divide, etc.) will critically depend on advanced semiconductor technologies. Mastering the development of these technologies will therefore bring significant societal benefits to Europe.
Highly skilled personnel will be required to fulfil these objectives, which means that Europe will also benefit from the quality of its higher education system.

7.3 Grand Challenges

7.3.1 Grand Challenge 1: Know-how on Advanced and Emerging More Moore Semiconductor Processes

Vision:
Develop European know-how on More Moore semiconductor process technologies for mastering future applications and drive Europe into the 'beyond CMOS' era.

Description:
Mastering knowledge of emerging semiconductor processes well in advance is a key asset for developing new products with the right time-to-market.
This is especially true **for advanced CMOS processes and the emerging 'beyond CMOS' era,** where the pace of progress is staggering.
The reasons why it is important are:

- a technology push in advanced CMOS enables and drives high added value applications
- there is a need to maintain R&D and expertise in Europe to specify and access the latest logic and memory technologies
- critical size can be achieved at the European level through cooperation between leading clusters of excellence in Europe
- Europe has the right 'tool box' to take the lead in the 'beyond CMOS'[17] era, due to its advanced research in relevant materials
- in the US and Asia, there is a strong involvement of public authorities (PAs) in supporting this industry, which must be paralleled in Europe.

It is therefore appropriate to propose a major Europe-wide public initiative on core CMOS technologies in support of a more comprehensive European industrial policy targeting micro- and nano-electronics. The technical program should be in line with the roadmap of technology generations detailed in the ITRS.

Europe has a world-leading position in the development of lithography systems for semiconductor processes, which is addressed by the work program of Chapter 8 on 'Equipment Materials and Manufacturing'. The concurrent development of advanced lithography process modules will need to receive particular attention.

Although process development is largely independent of wafer size, the historical trend towards using **larger diameter** wafers for cost efficiency should be acknowledged. In addition, although transitions to larger wafer sizes are mainly equipment and materials related (and thus included in Chapter 8), it is important to leverage the enhanced capabilities of semiconductor processes on larger diameter wafers, because once the

[17] For a description of activities related to 'beyond CMOS' devices and new computing paradigms, see the NANO-TEC project, see www.fp7-nanotec.eu

transition has taken place, developments will largely concentrate on the larger wafer size. More specifically, many differentiated technologies are currently produced on 150-mm to 200-mm wafers, but a transition to 200-mm/300-mm wafers should enable new process integration schemes through more capable tools. For leading-edge CMOS technologies, a transition to 450 mm should be taken into account. The European stakeholders should therefore partner with the leading 450-mm players, some of whom have a presence in Europe already, and provide an attractive environment for future investment in the region through the continued development of key skills, infrastructures and incentives.

A key capability for acquiring advanced CMOS knowledge is the availability of leading expertise in the TCAD, **characterization, modelling and simulation** of state-of-the-art semiconductor technologies and devices. This should be addressed not only for advanced CMOS but also for differentiated processes, where added challenges appear, such as multi-physics and multi-scale approaches.

Competitive Situation:

In the **advanced CMOS** domain, major changes are already taking place worldwide. For Europe, it is characterized by opportunities that need to be capitalized upon, and trends that should be addressed to benefit Europe:

- Early-stage research in this area is increasingly done in multi-partner consortium-type structures, because of the associated cost and risk (imec and Albany being notable examples). Pre-industrial development and qualification are still performed by companies in Europe in their local facilities. There is therefore a need to *support CMOS R&D in Europe in order to accelerate build-up of the technology in Europe.*
- Some European companies are going fab-lite or fabless, which means that they need to *understand next-generation CMOS technologies and processes in order to choose suppliers and specify appropriate technology nodes for their foundry-based production.*
- While most advanced CMOS foundries are currently located in Asia, the emergence of a state-of-the-art production foundry in Europe can be observed. This represents a new *opportunity for Europe to compete with Asia in the foundry business.*
- With each new technology generation, there is a risk that more production will move outside of Europe. It is therefore important *to enhance Europe's pool of CMOS expertise in order to encourage more semiconductor production activities in Europe, even on 450-mm wafers.*
- The industrial landscape for advanced memories is evolving fast and currently represents 25% of the overall semiconductor market. Stand-alone memory production has disappeared from Europe, but conventional memories are running out of steam anyway. However, *highly innovative non-volatile memory (NVM) companies are already active in Europe, and their NVM technologies are especially suitable for the application-specific devices that will be needed to address Europe's societal challenges*.
- Best-in-class R&D centres are present in Europe, which do not exist elsewhere in the world. There is a real need to *maintain the viability and expertise of these*

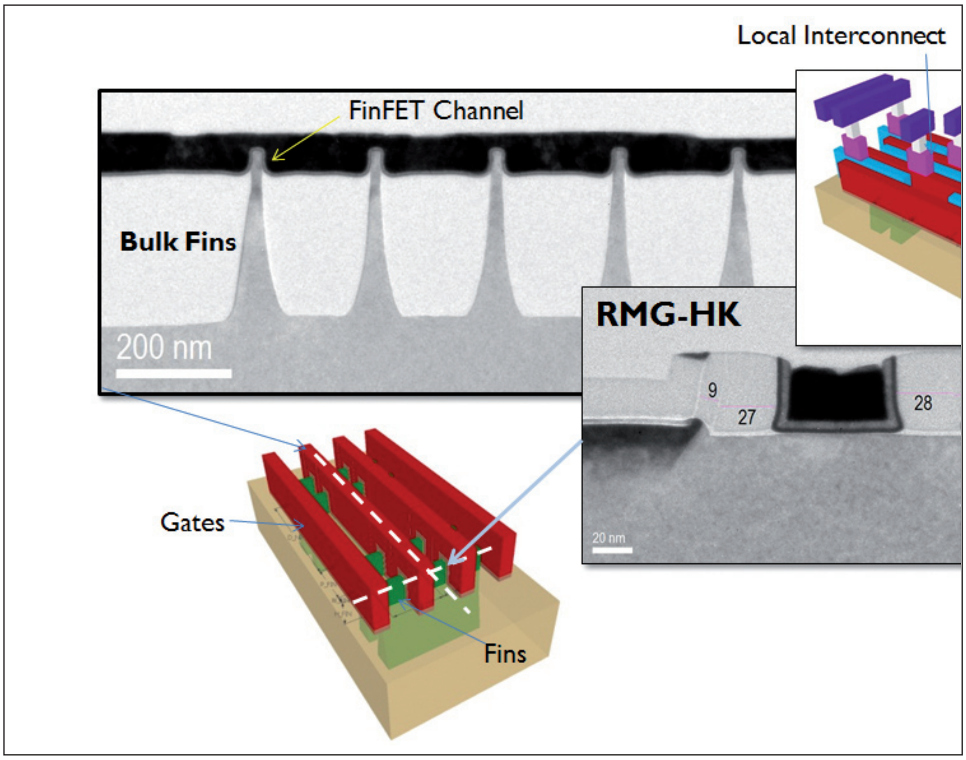
R&D centres. A focus item here should be the flow of this expertise (e.g. appropriately qualified graduate students) into the industry.

- It is also important that universities and engineering schools provide high-level technical training (for example, apprenticeships) such that *the industry in Europe has experts who are capable of innovating.*
- In geographical terms, and contrary to other nanoelectronic technology fields, there are a few leading regions/clusters in Europe where advanced CMOS technologies are being developed. Because of the cost and time needed to establish such excellence clusters, European programs and calls should acknowledge this situation and *encourage projects to form around the few excellence regions in order to benefit from their critical mass of expertise.* At the same time, there should be a clear channel for linking with, and benefiting from, smaller research providers, especially for exploring disruptive concepts. *Through such mechanisms and initiatives, Europe's excellence clusters will induce an efficient spill-over of knowledge and expertise, benefiting other European regions.*
- A healthy technology ecosystem should address all developmental stages, from research and development through to pilot-lines and production. It should also ensure permanent advancement in all of these developmental stages. In the long term, it is important that the whole chain is competitive. Concentrating only on parts of the chain will not be enough to achieve success over an extended period of time, and will therefore not lead to sustainable growth.

TCAD, characterization, modelling and simulation are particular strengths of the European research community. However, commercial activities[18] in these areas are less well developed in Europe.

Expected Achievements/Innovation Foreseen:
Innovations in electronics-enhanced systems and applications are enabled by advanced knowledge in the relevant technologies.
A strong European R&D program on **advanced CMOS** is a prerequisite to specifying and accessing the latest technologies and securing further growth in European lead markets. Supporting this major program will allow Europe to remain state-of-the-art[19], and give it the power to prescribe the development of miniaturization technologies. Even if, owing to the cost of developing the latest CMOS generations, leading European companies execute early R&D in clusters outside Europe (such as the IBM cluster at East Fishkill, NY, US), the final processes must be adapted in the appropriate industrial environment to the specific needs of the target application. For several years, even the ITRS has accepted that there are at least three different versions of advanced CMOS processes.
A European program on advanced CMOS will allow the creation of value through differentiation in specific process steps and building blocks, for which integration into a CMOS platform requires an in-depth knowledge of the development of MOS transistors.

[18] We are not considering here the equipment industry which is addressed in Chapter 8.
[19] (1) STMicroelectronics announced in December 2012 that its 28-nm FD-SOI technology is ready for manufacturing (http://www.st.com/web/en/press/t3370); while in June 2012 it announced that it had secured additional sourcing for its 28-nm and 20-nm FD-SOI technology from GLOBALFOUNDRIES (http://www.st.com/web/en/press/c2680); (2) Intel CEO Paul Otellini confirmed in May 2012 that Intel's Ireland plant is one of three plants that has been chosen to produce the company's next-generation 14-nm chips



Schematic and transmission electron microscopy images of replacement-metal-gate high-k bulk finFETs (source: imec)

Specifically funded programs should demonstrate advanced CMOS prototyping in line with or ahead of the ITRS roadmap (e.g. 14-nm logic CMOS in 2017 or earlier, see Table below).
Closely linked to advanced CMOS are **advanced memories,** which are critical components in most systems (communications, automotive, consumer etc.). There is an opportunity for Europe to gain leadership in **disruptive technology approaches** that offer differentiation with respect to mainstream technologies (Flash and DRAM).
Technology/system co-development is another way to bring differentiation by taking into consideration the technology impact of system constraints (e.g. system bandwidth, power / energy consumption, harsh environments, etc.).
More specifically, process modules applicable to the next two CMOS generation (i.e. modules for 10-nm logic and memories in 2020, see Table below) should be demonstrated as an outcome of the funded projects.

Table: CMOS logic 'nodes' according to the ITRS

	2014	2017	2020
Flash - ½ pitch uncontacted (nm)	17	13	10
Contacted DRAM – ½ pitch (nm)	25	18	13
MPU/ASIC - M1 ½ pitch (nm)	24	16.9	11.9
MPU High Performance - physical gate length (nm)	18	14	10.6

It is equally important to prevent a research gap building up between the shorter-term projects considered in this document and the more disruptive approaches explored in the 'classical' Framework Programme (or Horizon 2020 from 2014 onwards) projects

or other programs. A clear process should be set up to connect into the outputs of these programs, such that extrapolation from the best projects dealing with 'stretching Moore's Law' can help to prepare a pathway to the '**beyond CMOS**' era.
Programs in TCAD, characterization, modelling and simulation should lead to worldwide recognition of European leadership in these areas. More specifically, some of the techniques developed through funded projects should become strong candidate for (de facto) standards[20].

7.3.2 Grand Challenge: Competitiveness through Semiconductor Process Differentiation

Vision:

Develop European competitiveness through semiconductor process differentiation, permitting different European business models and supply chains to succeed.

Description:

Even though the ITRS recognized, as early as 2005, the growing need for a roadmap on **differentiating technologies** (dubbed **'More than Moore' technologies**), which would

include all the non-digital components of an electronic system, only partial roadmaps have so far appeared. In contrast to the development of generic digital logis and memories, 'More than Moore' technologies are highly diverse, and their performance metrics are multi-fold and strongly application-driven.
As a result, close links with application specialists will be essential when developing general concepts (roadmaps) to drive 'More than Moore' technology development.
In this respect, one very important asset for Europe is the strong link between semiconductor companies and application companies in critical sectors, as detailed in the Application Chapters of this document.
Technologies should be considered that are:

- generic enough to leverage the high development costs and long development times in a broad range of applications
- already prone to European cooperation among R&D players
- not sufficiently supported in the classical EC Framework Programme.

Following these guidelines, this chapter proposes a pan-European effort on generic technologies in the following fields (the list is not exhaustive):

- enhanced process generality for **sensors and actuators**
- **analogue/mixed signal** technologies (e.g. BiCMOS)
- integration of **RF LDMOS transistors with passives** on a single die
- **RF and mm-wave integrated devices** (including passives, RF and mm-wave interfaces, antennas, tunable filters, etc.)

[20] As an example, the present compact model chosen by the Compact Model Council was partially developed in Europe.

- **power/high voltage devices and smart power** (although most of these projects are likely to fit within the 'Energy Efficiency' and 'Automotive and Transport' chapters)
- silicon **photonics**
- **mixed technology** integration e.g. logic with analogue/mixed signal, RF and mm-wave, power and non-volatile memories
- **non-volatile memories,** for which strong research on materials offers novel approaches for applications invented in Europe
- **one-time programmable silicon devices** with special operating modes - traditionally dominated by American companies
- **biomedical devices**, e.g. smart catheters, lab-on-a-chip or organ-on-a-chip
- **SoC** and **SiP** for the above technologies and/or device families.

Competitive Situation:
Europe has a key competitive advantage in **differentiating technologies** for the following reasons:

- there is historical synergy in Europe between system/application companies and component suppliers (including SMEs)
- a strong R&D and manufacturing base exists, widely distributed throughout Europe
- there still exists a large installed base for 'More Moore', which can provide access to low-cost technology for 'More than Moore' development and production.

Expected Achievements/Innovation Foreseen:
The European industry can profit from the presence in Europe of major application drivers (e.g. security, automotive, medical) and an extensive competence base to further extend its market position, especially through the development of new technologies and architectures (e.g. 3D stacking).

As envisioned in the 'beyond CMOS' approach, nano-devices that add functionalities to CMOS will lead to disruptive functions in the MtM field. This will be especially true in areas such as high-performance sensors and energy harvesting, interaction with the 'smart energy' and communications domains, and RF applications.

In particular, embedded memory technologies are of paramount importance for Europe, because they are needed in virtually all the applications that drive the industry in Europe. To support this segment, specific programs addressing logic and memory convergence at technology level (28 nm and below) and architecture level ('memory in logic' and neuromorphic architectures) are required.

The funded projects should demonstrate the industrial viability of these disruptive approaches.

By setting the worldwide pace of R&D in differentiating technologies, Europe can expect the same benefits that the US (and more recently Asia) enjoyed by aligning the world's R&D efforts in the digital technology domain. By developing industry-grade differentiating technologies in Europe and by maintaining the synergy between technology and applications, further development of existing and new markets can be expected. The applicability of these new technologies to a wide range of applications should be one of the results of the funded projects.

7.3.3 Grand Challenge: Opportunities in System-in-Package

Vision:

Develop a European SiP supply chain for innovative systems integrating advanced CMOS and differentiating technologies developed in Europe, through 3D and heterogeneous integration - bringing MtM and MM together.

Description:

Highly complex integrated systems increasingly need to combine high performance computing, information storage, dedicated devices for interfacing, and energy/power management in a single package. While integrating different technologies on a single chip (the so-called System-on-Chip or SoC approach) can be useful in some applications, in others it does not provide a competitive advantage in terms of cost and size (e.g. integrating high cost/mm^2 advanced CMOS circuitry and large-area sensors onto a single die may not make economic sense). In many cases, integrating heterogeneous parts in a single package (rather than onto a single die) makes more sense - for example, by offering a degree of flexibility in bringing new system solutions to the market on time or in adapting to evolving standards.

Bearing in mind the complex interplay between integrated device manufacturers (IDMs), fabless companies and foundries, it is expected that for a given system solution, components will be supplied from many sources, some of them outside Europe.

This will enhance the need to find cost-effective solutions to integrate heterogeneous technologies in a single package.

One of the most important challenges is to stimulate the take-up of key enabling technologies - for example, nanotechnology or photonics - for the development of new high-performance products. However, while a manifold array of components and devices (e.g. nanosensors) is being developed in European R&D labs, these devices cannot currently be fabricated on an industrial scale because there are no continuous-process manufacturing lines to allow their commercial implementation.

3D[21] -integration of Key Enabling Technology based components and devices on micro- and nano-electronics chips is a very promising approach for realizing miniaturized smart systems with significantly enhanced functionalities.

As well as developing SiP solutions, Europe needs to provide the proper technologies and the proper design environment (chip/package/board) if it is to be successful.

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[21] '3D' means three-dimensional integration of electronic components.

The definition of optimum trade-offs between SiP and SoC - i.e. optimum (sub)system design capabilities - will not only require technology competences; it will also require close integration of technology and design.
In order to develop generic processes and 3D / SiP standards that are applicable in many application domains, Europe should take a holistic approach to technology development that includes:

- methodologies and tools for system-level co-design[22]
- chip embedding technologies for SiP integration, where different approaches currently exist:
  - i) chip embedding based on molded wafer (e.g. eWLB[23])
  - ii) chip embedding in printed circuit board (PCB) type material
  - iii) chip embedding in flexible substrates
  - iv) chip embedding in silicon/glass substrates
  - v) chip embedding in bio-compatible devices (e.g. for minimally-invasive surgery)
- advanced substrates (including interposers, embedded device technologies, innovative antennas, printable wiring on organic and silicon substrates, thick copper power lines, etc.)
- wafer-level integration: CSP[24] & WL-SiP[25] which includes chip-to-chip, chip-to-wafer, wafer-to-wafer, and passive device integration
- module integration - i.e. merged package and board technologies in addition to chip / package technologies
- heterogeneous integration of different technologies, e.g. Si combined with MEMS, sensors, passive components, optical components, or III/V materials such as GaN, SiC, etc.
- 3D integration, including TSV[26], TSV interposers, thin wafer technologies, bonding, handling of thin wafers/dice, etc.
- interconnection (electrical, RF and/or optical) and interposers - high density and fine pitch
- assembly and packaging (including wafer dicing, thin device assembly and stacking, and encapsulation technologies)
- device impact of 3D technologies and chip-package interaction
- diversification and management of complexity: many different materials with different properties, adhesion, stress management, etc.
- characterization and modelling (e.g. RF, optical, mechanical, etc.)

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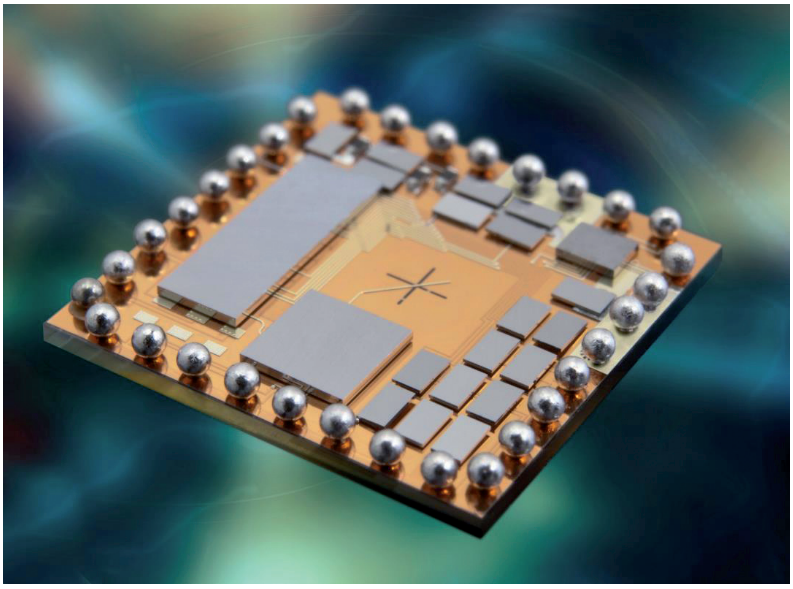
22 Addressed in the chapter on ‘Design Technologies’
23 Embedded Wafer-Level Ball grid arrays
24 Chip-Scale Package
25 System-in-Package on Wafer Level
26 Through-Silicon Via (vertical electrical connection passing through a silicon wafer or die)

- test (including KGD[27]) (e.g. fine pitch testing, etc.)
- thermal management (active / passive cooling)
- signal integrity, EMC[28] and reliability, failure analysis, etc.
- a coherent chip/package/board co-design environment (link to Chapter 6).



24 GHz low-power wireless sensor node for localization. Based on a thin film multilayer glass substrate; capacitively coupled patch antenna on the bottom side; top side consists of a three metal layer set-up with strip antenna. RF receiver, RF chip and ultra-thin SMD components are flip-chip bonded onto the substrate; peripherally arranged solder balls for interconnection to the next substrate level (source: Fraunhofer IZM).

Competitive Situation:
There is a clear opportunity for Europe to both develop its own SiP supply chain and take significant leadership worldwide. This is because:

- the supply chain for 3D/SiP is not yet firmly established worldwide
- standards for SiP are under-developed
- there is historical synergy in Europe between system/application companies and technology suppliers (including SMEs). Because the technological solutions for heterogeneous integration will be driven by different classes of application, a strong interaction between technology development and application domains is mandatory
- there are leading R&D centres in Europe.

Europe is driving innovative SiP integration with technologies like eWLB (Infineon, Nanium), chip embedding in laminate (AT&S, Schweitzer, etc.), and heterogeneous 3D WL-SiP using interposers. These skills need to be strengthened, because chips, packages and boards are increasingly being merged together.

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27 Known Good Die
28 Electro-Magnetic Compatibility

Expected Achievements/Innovation Foreseen:

3D/SiP heterogeneous integration is expected to be a key differentiating factor for complex integrated systems. In mastering the supply chain, Europe will secure its future in many different application domains.

Traditional assembly and packaging has moved mostly to the Far East. Innovative technologies for complex packages are partly derived from IC manufacturing techniques and could therefore benefit from the geographical proximity of R&D competence centres in SiP and from IC manufacturing lines. As a result, there is a real opportunity for Europe to relocate part of the worldwide 'back-end' supply chain to Europe, by establishing its leadership in the heterogeneous integration of complex systems.

The expected outcome is the establishment of a European ecosystem of actors for the development of 3D integrated smart systems, extending through the entire value chain from research (TRL 2), through design and manufacturing, to high-performance products (TRL 9). This will strengthen the European supply chain in designing, developing, optimizing and creating future electronic systems based on heterogeneous integration. This approach will help to improve the innovation capacity of the European industry and contribute to reinforced industry leadership through miniaturization, performance increases, and the improved manufacturability of innovative smart systems.

To make 3D heterogeneous integration a reality, long-term R&D efforts are needed with a focus on modelling at system level. Specific attention has to be paid to the next generation of active and photonic interposers, and alternative materials to silicon, in order to master the impact of TSV and interconnects.

7.4 Conditions for Success

Addressing the three Grand Challenges in 'Semiconductor Process and Integration' technology requires more than research funding alone. It also requires the availability of dedicated pilot lines, where technology development can be performed from the validation stage to the prototyping stage (TRL 5 to 8), and where the large investment in equipment and facilities can be shared among various research actors.

Such pilot lines have been strongly advocated in the HLG report on KETs [29] as a way of overcoming the so-called 'valley of death' between research and innovation, and have already been part of the last two ENIAC calls.

Among the main needs are:

- A pilot line for next-generation CMOS technology. The cost of this has been estimated at €1 billion, so public support should be significantly increased beyond its current level, and long-term public commitment (e.g. 10+ years) should be secured (as has already been achieved over the last 30 years) despite a rapidly changing industrial landscape.

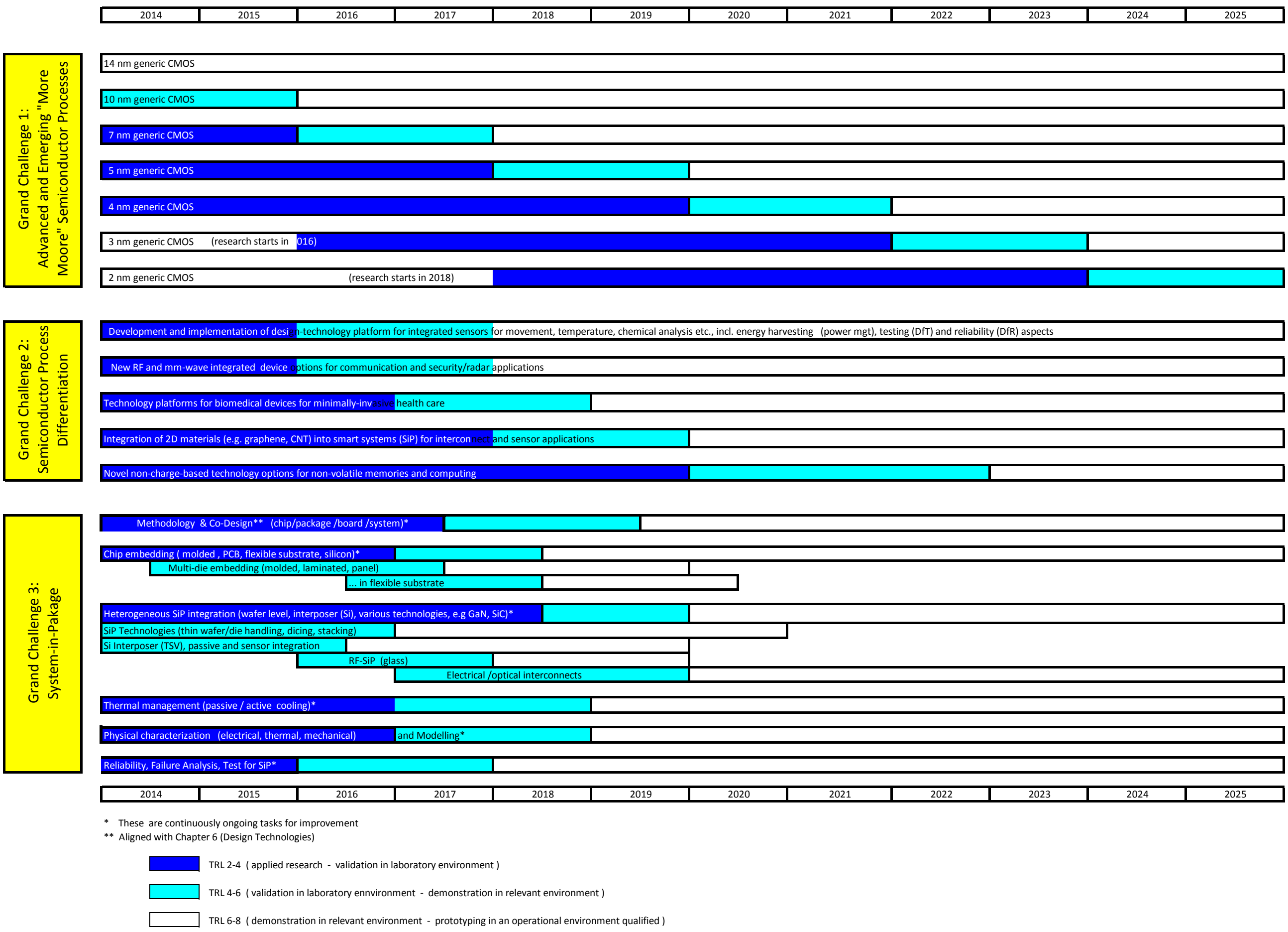
[29] High-Level Expert Group on Key Enabling Technologies – Final Report, June 2011: http://ec.europa.eu/enterprise/sectors/ict/files/kets/hlg_report_final_en.pdf

- A pilot line for silicon photonics in 2015-2016, possibly based on an existing industrial CMOS fab. Silicon photonics fabrication is based to a large extent on standard CMOS processes, but will include additional technologies (e.g. III-V-based), and photonics/electronic integration and packaging will be key issues.
- Pilot lines for next-generation power devices and MEMS, possibly representing lower capital cost, but able to handle a wide variety of new materials and close integration with dedicated packaging.
- Pilot lines for bio-compatible microelectronic devices for medical applications.

Differentiated technologies are interrelated with advanced and emerging technologies. They are unlikely to succeed, other than in dedicated or niche markets, if the first Grand Challenge 'Know-how on Advanced and Emerging More Moore Semiconductor Processes' is not met. Addressing topics outside the traditional scope of the semiconductor industry (e.g. biochips) is critical in order to build competitive new European differentiation factors. The coexistence of different European funding mechanisms should be maintained to accommodate the diversity of the technologies to be developed, and to insure maximum flexibility. The development of European lead markets and standards may help to enhance existing synergies between European systems houses and semiconductor suppliers.
To gain a significant role for Europe in the SiP supply chain, a few lead markets should drive technology development, with the potential emergence of European norms and standards.

7.5 Timeframes

The time-line for advanced CMOS is defined by the ITRS roadmap but it should be borne in mind that the most aggressive semiconductor manufacturers try to achieve results earlier than forecast. It is still expected that a new generation of CMOS technology will be developed every two years, even if there is a recognized shift of focus from pure geometrical scaling to 'equivalent' scaling, linked to the introduction of new architectures and materials.
For the differentiated technologies, the time frame is more difficult to predict, other than for a few technologies (analogue, RF and more recently MEMS) where tentative roadmaps have been developed by the ITRS. Only application-specific milestones can be defined in domains where progress can be achieved in many different ways.
With respect to the heterogeneous integration of technologies, major achievements should be realized by the end of the considered time frame, especially for 3D integration and the way it redefines the supply chain.



7.6 Synergies with Other Domains

As discussed above, the strength of the European industry is in developing technologies that address specific application sectors. This chapter is therefore synergetic with the application-driven chapters (*'Automotive and Transport'; 'Wireless Communications'; 'Energy Efficiency'; 'Health & the Ageing Society' and 'Safety and Security'*).
Semiconductor process development and integration rely critically on the availability of equipment and materials. It is also fully consistent with the development of competitive European manufacturing, and therefore interacts strongly with the chapter on "*Equipment, Materials and Manufacturing"*. The importance of dedicated test-bed facilities for equipment and materials development, and pilot lines to prove state-of-the-art technologies, has been discussed in the AENEAS/CATRENE positioning paper on nanoelectronics.[30]
Interaction between design and technology is more and more central to the development of successful products. TCAD, characterization, modelling and simulation are classical interfaces between the two domains, but growing interaction is expected between the topics covered in this chapter (especially differentiating technologies and heterogeneous integration) and the topics discussed in the chapter on 'Design Technologies'. In order to address growing technological complexity, it will be essential to develop new design methodologies and efficient statistical tools that, early in the design flow, take into account the sensitivity of circuits to the increasing diversity of manufacturing processes.

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30 "Innovation for the future of Europe: Nanoelectronics Beyond 2020" (November 2012), http://www.aeneas-office.eu/web/downloads/strategic-docs/position_paper_final.pdf

CHAPTER 8

EQUIPMENT, MATERIALS, AND MANUFACTURING

8.1 Introduction

Europe's semiconductor manufacturing industry suppliers have a long history of successful mechanical engineering, tailor-made machinery, optical 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 and wafer handling. The semiconductor equipment and semiconductor materials sectors in Europe employ more than 100 thousand individuals, the majority of them in high education level jobs.

Furthermore, thanks to international collaborative research projects involving semiconductor manufacturers, solution providers and academics, Europe has acquired excellence level in manufacturing science. Maintaining this level of excellence is of paramount importance to keeping competitive semiconductor manufacturing in Europe, despite the economies of scale achieved by far-east companies as a result of their widely adopted foundry model.

Furthermore, European research centres, 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 development capabilities and involvement in transnational development projects.

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

Figure 1. Integration of projection optics in ASML TWINSCAN Wafer Scanner. Source: ASML.

8.2 Relevance for Europe

8.2.1 Competitive Value

The value of the Equipment, Materials and Manufacturing (E&M) industry for Europe is twofold. Firstly, E&M products address large multi-billion Euro, self-sustaining markets. Based on their technical excellence, several European E&M players have achieved world-leading positions in several global market domains, and therefore constitute a powerful engine for European economic growth by themselves. This is underlined by the fact that more than 100 thousand individuals[31] currently work in the European E&M industry. Secondly, the products and technologies developed by European E&M companies exhibit high leverage/re-use potential for Europe's core industries. Hence, the research and development activities of Europe's E&M players strengthen its capability to maintain and develop a profitable and sustainable semiconductor manufacturing base of key strategic relevance, both in economic and political terms. Accordingly, close interaction between the E&M industry, European chip manufacturers and research institutes is required to develop E&M solutions and standards that serve the semiconductor industry - for example, providing energy efficient manufacturing and tailored E&M solutions. Figure 2 illustrates the twofold competitive value of Europe's E&M industry. Semiconductor equipment sales reached US$39 billion in 2012, which is more than 10% of the revenue of the semiconductor industry as a whole.

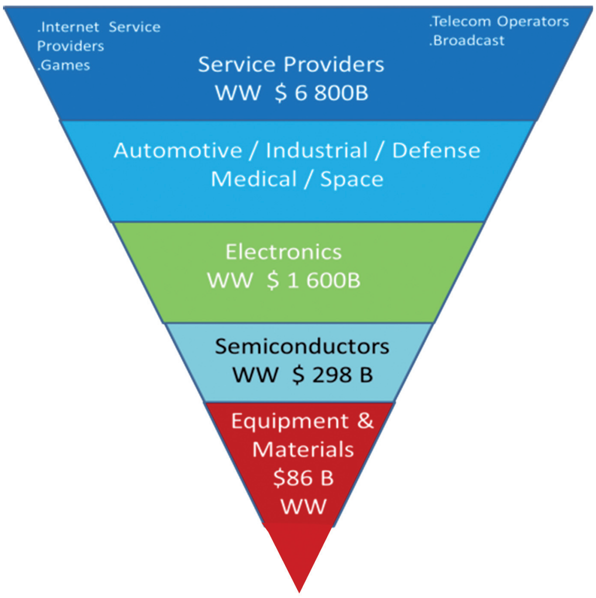

Figure 2. Economic impact of the E&M industry on key downstream sectors showing the twofold competitive value. Starting from a substantial, self-sustained global market (red triangle), the E&M industry exhibits a huge lever to key European industries (Source: CATRENE program Review Report 7 2S 2012)

[31] Source: SEMI.

8.2.2 Societal Benefits

The European E&M industry enables the semiconductor industry to provide new solutions for sustainable growth and key societal needs of the future, including mobility, communication, energy efficiency, and health care. With its highly-educated workforce, the European E&M industry provides solutions and innovations that are keys to success in several other technology-based European industries. Combining this ability to leverage a large home market with success in global E&M markets, Europe's E&M industry significantly contributes to a European economy that is based on knowledge and innovation.

8.3 Grand Challenges

8.3.1 Grand Challenge 1: Advanced CMOS – 1X nm & 450 mm

Vision:
Develop European know-how in Equipment, Materials and Manufacturing for 1Xnm advanced CMOS and 450-mm wafer processing.

Description:
This Grand Challenge targets the discovery of new E&M solutions for:
a) advanced CMOS processes that enable the nano-structuring of electronic devices with 1Xnm resolution in high-volume manufacturing and fast prototyping.
b) 450-mm wafer process development and manufacturing.

The overarching goal of 1Xnm technology development is to lead the world in miniaturization by providing nano-structuring equipment around two years ahead of the corresponding volume production as scheduled by the ITRS (International Technology Roadmap for Semiconductors). Accordingly, research and development is needed to facilitate innovations for, 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, 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:
    - o Nanometer process development including thin film deposition, and (PE)ALD

(Plasma Enhanced Atomic Layer Deposition) processing, specific enabling materials such as copper, (PE)ALD precursors, and specific etching and cleaning gases.
  - 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 and Nanowires, and corresponding manufacturing techniques, equipment, and facilities.

- Wafer preparation: equipment and processes for polishing, cleaning, 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).
- 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.
- 300-mm equipment and materials (including retrofit to 300 mm).
- 450-mm equipment and materials, specifically wafer process equipment for lithography, metrology and wafer inspection, and wafer substrate elaboration (Si, SOI).
- Open platform technologies, including automation, handling, software, interfaces (hardware and software) and standards for 450 mm.

To enable sustainable support in the 450-mm domain, a long-termed environment for the assessment and demonstration of 450-mm equipment is required.
This will be beneficial for both larger and smaller equipment makers to prove the manufacturability and the process capabilities of their tools.

Competitive Situation:

In E&M for advanced CMOS, Europe has a world leading position in several areas, foremost in lithography, metrology, silicon and advanced substrates. For example, according to ASML, the technology leader for advanced exposure systems, the annual market size for exposure systems is at least €5 billion, of which EUV lithography alone will represent a substantial proportion for the current decade. The markets for metrology, EUV infrastructure and EUV complementary patterning technologies will add to this figure. For 450-mm E&M, a multi-billion Euro annual market size can be expected, because 450 mm may become the dominant segment in the worldwide E&M market by the end of this decade. Forefront R&D for the development of 450 mm equipment and materials will create new opportunities to increase Europe's market share in this highly competitive domain. The introduction of 450-mm production will further secure and generate highly skilled jobs.

Expected Achievements/Innovation Foreseen:
The key achievements targeted in E&M for advanced CMOS are: to lead the world in shrinking by supplying new equipment and new material approximately two years ahead of the ITRS volume production schedule, and to provide competitive 450-mm E&M according to market demand. In a timeframe of around five years, European lithography systems suppliers will have to provide solutions for 1Xnm patterning for high-volume high-yield manufacturing. In addition, the corresponding mask technologies, processes and process control techniques, infrastructures and metrology tools will be available. Furthermore, European E&M solutions for 450-mm chip manufacturing, starting with pilot line versions, will be made available at the right time.

8.3.2 Grand Challenge 2: More-than-Moore

Vision:
Strengthen European competiveness by developing advanced More-than-Moore (MtM) Equipment, Material and Manufacturing solutions for front and back-end wafer processing, and device packaging.

Description:
More-than-Moore 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. A major challenge will be synergizing electronic and biological (bio-medical) skills such that challenges associated with Europe's ageing society can be met. The overarching goal of the More-than-Moore Grand Challenge for European E&M companies is to enable semiconductor companies to provide sensors including MEMS (Micro-Electro-Mechanical Systems), imagers, power electronics, automotive electronics, mm-wave technologies, and advanced low-power RF technology compatible with an increasingly 'mobile' world and with the needs of bio-technology markets. Mastering CMOS production technology for future leading-edge process generations is also important and challenging, and will be key for competitive advantage. Europe should therefore never neglect its capabilities in mainstream advanced CMOS, including advanced BiCMOS.

For More-than-Moore, which is a definite European strength, 200-mm and 300-mm technologies are the main focus. The transition to larger wafer diameters (for instance to 300 mm) is a challenge, but should enable new process integration schemes through more capable equipment - for example, by the retrofit of tools used for more advanced nodes.

In the coming years, 3D integration and More-than-Moore manufacturing will add complexity to the global supply chain and generalize the concept of distributed manufacturing (different process steps realized in different lines with different manufacturers). This will require the development of new concepts for Information and Control Systems (see Grand Challenge 3).
More-than-Moore technologies will require working more closely together, combining front-end wafer equipment and assembly and packaging (A&P) equipment. Technologies well established for Si wafers will at least partially be reused and adapted for A&P.
In addition, new materials will be required for future A&P as well as new equipment, 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 processing methods and equipment.

More-than-Moore will pose significant challenges and therefore require R&D activities in the following fields:

- Back-end equipment, in particular for 3D packaging (wafer level and chip level), and novel approaches for die separation, 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/back-end process E&M, for processes such as sintering, die-attach bonding, copper bonding, lead-free soldering 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).
- E&M for wafer thinning and singling.
- Advanced chip-to-chip, chip-to-wafer and wafer-to-wafer bonding techniques.
- 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.
- 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.
- Advanced 3D applications: methods, materials and equipment.
- 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).
- 300-mm Si-substrates, including low-resistivity substrates for power applications, high-resistivity substrates for RF applications, and SOI (Silicon on Insulator).
- Advanced substrates - e.g. for Si interposer, glass interposer, ceramics.
- Alternative semiconductors and photonic materials, such as GaN and SiC.
- New materials - for example, for packaging, 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).
- New engineered substrates and solutions for layers and material stacking 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.
- 'Green' equipment design by reducing chemical usage (water, power, chemicals, etc.) and using smaller processing chambers (for CVD, spatial ALD, etc.).

To enable the development of dedicated MtM equipment and materials, a roadmap of relevant specifications is required. In addition, a long-term funding environment for the development and assessment of innovative MtM equipment and materials is needed. This would certainly help to penetrate markets of typically smaller sizes than the high-volume More Moore markets.

Competitive Situation:

More-than-Moore processes and E&M can be partially sourced from previous-generation CMOS infrastructures. However, new technology generations[32] will also require capabilities which are not yet available in advanced CMOS fabs. Furthermore, the constant trend in More-than-Moore solutions of ever-decreasing feature size, with ever-more features and interconnects packed onto an IC, puts strong demands on product validation and verification methodologies and on test methodologies and equipment. Because today's equipment is designed for high-volume continuous production and is therefore less efficient for smaller lot production runs, the performance of More-than-Moore production tools must be enhanced to provide low Cost-of-Ownership (CoO). In general, this requires major modifications to existing equipment or the re-design of equipment.

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. The trend towards extension of MtM process innovation increases the opportunity for SME's to enter the market with new products. The backend materials segment is currently dominated by Japanese and US companies.

[32] e.g. based on Silicon Carbide SiC or Gallium Nitride GaN or new metallization technologies based on thick copper

In terms of silicon-based MtM manufacturing, most of the world's activity is presently done on 200-mm wafers (although there is still significant 150-mm production, especially for discrete devices). A few years ago, TEXAS INSTRUMENTS initiated the first move of analogue IC technologies into a 300-mm fab, based on the re-use of partially depreciated equipment installed in a new state-of-the-art eco-friendly facility. This proved to be a good productivity and cost efficiency move, and INFINEON duplicated the move for power devices in the 300-mm former Qimonda fab in Dresden. In the coming years, MtM production in Europe will have to move from 200 mm to 300 mm, because most 200-mm equipment will no longer be built or maintained by its manufacturers after More Moore CMOS starts the transition to 450 mm (around the years 2018 - 2020). This will lead to consolidation in the industry, and possibly other major changes, such as a movement towards multiple-ownership fabs or towards a foundry model. The move towards 300-mm wafer fabs will be necessary in the near future anyway, because many technologies - for example, high frequency BICMOS, advanced power BCD and imager technologies - start to require feature sizes (80nm and below) that were only developed on 300-mm tools. The rapid obsolescence of first-generation (2000-2006) digital 300-mm fabs after 450-mm deployment gets in full swing (2020-2023) will force these fabs to find other opportunities for business in specialized digital niche markets and within the MtM space. The 300-mm conversion for MtM lines will therefore be a key challenge over the coming years.

Expected Achievements/Innovation Foreseen:
More-than-Moore (especially combined with 3D heterogeneous integration) is creating future opportunities by addressing increased demand for new functionalities. Product volumes per function will be smaller compared to More Moore semiconductor production, but the range of specialised functions will be much wider. It will provide the European industry with the opportunity to creatively develop More-than-Moore solutions and further exploit its wide-ranging experience and expertise in agile market-sensitive production. Furthermore, the production means must also be adjusted to this kind of market, requiring equipment suppliers to continue the tradition of highly sophisticated but cost-effective equipment. In addition, European E&M companies must target the provision of equipment and materials to produce devices such as sensors/MEMS, power electronics, RF, and bio-tech devices according to market needs. Finally, in order to create an industry-wide basis for technology development, the roadmap definition process for More-than-Moore has to be continued and corresponding actions need to be defined. This also relates to standardisation.

8.3.3 Grand Challenge 3: Manufacturing

Vision:
Develop More Moore and More-than-Moore software and hardware solutions for highly flexible and cost-competitive semiconductor manufacturing in Europe.

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. 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. The key will be to invest in people's skills and competencies.

Solutions for manufacturing will have to address More Moore and More-than-Moore related challenges.

More Moore manufacturing will especially require innovative solutions to control the variability and reproducibility of leading-edge processes. This implies that domains traditionally seen as independent (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 sharing. This also applies for More-than-Moore, where inter-facility flows will require considerable transfer 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 More-than-Moore 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 moulding etc.).

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Figure 3. 300 mm Wafer Fab

To achieve this, new fab management and equipment solutions will be required in several fields. For example:

- 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, and Design-for-Test.
- 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). With the transition to the 1Xnm node and 450-mm wafers, problem intricacy will become severely magnified. This holds true even more 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.

These innovative solutions might address new materials (for example, in terms of quality, defectivity, functionality), new designs (e.g. in terms of functionality, robustness, reliability, operating cost), new software/automation, new environmental solutions (e.g. in terms of energy consumption, chemical usage), and innovative man-machine interfaces.
The key goal is the development of 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.

Competitive Situation:
The topics addressed in the 'Manufacturing' Grand Challenge are of key importance in several areas of the European semiconductor and E&M manufacturing industry. They consider both the strengths, and the challenges, of the European semiconductor environment. On the one hand, developments for fab manufacturing and corresponding E&M innovations should capitalize on Europe's strengths - for example, its world-class levels of R&D and engineering expertise, its large technology portfolio, and its expertise and creativity. They should also capitalize on the multitude of SME's operating in these narrow but highly technical fields, and, in particular, on the world-class status of several European E&M suppliers, which are already creating ecosystems within their fields of activity. On the other hand, European E&M actors should also consider distinct European challenges - for example, Europe's high-cost environment (labour, logistics, services) compared to Asia, its lack of flexibility (e.g. regulation, employment), a relatively small market size for some products, and the lack of incentives for manufacturing.
Substantial market potential for the European E&M industry exists for both, high-volume advanced CMOS IC manufacturing (More Moore) and More-than-Moore manufacturing. For More Moore the focus is to cope with the requirements and challenges resulting from the ITRS. The focus of More-than-Moore E&M solutions is serving high manufacturing flexibility, ability to handle small and variable sized lots, and energy and resource saving.

Expected Achievements/Innovation Foreseen:
New developments in equipment, materials and manufacturing should support flexible and competitive semiconductor manufacturing in Europe, as well as competitiveness in the world market. Accordingly, the innovations foreseen must 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 labour costs). The challenge is therefore 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 in advanced CMOS fabs. 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.

8.4 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 in other E&M-related industrial domains. However, timing is of the essence, and high technology risks have to be taken and upfront investments have to be made, often many years before the first products will reach the market.
European excellence in lithography, metrology and deposition processing tools already supports the worldwide semiconductor industry (Figure 2, page 142) and, in effect, 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 and deposition processing. This will lead to better reciprocal understand future technical needs and corresponding solution options, resulting in optimally tuned solutions of world-class standard. The ability of Europe's semiconductor and E&M industries to leverage synergies in domains such as photovoltaics, LEDs (Light Emitting Diodes) and photonics will also be important. In addition, it will be in both industries' interests to establish the prerequisite E&M capabilities needed to move forward the development of heterogeneous system integration, specifically the combination of MM and MtM devices.

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.

The extension of pilot lines may vary between a complete assembled semiconductor line for front-end or back-end up to a small process application line or test bed for specific equipment or material evaluation.
Test beds and pilot lines will also foster the development of future 450-mm equipment.[33] This holds true for SME's and large Europeans companies.
Ultimately, a program of accelerated and massively intensified European research and development in the field of E&M and all its various facets is required, making public funding a key success factor for the future of the European E&M industry.

8.5 Timeframes

Grand Challenge 1: Advanced CMOS – 1Xnm & 450 mm
The 1Xnm nano-structuring solutions to be developed in the 'Advanced CMOS – 1Xnm & 450 mm' Grand Challenge will need to be available two years ahead of the point in time at which the ITRS roadmap schedules the start of high-volume IC manufacturing at the corresponding node. For example, the ITRS roadmap schedules 13 nm half-pitch FLASH /DRAM manufacturing for 2017/2020. Accordingly, the corresponding nano-structuring solutions enabling this technology should be available from 2015 onwards.
The introduction of 450-mm wafers to high-volume manufacturing is currently expected around 2018. This means that the first exploratory tools should also be available from the year 2015 onwards.

Grand Challenge 2: More-than-Moore
The timing of new E&M solutions for the 'More-than-Moore' Grand Challenge should be derived from the draft More-than-Moore roadmap for devices and technologies [34]. This 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.

Grand Challenge 3: Manufacturing
New E&M solutions for the 'Manufacturing' Grand Challenge should be developed according to the market needs defined in the ITRS roadmap and according to state-of-the-art manufacturing practices (mainly in the Far East where semiconductor manufacturing is deployed on a large scale and strongly supported by major stakeholders in the semiconductor arena). 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.

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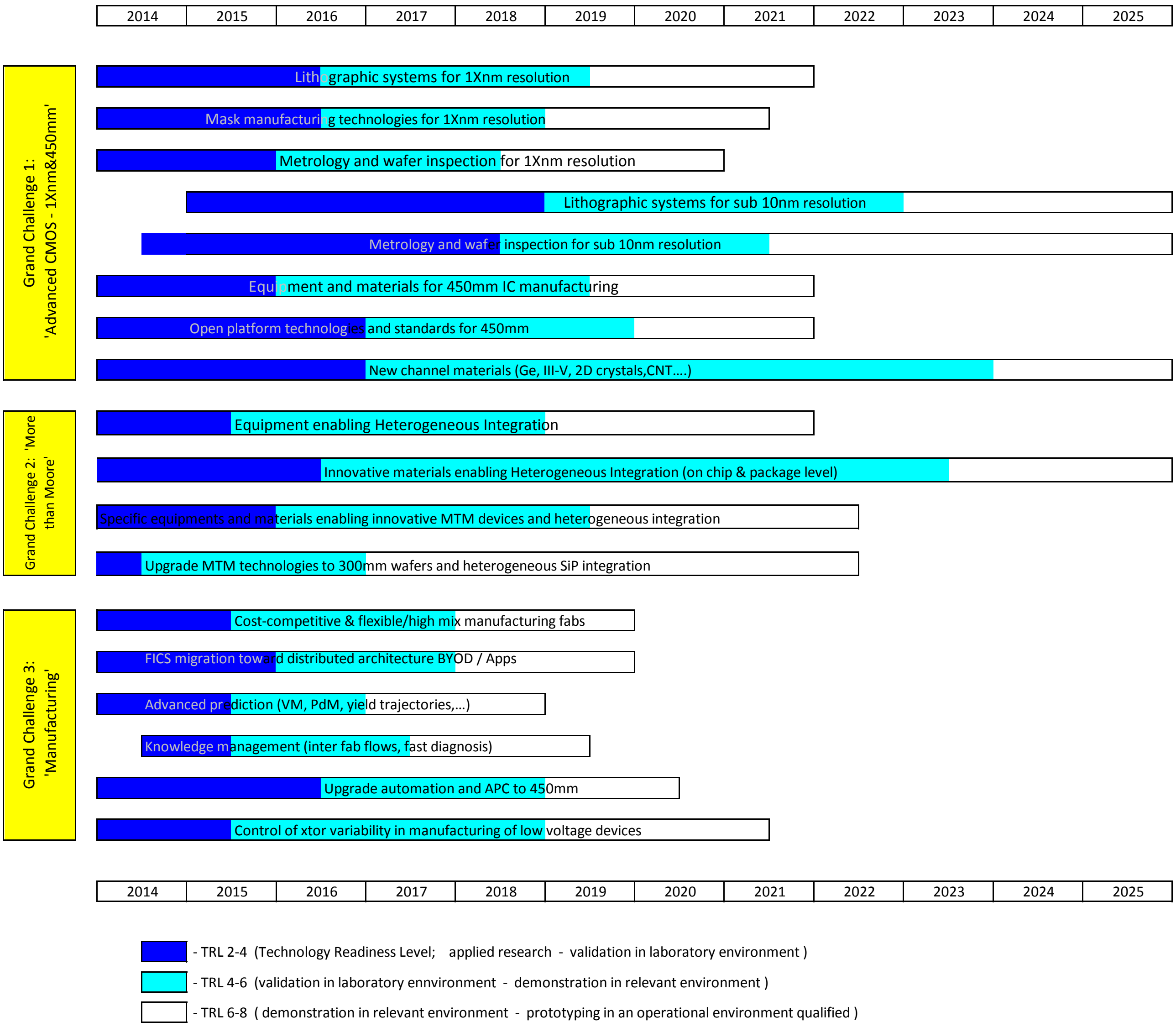
[33] "Innovation for the future of Europe: Nanoelectronics Beyond 2020" (November 2012), http://www.aeneas-office.eu/web/downloads/strategic-docs/position_paper_final.pdf
[34] "More-than-Moore" roadmap, Report from the CATRENE Scientific Committee, 2012



8.6 Synergies with Other Domains

All these Grand Challenges clearly exhibit synergies with the ‘Silicon Process and Integration’ domain. Furthermore, synergies also 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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